S+V+M:
RELATIONSHIPS BETWEEN THE SOUND, VISUAL AND MOVEMENT DOMAINS IN INTERACTIVE SYSTEMS

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1　　　　I am probably missing someone.

ABSTRACT

This dissertation explores the relations between the *Sound*, *Visual* and *Movement* domains in real-time interactive systems. The targeted systems are dance performances, performing interfaces, installations and immersive spaces, where the three domains are present, and where processes of transformation and translation occur between them in real-time (movement into sound, sound into visuals, movement into visuals, etc.).

This research proposes a new framework , *S+V+M* (Sound+Visual+Movement), that aims to classify interactive artworks based on the flow of data through their system. This approach provides a high level of abstraction by looking at the inputs and outputs, transformations, and data flows occurring inside the interactive system, which helps to establish common parameters in artworks with different characteristics, so they can be evaluated and discussed under a unified perspective.

This research is split in two interrelated and parallel paths:

- A theoretical path, where a series of interactive artworks were collected and catalogued according to their processes of transformation. Also a series of related classification systems from the literature were analyzed. Using as baseline the collected artworks, the methods and processes from the analyzed classifications systems as the inputs from the practice based research, a new framework (*S+V+M*) for the classification of interactive artworks was proposed;

- A practice-based research path, focused on the development of artworks exploring the relations between *Sound*, *Visuals*, and *Movement*, and this way giving inputs and shaping the development of the framework. A group of thirteen projects were developed and their documentation is presented, providing insights on techniques, software, hardware and critical analysis for the development of interactive artworks.

Through the *S+V+M* framework different data-flow patterns and system typologies are highlighted within the interactive systems of the case-studies artworks. The framework offers a high level of abstraction, helping to recognize similarities and establish common parameters between different systems. Providing this way a language for analysis and critique of the interactive artworks, both for creators and experts as well as for the audiences.

The *S+V+M* framework also proved to be a catalyst for new interactive artworks, since when observing the emerging patterns and relations between domains new research questions and artistic paths emerge, triggering this way new projects with different interactions and *Sound*, *Visual* and *Movement* connections.

KEYWORDS: Sound, Visuals, Movement, Interaction, Transmutability

RESUMO

Esta dissertação explora as relações entre os domínios *Sonoro*, *Visual* e do *Movimento* em sistemas interativos. O trabalho foca-se em sistemas para performances de dança, interfaces performativas, instalações e espaços imersivos, em que os três domínios estão presentes e interagem em tempo real, transformando movimento em som, som em visuais, movimento em visuais, etc.

Esta investigação propõem uma nova framework, *S+V+M (Som + Visuais + Movimento)*, que pretende classificar peças interativas a partir dos fluxos de dados dos seus sistemas. Esta abordagem propõe analisar com um certo nível de abstração as entradas e saídas dos sistemas e as transformações e fluxos de dados que neles ocorrem. Esta estratégia permite identificar relações e parâmetros em comum entre sistemas com características diferentes, de modo a que possam ser avaliados e discutidos sob a mesma perspectiva.

O trabalho de investigação divide-se em dois percursos paralelos e interligados:

- Um percurso teórico onde foram colecionadas e catalogadas peças interativas de acordo com os seus processos de transformação, e em que analisados vários sistemas de classificação da literatura em arte interativa. Em consequência disto, e usando como referência as análises, os métodos e processos dos sistemas de classificação analisados, e os contributos da investigação pratica, foi proposta a *framework* para classificação de sistemas interativos *S+V+M (Som + Visuais + Movimento)*;

- Um percurso de investigação prática focado no desenvolvimento de peças interativas que exploram diferentes possibilidades e relações entre os domínios *Sonoro*, *Visual* e do *Movimento*. Foi criado um conjunto de treze projetos, sendo para cada um deles apresentada documentação, notas sobre o seu desenvolvimento, e descrições técnicas sobre o software e hardware utilizados;

Utilizando framework *S+V+M* foi analisado um grupo peças interativas onde foi possível observar diferentes padrões de fluxos de dados e tipologias de configuração, que ajudaram a identificar semelhanças e parâmetros em comum entre sistemas diferentes. A *framework* provou deste modo ser uma ferramenta para a análise e critica de peças interativas, tanto para criadores e especialistas como para os espectadores.

A *S+V+M* demonstrou também ser um catalisador de novas peças interativas, já que da observação e catalogação dos padrões emergentes e das diferentes relações entre domínios surgiram novas perguntas de investigação e hipóteses para novos caminhos artísticos, desencadeando deste modo novos projetos com o objetivo de explorar novas relações entre Som, Visuais e Movimento.

PALAVRAS-CHAVE: Som, Visuais, Movimento, Interação, Transmutabilidade

TABLE OF CONTENTS

INDEX OF IMAGES

INDEX OF TABLES

1. INTRODUCTION

1.1 MOTIVATION & BACKGROUND

Ever since I was a child I have been fascinated with computers, technology and inventions. I watched dozens of times the *Back to the Future* movies, and I wanted to create machines just like "Doc" Brown. In fact in my primary school yearbook, when I was about 10 years old, I stated that I wanted to become a scientist (not a chemistry or biology one, but the type of scientist that creates machines, just like "Doc" Brown).

When entering high school, I had to choose between Sciences, Arts, Economy, or Literature, and I chose Arts, as the Sciences program was not attractive to me, as it didn't seem to involve much creativity. I ended up following a graduation in Design and later started to work as a graphic designer in a studio in Madrid. Around 2006/2007 I attended some editions of the OFFF festival in Barcelona, where I saw some presentations that were a turning point for me, as they introduced me to the world of generative and reactive visuals, interactivity, physical interfaces, etc. Among others I watched Robert Hodgin showing his work with generative particles; John Maeda talking about drawing with numbers; Casey Reas talking about Processing; an audiovisual live performance by Golan Levin and Zach Lieberman created with a custom made physical sequencer; and a Raster Noton Live AV showcase. These presentations took me back to my early dreams of creating machines like "Doc" Brown, which led me to think: "This is exactly what I want to do in the future! ".

Fig. 1: 10-years-old-Rodrigo's profile at the school-yearbook, stating Scientist as the future career (top left); Frame from Back to the Future II (Zemeckis 1989), with "Doc" presenting one of his inventions (bottom left); 29-years-old-Rodrigo with a custom-made physical interface driven by water and mills created for the audiovisual interactive installation Prefalll135 (Carvalho, Antonopoulou, Chavarri 2012) (right);

Afterward, I began to explore and learn more about the field of interactive art. At the time I was living in Madrid, so I started to attend some Medialab's[1] events, and in early 2008 I had the opportunity to attend a big interactive art exhibition called *Maquinas y Almas* (Machines and Souls)[2], curated by José Luis de Vicente. There I watched among others: Daniel Rozin's interactive mirrors, John Maeda's software art, Sachiko Kodama's ferrofluids or Theo Jansen's machines, and I was then certain about my path. I applied to the Masters in Digital Arts from the University Pompeu Fabra in Barcelona, where I studied interactive art, learned to code (mostly Processing, Max and Quartz Composer) and learned how to work with electronics, Arduino and sensors. Since then I have been working on audiovisual interactive artworks on a range of different outputs, from screen-based work, interactive installations, and live visuals and interactivity for music and stage performances.

During these years my focus has been on the points of transition between the physical and the virtual world, the creation of immersive environments, and the use of technology to enhance artistic expression. Using technology not just as a background or an attachment but rather as a tool to augment the possibilities of creation. Just like Yacov Sharir stated on an interview when asked about the future of dance and technology:

> *The creator must ask himself first what is the objective of the technology, if it is really necessary. Technologies should be used to augment the performance (the dancer body, the space, the plot). Help to reach a point that would be impossible without them.*
> (Yacov Sharir, interviewed by João Beira, Austin 2012)

The path that lead to me to this research was strongly shaped by artist as Memo Akten, Golan Levin, Zach Lieberman, UVA and Klaus Obermaier among others. Artist whose artworks triggered me into questioning the relations and different possibilities of interaction between the Sound, Visuals and Movemen. Specifically pieces as *Manual Input Sessions* (Levin, Lieberman 2004), *Messa di Voce* (Levin, Lieberman et al. 2003) and *Apparition* (Obermaier 2004), which presented different setups and interactions between the three domains and were the starting point in the process of collecting and cataloguing interactive artworks based on their data-flow around the three domains, and the building of the S-V-M blog,[3] which laid the groundwork for these dissertation.

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1 Medialab Madrid. <http://medialab-prado.es/> Accessed 2017-05-05

2 Maquinas y Almas" (Machines and Souls). <http://www.museoreinasofia.es/sites/default/files/exposiciones/folletos/2008011-fol_es-001-maquinas-y-almas.pdf> Accessed 2017-05-05

3 Sound+Visual+Movement blog <http://s-v-m.tumblr.com/>. Accessed 2017.05.05

1.2 RESEARCH QUESTIONS

The central theme of this research is the exploration of the relations between the *Sound*, *Visual* and *Movement* domains in interactive systems, created for art installations or live performances. Particularly, on the processes of transformation that occur across those domains (movement into sound, sound into visuals, movement into visuals, etc.) in each different system. Each of the domains can be an input and/or an output of the system, and different configurations between the three can be explored, defining the outcomes of the system, the type of interaction and influencing the expressivity of the artwork. The data-flows and transformations across these domains can also be used to describe and catalogue an interactive system.

The fact that the interactive art field is very multidisciplinary, with creators from different backgrounds and perspectives from a wide range of fields (stage performance and visual arts to computer science or engineering) leads to the creation of artworks with a wide range of setups, technologies, levels of interactivity, presented in different media and with different approaches to classify them , arises the question on how can we describe all these projects coherently. This research is then focused on two main questions:

> *Can interactive artworks be defined and categorized based on their input/output configurations and the direction of the data-flow through their Sound, Visual and Movement domains?*
>
> *How can we frame interactive artworks with different characteristics in a common language? In a way we can relate, analyze and critique artworks presented in different media, with different setups, configurations, relations with the audience, and levels of interactivity.*

The goal is to provide a high level of abstraction, that allows us to compare and find a common language to analyze and criticize interactive artworks. In a way we can relate in the same scope audiovisual stage performances, interactive spaces or kinetic installations with different characteristics and configurations. The focus on the relations, transformations and data-flow across Sound, Visual and Movement domains arises as a solution to frame all the different systems in a common language, and connecting them between what they have in common.

During the research, as a consequence of the theoretical and practical work being developed, a new research question emerged:

> *Can we use the relations between Sound, Visual and Movement domains as a catalyst in the creation of new interactive artworks?*

By analyzing and categorizing interactive system, and by looking into the data-flow between domains and its emerging patterns, new artistic and research goals appear, leading to the exploration of new or uncommon interactions between *Sound*, *Visual* and *Movement* domains. This way the proposed *S+V+M* framework, as an instrument to catalogue interactive systems, can also be an important tool for generating new projects. Projects

whose technical features and artistic goals are framed from the beginning with the pur-
pose of achieving a specific interaction between *Sound*, *Visual* and *Movement* domain
(as an example, an interactive system where the domain *Movement* is an output of the
system).

1.3 METHODOLOGY

> *...many practice-led researchers do not commence a research project with
> a sense of 'a problem'. Indeed they may be led by what is best described as
> 'an enthusiasm of practice': something which is exciting, something which
> may be unruly, or indeed something which may be just becoming possible
> as new technology or networks allow (but of which they cannot be certain).
> (Haseman 2006, 4)*

The "enthusiasm of practice" stated by Brad Haseman in his *Manifesto for Performa-
tive Research* (2006) perfectly describes the basis of this research, and the paths that were
taken. The artistic practice, the curiosity of exploring new interactions and interfaces, and
to experiment different mappings of digital data between different domains, triggered the
initial research questions, and shaped the paths and directions for the following research.
Just like Haseman states "researchers construct experiential starting points from which
practice follows. They tend to 'dive in', to commence practicing to see what emerges."
(Ibid.). The work developed on this dissertation is also framed as practice-based research,
as defined by Linda Candy, "original investigation undertaken in order to gain new knowl-
edge partly by means of practice and the outcomes of that practice" (2006, 1). Artistic
practice is developed as an integral part of the research process, and its outcomes are then
documented and analyzed in order to create critical reflection.

This research has two interrelated and parallel paths:

1) A practical path, focused on developing artworks and experimental projects explor-
ing the relations between *Sound*, *Visuals* and *Movement* in real-time systems.

The development of these projects occurred according to exhibition or performance
opportunities, workshops, residencies, or research goals. Some were created to answer
to performative and stage challenges, others created with the specific goal of exploring a
particular aspect of the relations between the *Sound*, *Visual* and *Movement* domains, or
triggered by the inputs and analysis given by the development of the framework. A sheet
for each project was created to document the creation process, explaining the interactive
system, its operation modes, the software and hardware used and the project setup. These
projects were then also used as case studies in the framework implementation.

2) A theoretical path, focused on collecting and analyzing interactive artworks, and on
developing a framework for cataloguing their interactive systems, providing a language for
relating, analyzing and criticizing interactive artworks.

This process started with the collection and cataloguing of interactive artworks based
on their processes of transformation of data between different domains, from these a
group of twenty-two projects were selected, with the aim of serving as case studies for
the development of the framework. Then the definition on real-time interactive systems

and the limits and boundaries of *Sound*, *Visual* and *Movement* domains were stated. As a baseline for the building of the framework, nine classification systems from the interactive and computer art literature were analyzed, each one of them with different approaches, methods and processes, but all overlapping the viewpoints of this research. Which provided tools and inputs in the creation of the framework presented in this dissertation.

Both research paths were developed in parallel, but were always interconnected, with the artistic practice giving inputs and shaping many aspects of the theoretical path (such as the selection of case studies, literature review, and perspective on interactive systems, which were influenced by the artistic practice). And also in the reverse direction, as the development of the frameworks works as a catalyst for new ideas and projects.

There is therefore a constant feedback loop between both paths. Just like João Beira wrote to describe the approach used on his research dissertation, "this feedback loop between practice and theory established the direction and natural progression of the conceptual, technical and artistic elements of this research." (2016, 137).

1.4 STRUCTURE OF THE DISSERTATION

This dissertation is divided in four main chapters that unwrap and develop a narrative for the study of relations between *Sound*, *Visual* and *Movement* domains. It starts with a literature review and the theoretical context of the research work (chapter 2 : *Context*). It goes through a series of six main topics that represent the core areas of our artistic practice and theoretical research: *Seeing Sound,* *Visualizing Movement*, *The Computer*, *Audiovisual Spaces*, *Audiovisual Interactive Systems* and *Transmutability of Digital Data*.

The following chapter is focused on the review of the state of art related to audiovisual interactive artworks (chapter 3: *State of the Art*). The first section collects a group of pioneers on interactive art which we consider that establish the foundations and languages for real-time interactions with *Sound*, *Visual* and *Movement*, and with whom we relate our work. Then a catalogue of interactive artworks is presented, divided according to their process of domain transformations and interactive system similarities (namely: *Motion Sculptures*, *Sound Sculptures*, *Graphic Sound Visualizers*, *Shaping Sound*, *Movement Sonification* and *Kinetic Structures*). This catalogue, compiled on the blog S-V-M (Sound+Visual+Movement), provided the foundations and baseline for this study on the relations between the three domains.

In the conclusion of the chapter, a selection of twenty-two interactive artworks is presented, which are then used as case studies in the building of the classification framework.

Next, a framework named *S+V+M* (Sound, Visuals, Movement) is proposed. Its goals are the classification of real-time audiovisual interactive artworks based on the flow of data through the system (chapter 4 : *Sound+Visual+Movement*). The first section states this research perspective on the topic, its definitions on interactive and digital systems and the boundaries of the Sound, Visual and Movement domains. Then a set of nine interactive systems classifications from the literature review on the field is presented, each one of them relates to this work as they cover or overlap the topics, approaches and goals of this research, and had a significant contribution in the building of the framework.

Then *S+V+M* framework is presented, its goals, definitions and methods are explained, and each one of the case studies is classified.

The fifth chapter approaches the practice-based work and the projects, artworks and explorations created during this research (chapter 5 : *Artworks / Projects*). A set of ten projects are documented, describing its artistic goals, implementation, interactive system and other technical information as setup, techniques, code and software used. Then each of these projects is classified under the framework, and their similarities, common parameters, and flows of data are highlighted. In addition, a series of other experimental project and technical explorations are also presented. And lastly two ideas for future projects exploring *Sound*, *Visual* and *Movement* relations, are described.

Finally on the last chapter the outcomes of this research, discussion points, and directions for future work are presented (chapter 6 : *Conclusion*).

2. CONTEXT

2.1 OVERVIEW

This chapter addresses the literature review and theoretical context of the research work developed in this dissertation. It his divided in six topics which define the foundational areas of this research.

The field of interactive art is much broader, and many more topics could be included (as generative processes, robotics, human computer interfaces, etc.), but these six represent the core and main focus of this dissertation which is on interactive systems, and sound-visual-movement relations, always with a strong perspective on the visual outcome.

2.2 SEEING SOUND

2.2.1 COLOR ORGANS, VISUAL MUSIC and OPTICAL SOUND

The known history of relations between music and color goes back to 500 BCE in ancient Greece, with Pythagoras, whose "intuition of the analogy between vibrations in tone and vibrations in light led him to imagine the *Music of the Spheres* as the sounds created by the perfect movement of heavenly bodies as they proceed along their inevitable course" (Snibbe and Levin 2000, 1). These ideas inspired many creators, scientists, and artists until today, who have been trying to "create with moving lights a music for the eye comparable to the effects of the sound for the ear" (Moritz 1986).

The modern history of visual music or color music starts in the 18th century, inspired by the ideas of Pythagoras and recent advances of science in the fields of physics and optics, mainly the work of Isaac Newton who, in his publication *Opticks* (1704), for the first time made a comparison between color and a music scale (Jewanski 2009). In his research, Newton was able to divide "white" light in seven different colors with the help of a triangular prism. Later he assigned to each one of those colors a corresponding sound note.

Louis Bertrand Castel built the first known visual music instrument in 1754, a color organ called *Ocular Harpsichord* (Snibbe and Levin 2002), where he followed Newton's approach of establishing mathematical relations between wavelengths of different hues and pitchs (Ritter 1992, 4) .

Castel's harpsichord used candles placed behind colored glass and was controlled by a keyboard. When a key was pressed, a colored strip of paper or glass appeared in the panel, letting the light from the candle pass. This way each time a key or combination of keys was

pressed, the corresponding color was visualized, resulting in an expressive performance of light art. Castel's color organ was followed by a number of other visual music apparatuses like the *Color Organ* by Alexander Wallace Rimington in 1895 or the *Sarabet* by Mary Hallock Greenewalt around 1920 (Peacock 1988). Rimington was in fact the first to name it *Color Organ*, which became a generic term for similar devices (Ibid.). He claimed that "vibrations which stimulate the optic and aural nerve respectively" were the explanation for the relations and physical analogies between sound and color. (Ibid.)

It was clear for many creators that both sound and color are wave frequencies on a spectrum, and that there must be a relationship between them. "Most inventors of color organs were convinced that their instrument constituted a breakthrough" (Ibid.), but despite centuries of experiments and achievements, visual music is still an unsolved field with much to explore. Every tool or color-organ instruments remained until today as an "eccentric curiosity and a technology dead end" (Ibid).

In the early 20th century Thomas Wilfred created his own color-organ, the *Clavilux*, an instrument made of lenses, mirrors and colored lights for projection of light performances. The instrument was operated by a keyboard like a normal organ. Inside there was a triple light chamber with discs. The pressed keys would determine the discs position. There were 100 positions for each key, which provided many diferent visual outcomes (Popular Mechanics 1924).

Wilfred named this art form as *Lumia*, the art of light, in his words the eighth form of art. *Lumia* was an aesthetic concept, "the use of light as an independent art medium treatment of form, color and motion in a dark space with the object of conveying an aesthetic experience to a spectator" (1947, 252). For Wilfred, light is the artist's "sole medium of expression" (Ibid.). In the same way a sculptor models clay, a light artist controls light, its color and especially its motion. Light art is a time sculpture, motion gives the piece a third dimension, the time, and the light artist must be "a choreographer in space". [1]

Despite the *Clavilux* being regarded as a color-organ, it was very different from the other devices as it did not produce sound, only light and color. This was a silent art, an art of full stimulation of te visual sense, where the artist suggested abstract aesthetic concepts, and let the audience the freedom to materialize the forms, colors and motions into their personal visions, fusing imagination with reality (Wilfred 1947). Besides having done several public performances with the *Clavilux*, Wilfred also imagined a personal use of the instrument and created a home version. It was a small box with a screen similar to a television that could play images for days without repetitions (Moritz 1997). "These devices imagined a world where families would sit down after dinner, open a handsome hinged oak cabinet, and enjoy an evening of time-varying abstract light." (Snibbe 2010)

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1 Quotes taken from Mariana Rezende's article on Creators Project website, 2012. "Original Creators: Thomas Wilfred, The Father of Multimedia". In Creators Project. <http://thecreatorsproject.com/blog/original-creators-thomas-wilfred-the-father-of-multimedia>. Accessed on 20.05.2013.
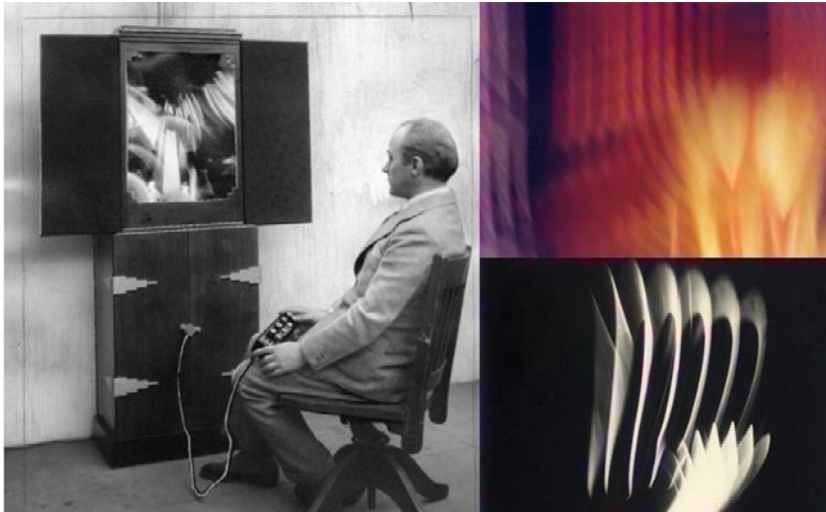
Fig. 2: Clavilux's home version (left), Clavilux's visual outputs (right)[2]

Oskar Fischinger (1900-1967), considered by many as the father of *Visual Music*, played an important role in the field of synchrony between sound and moving images. In the 1930s he started exploring and producing sound by drawing abstract patterns on the film's optical tracks. Fischinger painted sound waveforms on strips of paper, *sound scrolls* as he called them, and then by photographically exposing the waveforms to the optical soundtrack of the film, he was able to synthesize sound to accompany the animations and create a perfect synchrony between sound and image (Levin 2000, 31). His films were impressive non-narrative sound experiences, without any story line or acting, but with an amazing power to convey emotional experiences and synesthetic sensations.
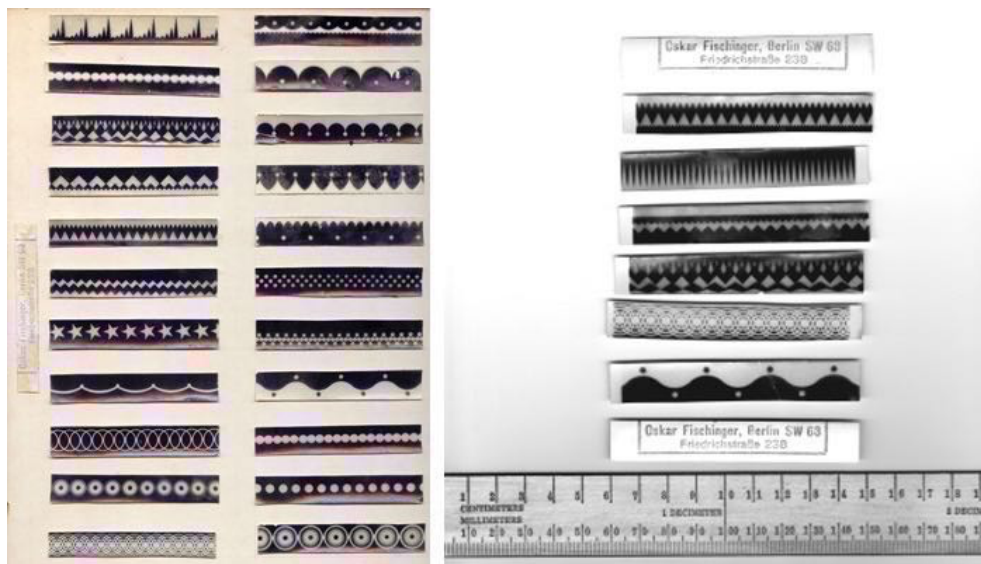
Fig. 3: Detail of different sound-shapes drawings by Oskar Fischinger. [3]

2 Yale University Library holds a wide collection of Wilfred's documents, and photographs related to his work on the Clavilux. They can be accessed through the Digital Database < http://images.library.yale.edu/madid/showthumb. aspx?q1=1375&qc1=contains&qf1=subject1&qx=1004.2>Accessed 14.10.2015

3 Taken from "Center for Visual Music's Fischinger pages". <http://www.centerforvisualmusic.org/Fischinger/SoundOrnaments.htm> Accessed 14.10.2015

In the article *Sound Ornaments* (1932), Fischinger describes how one could draw ornamental patterns on the sound strip and achieve sounds of "unheard purity" and achieve "fantastic possibilities". He describes how he creates synthetic sound by drawing ornamental patterns on a strip of film, which are then run through a projector and broadcast sound. Fischinger predicts a future where the music is not written in a musical score but painted in a more free and expressive way (Ibid.).

At the same time, in Russia developments were also being achieved based on the similar techniques for synthesizing sound from light. Many of these creations, that are often ignored in Western culture's perspective of visual music history, were carefully compiled and documented by Andrey Smirnov in the book *Sound in Z: Experiments in Sound and Electronic Music in Early 20th Century in Russia* (2013). The seventh chapter, titled *Graphical Sound*, documents a series of inventions and instruments for synthesizing artificial optical sound.

In the 1930s Arseny Avraamov developed a similar technique to the one used by Fischinger based on shooting still images of drawn sound waves and geometric shapes on an animation stand.[4] Avraamov created the *Multzvuk* group (composed by himself, Nikolai Voinov, Nikolai Zhelynsky, and Boris Yankovsky) dedicated to explore drawn music films, with whom he created several experimental films like *Ornamental Animation*, *Marusia Otravilas* or *Chinese Tune* (Ibid.).
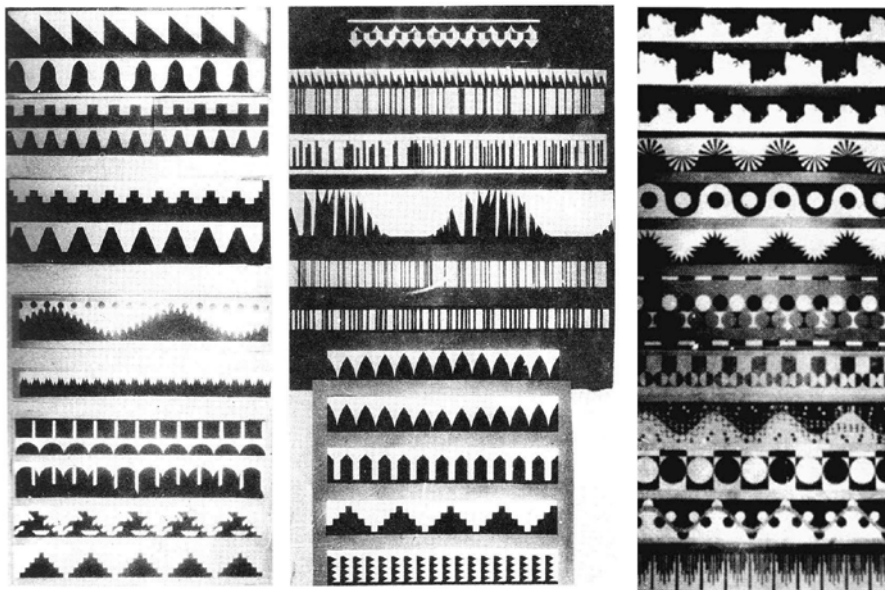
Fig. 4: Ornamental Soundtrack, drawn by Arseny Avraamov (left and center) and Boris Yankovsky (right). Images from *Sound in Z* (Smirnov 2013)

Also in the 1930s, Evgeny Sholpo created the *Variophone*, a mechanical device that used circular cardboard disks with cut patterns. The disks were rotating synchronously with a moving filmstrip, and the sound was produced through an optical sound synthesis technique. This mechanical method had some advantages over drawing directly on the strip like the ability of controlling the pitch and vibrato on real-time (Ibid.).

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4 "1930s Russian Drawn Sound: Arseny Avraamov's 'Ornamental Sound Animation".
<https://www.youtube.com/watch?v=8EGFPZdiVqI> Accessed on 14.10.2015
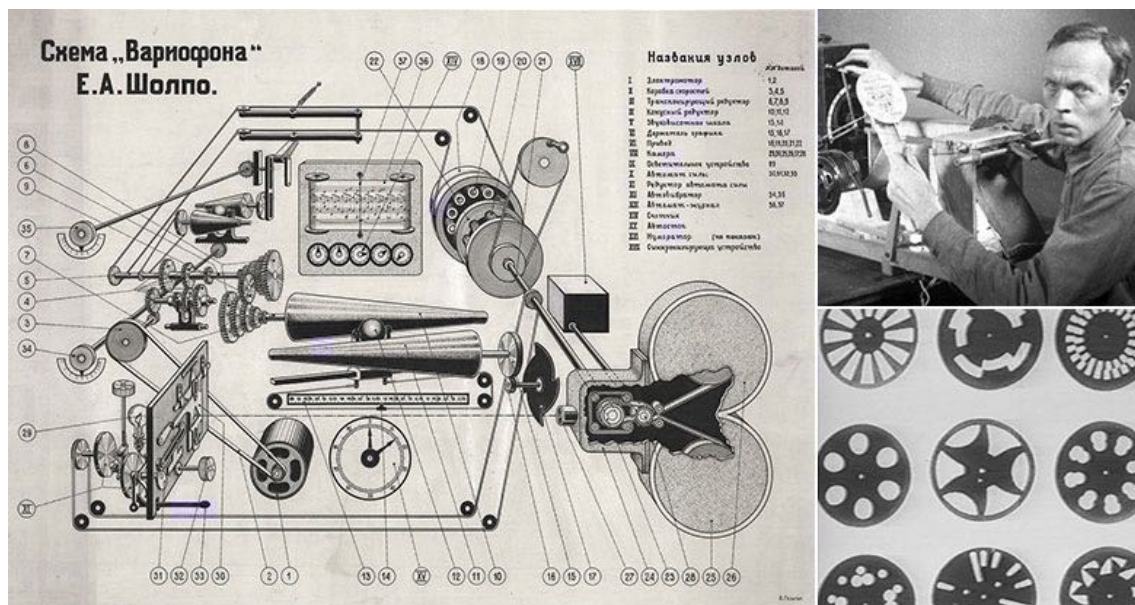
Fig. 5: *Variophone*'s schematics; Sholpo working with the variophone; Cardboard disks. Images from *Sound in Z* (Smirnov 2013)

Later Voinov developed his own technique for graphical sound. Instead of drawing on the film, Voinov developed a technique called *Paper Sound*, where pieces of paper were cut in different shapes, combined in sequences and used for sound synthesis[5]. Their carefully calculated sizes allowed a new "surprising efficient level of control over the dynamics of sound" (Ibid.).

Besides the work on abstract films, in the 1940s Fischinger also developed the *Lumigraph*, a Lumia art instrument or color organ to perform patterns of light. Despite the apparent similarity of approaches and concept between *Clavilux* and *Lumigraph* there were some fundamental differences between them. Fischinger guided his work to the creation of relations between sound and image, a goal that Wilfred rejected since he defined Lumia as a silent art (Levin 2000, 26). Also the way the performer interacted with both devices was different. On the *Clavilux* the performer controlled a remote motorized mechanism, while on the *Lumigraph* the interaction was made through the direct hand contact and gestures on a latex screen sheet (Ibid.).

The *Lumigraph* was composed by a large frame holding a thin sheet hiding light sources in the back, by touching the screen and making gestures, a performer was able to get a feedback of color fluids (Morits 1997). Although this was not a truly audiovisual interactive system (a second person was needed to put the music and change color palettes), it was a major influence in contemporary systems and audio visualizations. The audiences were delighted as it was something very ahead of its time. The expressive gestures of the player following the music had, as feedback, a magic interactive and generative visualization of the sound.

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5 "1930s Russian Drawn Sound: Nikolai Voinov's 'Paper Sound'. <https://youtu.be/Z7Zb4rso82M>. Accessed 14.10.2015
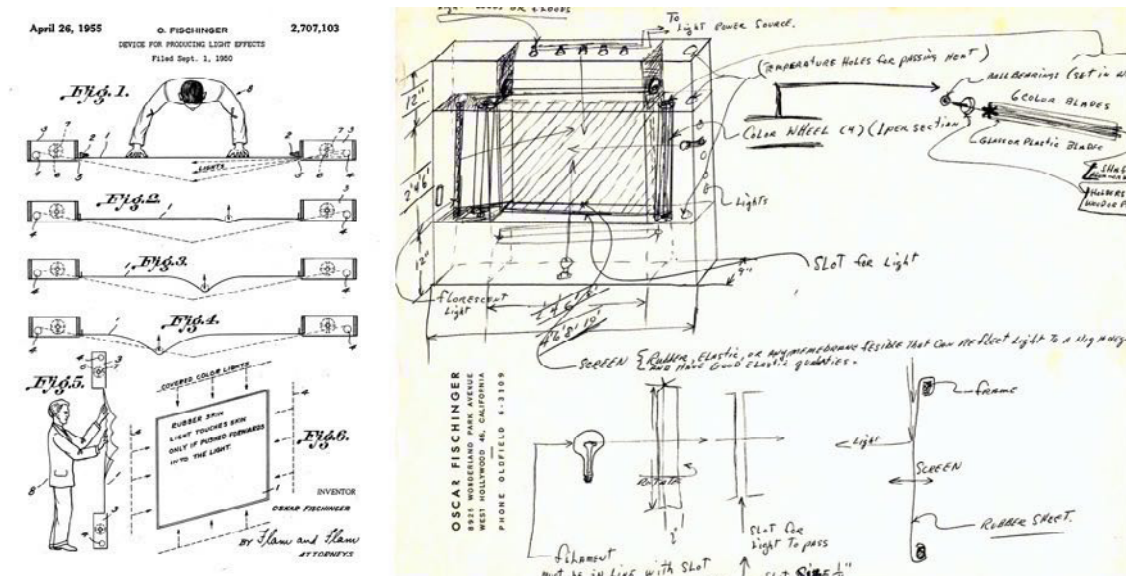
Fig. 6: Lumigraph's patent (left); Fischinger's schematic drawings (right).

Norman McLaren, another important pioneer in the field of abstract and experimental film, followed and improved Fischinger's techniques of painting on the film's sound strip. On the documentary *Pen Point Percussion* (1951) McLaren describes the process of painting the sound directly on the film. He demonstrates in detail how the technique works and how to obtain different outputs depending on the type of shape that is drawn on the strip.

Besides hand-drawing sound-waves, McLaren developed a variety of template-based systems where he created a series of index cards, painted with different patterns, whose shapes and spacing had been predefined to produce specific notes. Then he would use a paper mask to define amplitude envelopes and produce sounds with different attacks and decays (Levin 2000, 31). These techniques allowed to create and control a perfect and synthetic synchrony between sound and image. When we watch McLaren's films like *Dots* (1940) or *Synchromy* (1971) we find a strong influence of the abstract, surrealist and expressionist art movements, that brought new ideas to the relationship between sound and image, seeking not only the color-tone analogy, but also the concepts of motion, shape, rhythm and time.

Lis Rhodes, a filmmaker who explored similar techniques in the creation of audiovisual artwork, described the outcome of these techniques as "what you see is what you get". When talking about her piece *Dresden Dynamo* (1971) she explains that the film was made without a camera, "the soundtrack is exactly the image, and the image is exactly the soundtrack (...) that relationship between an image and a sound, instead of being added later, maybe dubbed, was actually synch from the moment it was made"[6].

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6 Lis Rhodes 2012 on a interview to Tate Modern about her exhibition "THE TANKs".
<https://youtu.be/ts5uT0Pdj4c> Accessed 9.11.2015
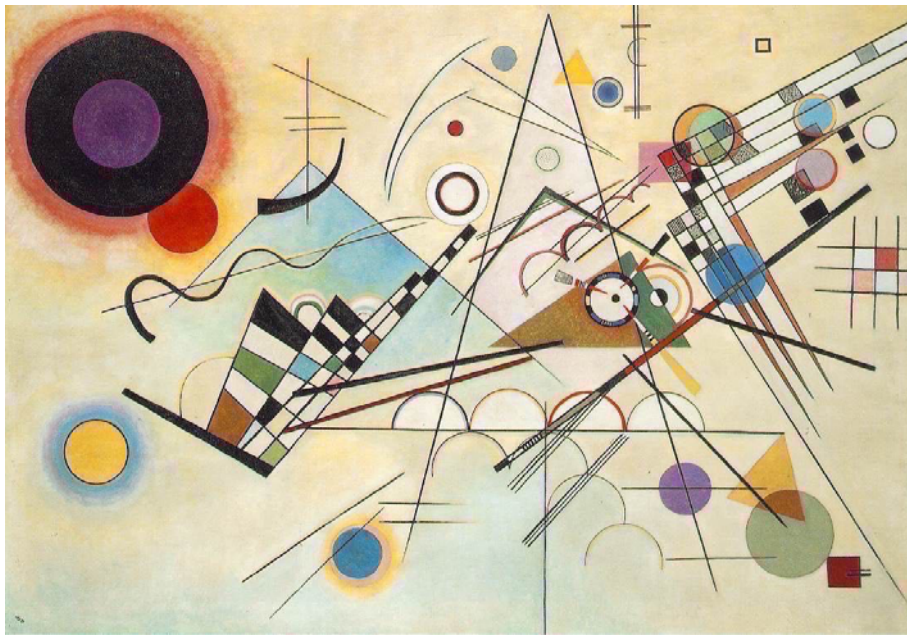
Fig. 7: *Composition 8* (Kandinsky 1923).

When looking at Kandinsky's paintings we have a clear perception of rhythm through his usage of shapes and colors. Through his paintings, specially *Compositions* series, we can clearly perceive expressive musical tones and rhythm, and establish a parallelism between spatial relations, structures, forms and planes of both image and sound (Barbara 2004). He translated music into abstract color patterns that return sound impressions and temporal proportions (Föllme and Gerlach 2004). The perception of time became the center point of his artistic work, it became a new category, taking into balance the importance devoted to space.

Mary Ellen Bute, a pioneer of abstract film, emphasized the importance of the abstract form opposed to representative symbols in the triggering of synesthetic sensations between sound and visual imaginary, because it "aimed not at the intellect but rather directly at the emotions" (1940-1945 qtd. in Naumann 2009, 50).

We can easily find the influence that Kandinsky's ideas on visual shapes, rhythm and structures of time had in many artists working with sound and images in motion up to the present day. In *Partitura 001*, a real-time generative sound visualization by Davide Quayola and Natan Sinigaglia (2011), we see how geometric shapes and colors transmit the oscillation of sound waves over time. The piece presents a horizontal linear structure, like a musical score, where different abstract elements evolve over time. On Quayola's words, "Partitura creates an endless ever-evolving abstract landscapes that can respond to musical structures, audio analysis and manual gestural inputs." [7]

If we look at Kandinsky's work, *Composition 8* (1923) as an example, and compare it with *Partitura 001*, we can immediately feel a connection. We see explosions of graphic elements (dots, lines, planes) that flow along an imaginary timeline, and the features of visual shapes transmitting musical expressivity. They do not just react to sound frequencies, like an audio visualizer, but they recreate the tension, motion and expressivity of the musical piece. The horizontal strings in *Partitura 001*, that swing and flow along with the music,

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7 Quayola quoted in Kelvin Homes' article "Quayola Sets A New Standard For Visualizing Sound"
<http://thecreatorsproject.vice.com/blog/quayola-sets-a-new-standard-for-visualizing-sound>. Accessed 19.10.2015.

are a perfect illustration for Kandinsky's thoughts in *Point, line to Plane* where he explains how the sharpness of a line can express the different levels of intensity of music, from pianissimo to fortissimo (1947, 98-99).
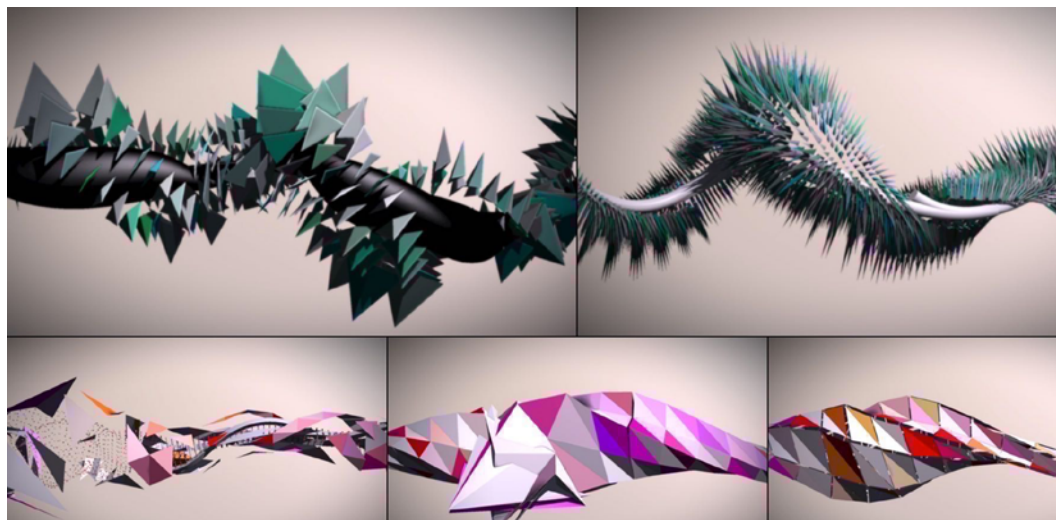
Fig. 8: Sequence of frames from *Partitura 001* (Quayola and Sinigaglia 2011).

Quayola acknowledges the influence of Kandinsky in his work and highlights the obvious connection between Kandinsky's paintings and music, "in fact he [Kandinsky] started to call his paintings, compositions. A musical term."[8] Quayola also emphasizes the graphical systems and languages that Kandinsky used to develop relationships between forms, shapes and geometry to build his compositions, which are somehow similar to composing music and to the way that Quayola itself works to develop his sound visualizations (Ibid.).

In the 1960s and 1970s, with the advent of video technologies, a group of artists and inventors (like Nam June Paik, Steven Beck, Eric Siegel, Steina and Woody Vasulka, or Steven Rutt and Bill Etra) created and modified video apparatus to explore this new medium. Devices like the *Paik-Abe Synthesizer* or the *Rutt-Etra Synthesizer* allowed them to manipulate the image in real time, treating the video signal as an electronic wave form, manipulating, deforming, changing and merging audio and sound signals (Spielmann 2009). These pioneers built different *Machines of the Audiovisual*, as Jihoon Kim called these systems capable of manipulating sound and images simultaneously (2013, 83), and shaped the aesthetics of synchrony between electronic sounds and abstract imaginary and traced the path to nowadays audiovisual artists and audiovisual digital tools (Ibid.). *Noisefields* (1974) by Steina and Woody Vasulka is a good example of the video-art aesthetics of the 1970s, a self-reflexive interplay of visual input and exploration across the pure electronic signal. "The image content is determined by the modulation of unformed electronic oscillation processes, in other words, video noise" (Spielmann 2009). One of the most famous video synthesizers was the *Rutt-Etra Synthesizer* developed by Steve Rutt and Bill Etra in the 1970s. This video synthesizer allowed a precise modulation of electric signals and the shaping of variable dynamic forms that could be seen and heard at the same time (Kim 2013). On *Scan Processor Studies* (Vasulka and O'Reilly 1974) a collection of

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8 Quayola (2011) Interview for "The Creators Project".
<http://thecreatorsproject.vice.com/en-uk/creators/quayola>. Accessed 20.05.2013.

works developed with the Rutt-Etra Synthesizer, the key characteristics of the *Machines of the Audiovisual* are already evident: "reciprocal translatability of visual and sonic elements as a key domain of video's material" seeking a "variable, multidimensional visual forms as manifestations of audio noise" (Kim 2013, 82).
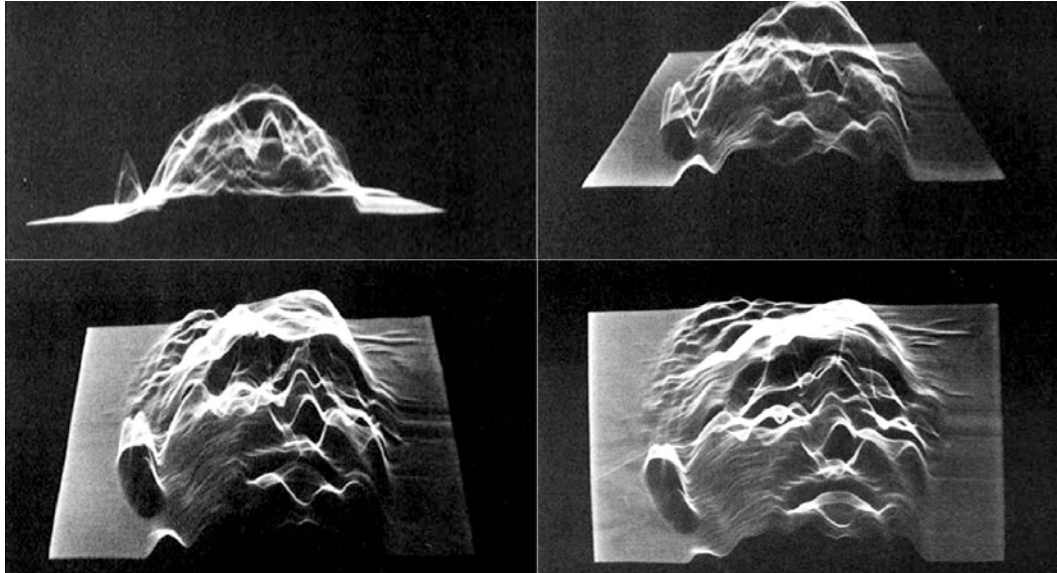
Fig. 9: Sequence of frames from *Scan Processor Studies* (Vasulka and O'Reilly 1974).

The concept of using electric signals as inputs to synthesize video and sound, to be used as used one synchronized element can be traced back to the optical sound explorations where sound was generated by shapes on film. "In the video, the wave forms of the pattern-generating oscillators as well as those of his voice can be simultaneously heard and seen. ... In video, one can see what one hears and hear what one sees." (Spielmann 2009)

2.2.2 SOUND-IMAGE ANALOGIES

> *...An absolute or best correspondence does not exist between music and image. (Ritter 1992, 5)*

Connecting the exact sound frequencies with color frequencies may have physical and mathematical justifications, but it is a closed, absolute and very limited approach. It does not include shapes, rhythm, motion, it does not permit the changing of rules and it does not represent emotional states. In fact, sound and image are two physically separated phenomena. Sound is vibrations in the air, and what we call light is a small part of the spectrum of electromagnetic radiation. The only place where they appear together and influence each other is in human perception (Daniels 2004). So there is not any scientific or objective connection between both elements apart from some conventions (for warm and cold colors as an example) everything else is subjective, it only happens in the human perception and cannot be explained or observed except by the ones who experience it (Ibid.).

Roger Shepard also stresses the point that sound and vision are physically two different phenomena and "what we perceive is not exactly the same as the physical reality of

the stimulus" (1999, 149). The way we perceive and quantify audiovisual experiences could not match the reality, as its parameters, as pitch for sound or brightness and hue for images, are subjective attributes. Shepard cites the studies of the cognitive psychologist Michael Kubovy (155), defining the "Dispensable vs Indispensable Attributes", to demonstrate how sound and images are perceived differently. He states that on visual perception color is dispensable and location is indispensable, and that on auditory perception pitch is indispensable and location is dispensable.[9] Shepard concludes that "the analogue to visual space is not auditory space, but auditory pitch" (157).

In neurology, *synesthesia* is a mental state where different senses are mixed or perceived concomitantly, like seeing sound or smelling colors. The term comes from the ancient Greek "syn" which means "at the same time" and "aesthesia" meaning "perception". So this term relates to simultaneous perceptions (Emrich, Neufeld and Sinke 2009). Despite being a topic of interest since ancient times, synesthesis only becomes an object of scientific research in the late 19th century. This phenomenon happens when a sensory inducer activates a perceptual feeling, and can have different forms and levels of complexity (e.g. colors triggered by numbers, shapes triggered by sounds, etc.) (Ibid.).

Synesthetic experiences can be divided in three types depending on their source: a) genuine synesthesia, when these events are and were always present in the subject since childhood; b) when they are acquired later in life due to brain damage or loss of sensory input; c) when they are temporary, induced or suggested by special immersive environment conditions, extreme sensory inputs, or by action of psychoactive substances (Grossenbacher and Lovelace 2001). Neuroscience research is focused mainly on genuine synesthesia, however most people can be induced into temporary synesthesia states when confronted with hyper-sensory environments. This is called "Multimodal Integration" (Daurer 2010), when the perception of surroundings is dependent from the information collected by several sensors simultaneously. Audiovisual immersive environments can play with our spatial and temporal senses and induce temporary synesthetic sensations.

Michel Chion (1994) , names the moments of synchrony between the sound and visual events as "points of synch" (58). These moments of synchrony lead to perceptual synthesis on the audiences, merging in the perception sound and images that "strictly speaking have nothing to do with each other" but may form "inevitable and irresistible agglomerations in our perception" (63). Chion describes the relation between sound and image as "added value", because sound manipulates the way the image on screen is perceived, it can enhance image expression and suggest scenarios that are not visible on screen. Sound works as the "audiovisual chain" (2004, 47), unifying and binding the flow of images and defining the atmosphere.

On the other hand Ryoji Ikeda and Carsten Nicolai highlight the inverse situation on how the image on the screen influences and manipulates the sound they are playing: "... we

9 Shepard explains the differences between auditory and visual perception and the "dispensable" and "indispensable" with two practical examples (1999, 156): 1) If we have two light projectors, one projecting a red spot and other a yellow one, and both pointing to different locations, the viewer will see exactly two different spots with two different colors in two different places. But if the two projectors are pointing to the same place, the viewer will see only one yellow spot. He is not capable to split the two colors, and he perceived it as one single spot; 2) In the case of sound, the situation is different. If two sound speakers emit two different notes, the subject will perceive the two different pitches, regardless of the sound sources are separated or in the same location. However if different sound sources, in different locations, emit a sound with a similar pitch the subject is not able to distinguish them, perceiving both as one same sound.

abandoned the idea that image act only as a functional accompanist to sound and instead subordinated the audio element for our desire for the image." (2011).

Nicolai, who has been for almost twenty years working on the physical and visual characteristics of sound, develops most of his work on the exploration of the limits of human perception and experimenting with high and low frequencies until the frontiers of audible sounds, sounds that even if we do not hear them, exist, and can be felt by the body. He explores sound not necessarily from a musical point of view, but more the graphic features of the waveform itself, shaping and sculpting it like if it was a physical object. Due to the fact that many frequencies are out of the audible sound spectrum, Nicolai has the need to make a visual representation of those frequencies, in a way he can see the waveform and perceive what is happening. He stresses that he is not interested in merging sound with image, but in making them interact mutually and creating a unified hyper-sensorial experience, "Our hearing can only hear a specific frequency, but our body can hear much more" (Mori 2009)[10].

In the approaches described before to relate sound and images there is one inherent element that is key to create a synergy between sound and images (or light): time. It connects, structures and gives a new dimension to both domains. John Whitney, in his book *Digital Harmony*, dedicates a chapter to this issue: "*The Problem: How Shall Motion Pattern Time*" (1980, 37). In his work he constantly tried to find solutions for manipulating visual elements in a way that they contribute to communicate time and to achieve a time-structured design. The relationships between sound and image are much more than the simple translation of sound frequencies to color and shapes. They are also about expressivity, dynamics, rhythm, motion and time.

Whitney described the factor of motion and time as a dynamic pattern, and the image as patterns in motion. He dealt with this topic by giving motion to patterns of graphics elements with certain rules (velocity, direction) which obeyed to a major pattern and that could be modified and deformed (Whitney 1980). This way he was successfully able to visually transmit the expressivity of music, as in both music and the visual "emotion derives from force fields of musical structuring in tension and motion" (41).

> *Many people with closed eyes at the concert, are "watching" the music.*
> *But after all the centuries, there stills exist no universal acceptable visual equivalent to music. (Whitney 1980, 15)*

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10 Alva Noto Interviewed by Juliana Mori for "Tugobot Tech-Doc", Barcelona. <http://tugobot.com/> Accessed 16.10.2015.

2.3 VISUALIZING MOVEMENT

This section approaches the topic of visualization of movement, where movement is captured, analyzed and output in the form of visual shapes whose features reflect the dynamics of each specific movement through time. *Time* then becomes frozen and expanded into a trail of motion events, gaining the features of a spatial dimension, and it is materialized through mapping metaphors into a digital or physical sculpture.

Many artistic works make use of movement visualizations as an aesthetic resource, a good example is the audiovisual installation *Forms* (Akten and Quayola 2012) a study of human motion, where the authors explored historical video footage from Olympic athletes performing different sports. The installation presents a series of abstract visualizations of the movement of the human body, where the focus is not on the observable trajectories but on the mechanics behind those movements.
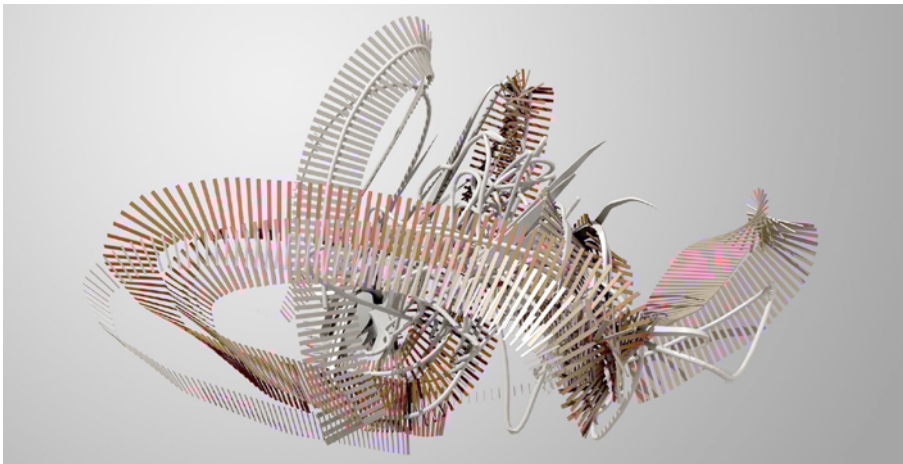
Fig. 10: *Forms* (Akten and Quayola 2012)

The audience observes on screen digital sculptures made of lines, dots and other visual shapes that are built from the deconstruction of the qualities of the movement over the time, visualizing this way not only the representation of the human movement itself but also the impact created by these invisible forces on an imaginary simulated environment.

There is a strong similarity between *Forms* (and other similar contemporary projects) and the work of Etienne-Jules Marey on the late 19th century.[11] Marey's studies capturing sequential moments of time from movement result in beautiful visual compositions. His work gave a new perspective of motion and time and allowed a detailed study of the motion of the human body and several other animal species. In his book *Movement* (1895), Marey describes a series of techniques and apparatuses that he used to capture and visualize the movement of humans, birds, fishes and other animals.

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11 In fact Memo and Quayola in an interview for The Creators Project refer to Marey, Muybridge and Harold Edgerton as a big influence on their work <http://thecreatorsproject.vice.com/blog/quayola-and-memo-akten-translate-athletic-movements-into-abstract-animations>. Accessed 30-04-2015.
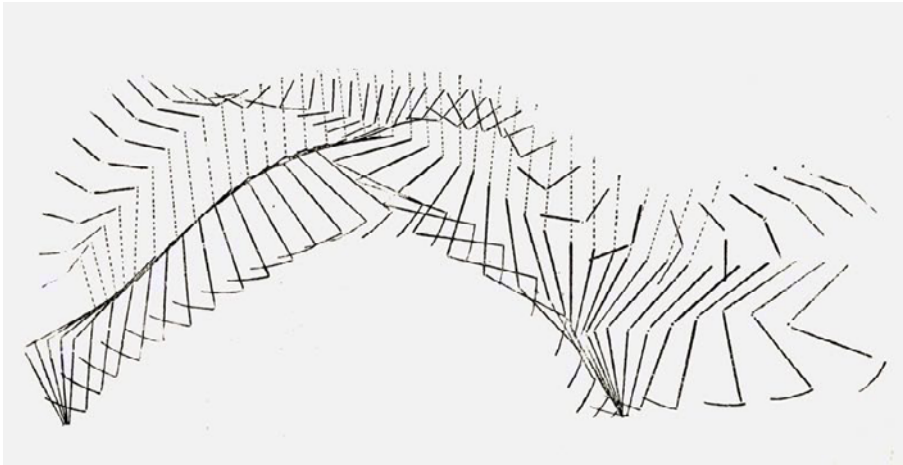
Fig. 11: *Chronophotographic print of a long-jump preceded by a run* (Marey 1895)

Through the book Marey emphasizes the importance of photography for the representation of movement, allowing its observation and cataloging with a detail that was not possible before. Photography allowed capturing micro elements of motion, keeping a time-stamp in each of the pictures, enabling to extract accurate motion data to use in diagrams, statistic and graphs (Zielinsky 2008, 245). This method, that was called "chronophotography" combined space and the time in one, dimension, and allowed to explain a wide range of factors in the movement (Marey 1895).

Christian W. Braune and Otto Fischer, two German scientists from the late 19th century, inspired by the work of Marey, created a movement tracking suit to study biomechanics and visualize and analyze body movement (Zielinsky 2008, 245). The motion tracking suit was an exoskeleton equipped with Geissler tube lights[12] placed along the limbs. The tubes produced short and quick flashes with great emission of light, that allowed to produce photographs with separated and clear lines, and produce better graphical information than the motion suit used by Marey, that used shiny metal strips that left blurry trails when the subject was in motion (Zielinski 2006, 248).

Braune and Ficher were not only interested in producing two dimensional visualizations of the body's movements, but they also wanted to explore its spatial dimension. They took photographies from two different angles, and at the end they had the exact space position information from each joint in every moment of time. They gathered that data and built a three-dimensional sculpture where it was possible to physically visualize the global cycle of body movement through space and time (Zielinski 2006, 247).

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12 Geissler tube lights were early gas discharge tubes, created by the german physicist Heinrich Geissler in 1857. Similar to nowadays Neon lights, it produced a glowing light.
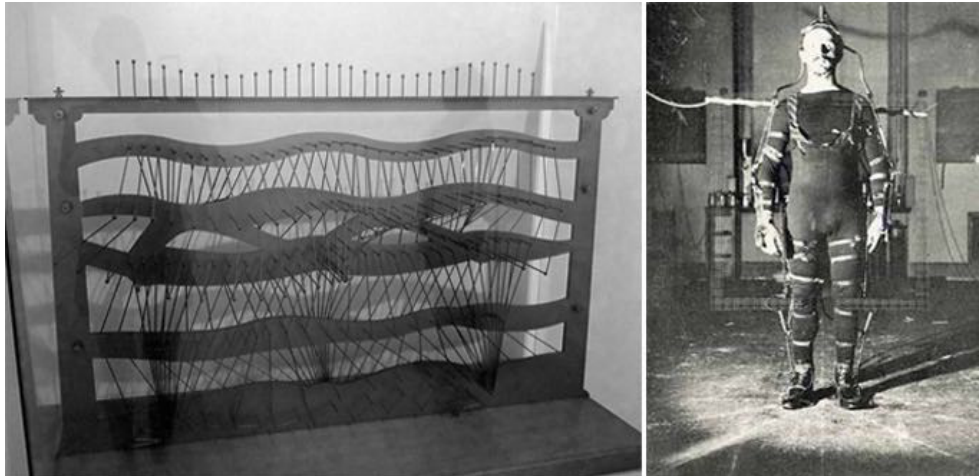
Fig. 12: Christian W. Braune and Otto Fischer's movement sculpture (left), a tracking suit (right). Images from *Deep Time of the Media* (Zielinski 2006)

The connection between the suits built by Marey, and later Braune and Fischer, and those used nowadays in motion capture systems is quite clear. Capturing technologies have evolved but the main ideas remain the same: markers with special reflective features are placed on specific locations, then under special light conditions the markers are highlighted from the rest of the image, which creates a path of lights that allows to track and record the movement. The data can then be use as an input for diverse types of visual outputs.

Marc Downie on his PhD dissertation on *Performance Graphics for Dance Theatre* (2005) describes motion capture as the base for "hybrid representations" (65). It allows to mimic the original movement and at the same time to extrapolate new representations, which is possible mainly because of the computer and its ability to manipulate and transform digital data. The "hybrid representation" is very visible on *Loops* (Downie, Eshkar and Kaiser 2001-2011), an abstract digital generative work based on motion-capture recordings of Merce Cunningham's solo dance for hands and fingers (Downie 2005, 102). From the exact movements recorded in a database a series of new graphic visualizations are extracted giving life to computational agents that flow along a network of nodes.

Another interesting approach to movement and visualization is the project *Improvisation Technologies: A Tool for the Analytical Dance Eye* (Forsythe 1993), a CD-ROM published in 1993 where the choreographer William Forsythe describes in video a wide set of choreographic sequences overlapped with geometric sketches. The purpose of the project was to train new members of the Ballet Frankfurt on an alphabet of movements that are described with geometric elements. The geometric elements were drawn frame by frame over Forsythe's videos (Downie 2005, 63). This resource, which was used to describe movements, reinforces Marey's main idea that geometrical drawings are the natural medium to represent "the positions of bodies in space, their forms and dimensions" (Marey 1895).

The idea of seeing time as physical spatial dimension presented on Braune and Fischer movement sculpture is again present in *Invisible Things of the Past*, a project by the German studio Art+Com (1996), where frames are extracted from a film sequence and translated to space according to the camera's movements. The result is a digital sculpture where the

time is represented as a spatial dimension and all the moments of time are physically represented at the same time. The final shape of the sculpture is the result of the movements performed by the camera during the shooting of the film.

The relation and influence that space and time have on our perception of movement lead us to the idea of time-structured design, where we can observe time from a higher dimension point of view, expand and stretch it. Also the way the time is perceived diverges according to the type of media used, just like Zienlinski suggests in *Deep Time of the Media* (2006, 31), where he describes how different media and technologies transmit different perceptions of time. Photography freezes moments of time in a two dimensional surface, telegraphy shrinks to an instant the time needed for a message to travel between two points and telephony updated the telegraphy with voice. With the motion picture camera, we are able to capture the illusion of motion by capturing sequential image stills that photography froze before, and with film we are able to manipulate time by stretching, reversing, speeding, cutting or expanding it.
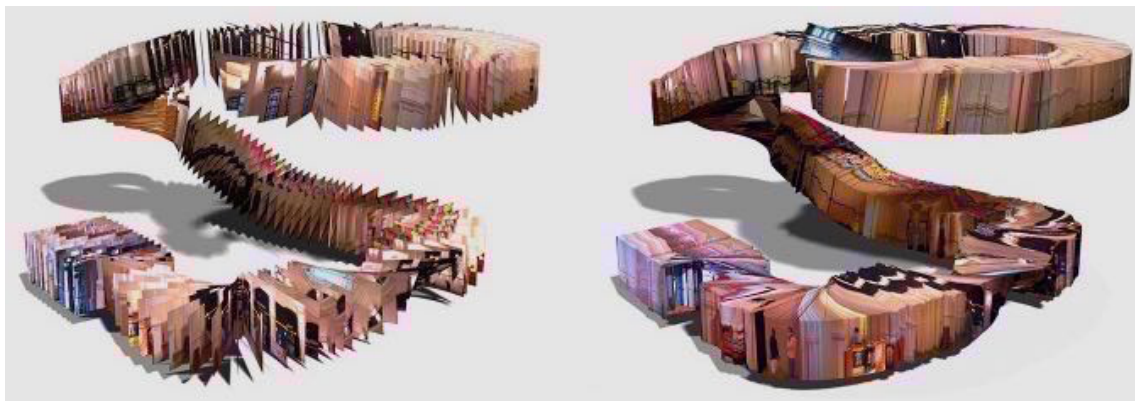
Fig. 13: *Invisible things of the past* (Art+Com 1996)

We can then talk of an aesthetics of movement, in other words of the usage and manipulation of the movement data, together with the space and time related to it, as an aesthetic resource. The reported project *Forms* is a clear example. It uses sports movement data to extrapolate expressive outputs and create generative graphical shapes. Its visual outcomes have strong similarities with Marey's work, that despite of being focused towards scientific purposes, shared the same concept of tracing movement with geometrical drawing along the time as a way to observe the "relation of space to time that is the essence of motion[13]".

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13 From the descriptions provided by Musee d'Orsay website related to Marey exhibition. "Movements of Air Etienne-Jules Marey (1830-1904) Photographer of Fluids". Musee Orsay, Paris. < http://www.musee-orsay.fr/en/events/exhibitions/in-the-musee-dorsay/exhibitions-in-the-musee-dorsay-more/article/mouvements-de-lair-etienne-jules-marey-1830-1904-photographe-des-fluides-4216.html?tx_ttnews%5BbackPid%5D=649&cHash=4c4050acf5> Accessed 30-04-2015.

2.4 THE COMPUTER

The earliest uses of the computer for artistic purposes can be traced back to the 1950s (deLaHunta 2002a, 118) when the first computer graphic experiments were developed.

One of the pioneers was John Whitney, Sr. who during the Second War worked with high-speed missiles at the Lockheed Aircraft Factory. He realized that the linear numerical calculations used to target missile trajectories could be used for plotting graphics or guiding movements for artistic drawing (Moritz 1997). After the war Whitney and his brother James built an analogue computer by converting an M-5 anti-aircraft gun director into a machine that was able to perform and animate complex drawings[14]. With this analogue computer they were able to explore and control movement of cameras graphics achieving a new kind of aesthetics and creating functions and languages that nowadays are common in most of digital video software.

Whitney is recognized by many as the father of motion graphics, in fact he founded a company named *Motion Graphics Inc.*[15], where he produced motion-pictures for television sequences and commercials. Some of his most iconic and recognizable works were the animated graphic vortex developed for the *Vertigo* title sequence in collaboration with Saul Bass (1958), and *Motion Graphics Inc*'s demo reel [16]composed by samples for promotion proposes. Despite working, at first on an analog computer, some of his technical and aesthetic achievements remain timeless landmarks and are part of the computer graphics, visual effects and motion graphics history.

During the 1960s and 1970s, Whitney and a number of other visual artists, as Lillian Schwartz and Stan Vanderbeek, joined research labs and worked together with engineers and computer scientists exploring computer graphics and technical applications (Cuba 2002). At the time, before the personal computer, the only way to access a computer was in military and academic institutions or in private research labs like Bell Laboratories where Schwartz and Vanderbeek[17] developed their work. Here they promoted the "view that the artist should be working together with scientists and engineers from within whose domain *arts-useful computing discoveries* were being made" (deLaHunta 2002a, 118). On a documentary related to their work at the Bell Laboratories, Vanderbeek[18] stresses the computers capabilities as a augmenting tool: "The computer, like a new tool, is there for the artist to use it. It's a men and computer relationship, new languages new thoughts, new approaches. (...). It's an amplifier. My thoughts can be magnified."

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14 Details found on a article by Kevin Holmes on "The Creators Project" reviewing the life an work of John Whitney. "Original Creator: Computer Animator John Whitney Sr.". <https://creators.vice.com/en_us/article/jpd4ky/original-creators-visionary-computer-animator-john-whitney-sr>- Accessed 10.01.2013.

15 John Whitney oficial biography at SIGRAPH.
< http://www.siggraph.org//artdesign/profile/whitney/nowhitney.html >. Accessed 30.012.2012.

16 John Whitney, Motion Graphics catalog, 1961. <https://youtu.be/TbV7loKp69s>. Accessed 2015.05.20

17 Documentary about Lillian Schwartz and Stan Vanderbeek work at Bell Laboratories, 1976.
In "The Artist and the Computer". <http://youtu.be/diLa2lig3dw>. Accessed 2015.05.10

18 Documentary about Lillian Schwartz work at Bell Laboratories, 1976.
In "The Artist and the Computer". <http://youtu.be/diLa2lig3dw>. Accessed 2015.05.10

Murray describes computers as "the most capacious medium ever invented, promising infinite resources" (1998, 83), able to merge in one medium diverse technologies of communication and representation, translating to digital format "all the major representational formats of the previous five thousand years of human history" (27).

The digital medium provided by the computer can be characterized, according to Murray (71), by four essential properties: *Procedural*, *Participatory*, *Spatial* and *Encyclopedic*. These properties define the way we interact with the medium, being the first two directly related to the definition of *interactivity* itself. The *Spatial* property describes the power to navigate in multi-dimensions and directions within the digital content, against the linear script of books or films (79). And the *Encyclopedic* feature relates to its seemingly infinite capacity of storage and instant access to vast quantities of information, virtually extending the human memory (83).

Another of Whitney's visual works, now on a digital computer, is *Arabesque* (1975), developed in collaboration with Larry Cuba. It explores a series of Islamic patterns, sine waves and parabolic curves that flow in constant motion and synchrony with Manoochelher Sadeghi's Persian Santur soundtrack. This animated piece is an example of the new possibilities that the computer with graphic and sound capabilities brought. The computer brought new paradigms, aesthetics, and creative processes to art, it "introduces a novel element into the real of the creative art process and stimulates a desire to re-examine the concept of such creativity" (Cornock and Stroud, 1973). As Manfred Mohr described "it became a physical and intellectual extension in the process of creating"[19] . The computer allowed to execute complex processes in a fast and cheap way, which enabled the artists to have a much more freedom for experimentation (Knowlton 1976), specially freedom to experiment with algorithms and generative work that "could not be realized in any other way" (Ibid.).
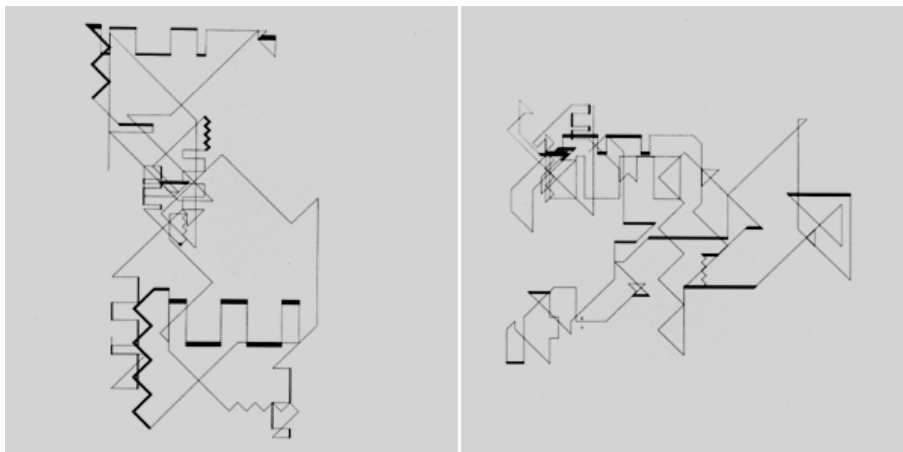
Fig. 14: Different outputs from P-18, Random Walk (Mohr 1969)

Mohr, another computer art pioneer, explored computer artworks by writing algorithms, defining visual parameters and probabilities that generated endless and varied artistic outcomes that could not be realized in any other way. "My artistic goal is reached when a finished work can dissociate itself from its logical content and stand convincingly

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19 Manfred / MONOGRAPH <http://www.emohr.com/manfred7.html>. Accessed 2015.05.25

as an independent abstract entity."[20]. On the *Random Walk* series Mohr defined a set of lines with different orientations (horizontal, vertical, 45 degrees) and different probabilities for its width and length, he left them the algorithm run, choosing sequential line elements and creating this way a *random walk*.[21]

Murray described the computer as an "enchanted object" (1998, 99), that can act autonomously, sensing its environment, performing generated processes by itself, leading to creations of artworks never seen before with endless possibilities, new forms and creative processes. Also enabled in the creators the "attraction of serendipity: the possibility of an unpredictable but satisfying outcome" (King 1995).

The word *Serenditipy*, as unpredictable but satisfying outcome, took part of the title of one of the first computer art exhibitions, *Cybernetic Serendipity*, in 1968, held at the Institute of Contemporary Arts in London. This exhibition was a very important landmark for the recognition of this new medium for the art world and for the mainstream audience. It was organized by Jasia Reichart, Mark Dowson, Peter Schmidt and Francizka Themerson and featured the work of leading authors at the time like John Whitney, John Cage, Frieder Nake, Georg Nees, Edward Ihnatowicz or Nam June Paik, distributed by three sections: *Computer generated graphics* and *computer animated films*; C*ybernetic devices as works of art*, *cybernetic environments*, *robots* and *painting devices*; and *Machines demonstrating the used of the computer and an environment dealing with the history of cybernetics* (Reichart 1968, 5).

The title and description of the exhibition shows the impact that the computer had in the perception, creative processes and shapes of art, in an exhibition that "deals with possibilities rater than achievements" (Reichardt 1968, 5). One of the artists featured at the computer graphics section Frieder Nake, which had been exploring the medium since 1963, explains in the exhibition catalogue the different parameters and random elements that he defined in the computer programs to achieve his artwork outcomes (Nake 1968, 77). As an example on *Polygonal Course No 7* (1965) the varying parameters included: *number of polygonal angles*, *direction and length of each polygonal side*; on *Klee No 2* (1965) the parameters were: *variation in width from break of curve to break of the horizontal bands*, *breaking of the horizontal bands*, *selecting of symbols for each square of a band/ no symbol/vertical lines for squares, number of symbols, position of symbols per square and number/position/radius of circles*. This description is a good illustration of the changes on the creative process that the computer brought to the art world. The random aspect of the process able to produce an almost infinite variety of outcomes is also a good example of the *Serendipity* aspect of the exhibition.

Also on the exhibition was the work of Jeanne H. Beaman with *computer programmed choreography* showing a different viewpoint on the use of the computer on a creative process, not on creating a final output but on generating random instructions and new choreographies for dancers. Beaman's work was based on giving a set of commands to the computer that would compute them and generate a set of specific instructions to the dancers like *tempo*, *movement* or *direction* (Reichardt 1968, 33). Likewise A. Michael Noll published an article named *Choreography and Computers* (1966), where he reported his work on Bell Laboratories on using the computer for dance notation and choreography. Noll describes a system with a visual display where a choreographer could input dance

20 Manfred Mohr / MONOGRAPH <http://www.emohr.com/manfred7.html>. Accessed 2015.05.25

21 Mohr's algorithm description. <http://www.emohr.com/ww4_out.html>. Accessed 2015.05.25

instructions and visualize instantly on the screen figures representing the dancers on a three-dimensional plane. The choreographer could then, through buttons on the console interface, explore different movements and elements of change and randomness, "all this is completely new creative process and might result in new dance forms" (Noll 1966). Noll stresses also the fact that all the movements explored by the choreographer on the computer would be automatic stored in a digital form, easing this way the notation systems.

One of the most emblematic artworks at the exhibition was the *Sound Activated Mobile* by Edward Ihnatowicz (1968), the first moving sculpture which was activated by sound, and reacted to presence around it[22]. It was composed by an articulated hydraulic structure controlled by an electronic system that used a number of microphones around the structure to detect the presence of the audience and make the structure turn on that direction. It was one of the earliest art projects to interact with the environment and the audience, and run by light sensors and a electronic systems. At the time this type of work, that emerged with strong connections with the ideas of cybernetics, was not called *interactive art* but instead *cybernetic*, *responsive* or *reactive*. (Kwastek 2013, 7).

Cybernetics was in fact another key concept in this exhibition and an influence on the computer artist, "providing the intellectual underpinning for the emphasis on process in art works and the developments of participatory art in the 1950s and 1960s" (deLahunta 2002b). Norbert Wiener coined the term in 1947, which comes from the Greek word *Kybernetike* - the art of helmsman- (Kwastek 2013, 5) meaning "steersman", "rudder" or "pilot". Wiener used the term in his book *Cybernetics – Communication and Control in the Animal and the Machine* (1948), where he suggested the importance of a control of the system, in order to be able to get an efficient communication with the machines (Reichardt 1968b). Wiener added the "control" element to communication because he concluded that every system that interacts with external elements has a natural tendency for chaos, raising the level of entropy through time (1948, 50). *Feedback* appears as an essential tool for controlling the system. In an interactive system the "inputs" are the result of the external elements into the system, and the "outputs" are the system's response. Feedback returns the output information to the beginning of the loop in a way that it allows the system to readapt, correct errors and ensure an efficient communication (Rosnay 1979).

> *Society can only be understood through a study of the messages and the communication facilities which belong to it; and that in the future development of these messages and communication facilities, messages between man and machines, between machines and man, and between machine and machine, are destined to play an ever increasing part. (Wiener 1954, 47)*

Wiener imagined a future where machines would be an inseparable part of the human life, and where communication between Human and Machine would be constant. In this scenario the objective of Cybernetics would be to improve the existence and quality of life of humans, since their lives are directly influenced by the quality of the communication with the machines.

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22 Authors description at the project's webpage.
<http://www.senster.com/ihnatowicz/SAM/sam.htm>, Accessed 2015.05.25

In 1963, *Sketchpad*, the first graphical interface for human-machine interaction, was created by Ivan Sutherland. It used a custom designed light pen that allowed users to draw and interact with the system directly on the screen. *Sketchpad* presented a huge advance on the field due the fact that until then the interaction was text based "people had to write letters to computer", *Sketchpad* presented "a new era of man-machine communication" (1963, qtd. in Kwastek 2013, 6).

The personal computer with full multimedia capabilities and graphic interfaces arises in the 1970s and 1980s, mainly following the work developed at *Xerox Palo Alto Research Center* (PARC), specifically Alan Kay and Adele Goldberg's research on the *Dynabook*, a " 'dynamic medium from creative thought', capable of synthesizing all media - picture, animation, sound and text through the intimacy and responsiveness of the personal computer" (Packer and Jordan 2001, 174). *Dynabook* was inspired in the *Memex* - Vannevar Bush's informational storage device - and in Douglas Engelbart's navigational conventions (mouse, windows and menus) in the *oNLine System*. It was a meta medium, a desktop hypermedia machine containing "within it all other media" (Ibid.), which led to huge transformations in the use of computers and digital technologies for artistic and creative proposes, emerging in the process different branches of computer art like digital art, interactive media art, telematics or net art (deLahunta 2002a, 118).

The computer took the position of a universal machine bringing together different media and tools and being able to deal with image, sound and text at the same time (Daniels, 2004) the medium that "would appeal to all senses simultaneously" (Packer and Jordan 2001, xvi).

2.5 AUDIOVISUAL SPACES

The denomination "Audiovisual Spaces" intends to include a wide range of media spaces where audiences are exposed to audiovisuals. Not only in virtual or mixed reality and motion tracked environments, but a more broad approach from 360° projected domes and installation spaces to performance stages. Audiovisual Spaces as metaphoric spaces of transition between the physical/real world and virtual or imaginary ones, spaces that are able to "engage the most basic aspects of human perception and cognition, (...) and play there with our most fundamental categories of world formation and orientation, of belief and confusion, of certainty and play" (Gunning 2009, 24).

Audiovisual environments have been explored for a long time to create augmented realities and temporary autonomous spaces. Spaces that converge existing physical spaces with the virtual, digital or imaginary ones, where audiences are immersed and where physics, logic and perception can be manipulated and augmented. "The fantasy of being transported into another world, to be taken wholly into the imaginary real, is a primal desire" (Packer and Jordan 2001, xxii). This fantasy exists since ancestral times, crossing time, civilizations and technologies. It is embedded in human conscience and it is present in a wide range of fields, from literature, science, visual art, cinema. We can track these spaces back in time to ancestral rituals in dark painted caves, which can be compared to nowadays immersive spaces, were "theatres for the performance of rituals that integrated all forms of media and engaged all senses" (Ibid.).

In the archeology of media we find renaissance to be a very rich period in progresses on audio and visual fields. Scholars like Giovanni Battista della Porta[23], Johannes Kepler[24] or Athanasius Kircher[25] researched in a wide range of artistic and scientific fields.

Important progresses achieved in this period (in the fields of light, lens and optics technologies) were determinant for the appearance and development of the visual media technologies as we know them today. One of the more important publications of the time was *Magia Naturalis* by della Porta, where approaches a wide ranges of topics, from zoological observations, (alchemic) transmutation of metals, synthetic production of precious stones or secret ciphers, among many others covering all areas of life (Zielinski 1996). *Book XVII* of *Magia Naturalis* is dedicated to optics, projection and reflexion. In his studies della Porta focuses his attention in the visualization of the imagination, in the dilations, changes of dimension, deformations and transmutation of reality that can be achieved with the lenses and the mirrors. He also gave a full description of the camera obscura, or as he called *obscurum cubiculum*, where he states that hunting scenes performances or battle fields could be presented in a room as these scenes were taking place before the observer eyes. Della Porta reports "how an image can be made to appear in the air without either the mirrors or the form of the thing itself being seen." (della Porta 1558, quoted by Zielinski 1996) In his descriptions the possibilities of the optical illusions, and other apparatuses, and tricks to create imagined scenarios and narratives are surprisingly up to date to nowadays new media technology features and expectations.

It is also important to highlight the work of Athanasius Kircher who in 1646 published the book *Ars Magna Lucis et Umbra*. In it Kircher collected and compiled the state of the art about light, lenses, mirrors, astronomy and he detailed descriptions and illustrations about the camera obscura and the magic lantern. Kircher collected many of the artifacts of his studies in his own museum, called Museo Kircherianum established in the Collegium Romanum in Rome, which "was full of marvellous optical and acoustic devices" (Zielinski 2008, 125) that would create illusions and delight to his visitors.

By the end of the 17th century the magic lantern became a common instrument. Throughout Europe traveling showmen would setup magic theatrical shows with it (Burns 1999). Ettiene-Gaspard Robertson, who created the show *Phantasmagoria* was one of those travellers. Under the theme of terror, demons, and spirits from the darkness, Robertson created an immersive audio and visual space. Using projections, light tricks, transparent screens, smoke, magic lanterns, mirrors, projections on glass, moving lanterns (Burns 1999), among other techniques, he played with the perception of the audience, creating illusions, space-time ambiguities and deformations of reality. These illusions created by the control of light and shadow, allowed him to manipulate, create and cancel the physical space.

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23 Giovanni Battista della Porta, Italian scholar (1535-1615)

24 Johannes Kepler, German mathematician and astronomer (1571-1630)

25 Athanasius Kircher, German jesuit scholar (1602-1680)
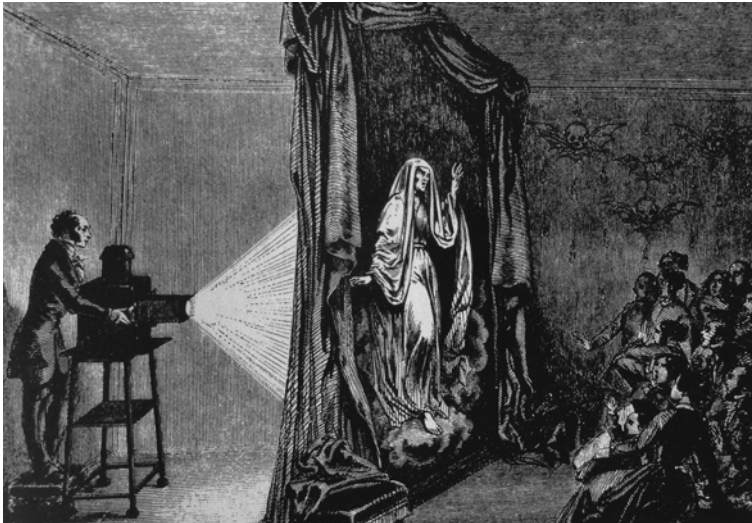
Fig. 15: Etienne- Gaspard Robertson performing *Phantasmagoria*.
Image from *Art of Projection (Stan and Eamon 2009)*

Magic lanterns were already well known and common for a long time, but in *Phantas-magoria* the lantern (or the "phantascope" as Robertson called it) was hidden. The audience saw the projected images but not their source nor the screen, which created a feeling of miraculous events. The ghosts seemed to appear in the air. Robertson created an immersive media space, a temporal alternative space where abnormal events happened. His mastering of the illusion techniques allowed him to play with the audience perceptions and emotions (Gunning 2009).

An important concept is the idea of *total artwork* (*Gesamtkunstwerk*) idealized by Richard Wagner in 1849 (Packer and Jordan 2001, 4). For Wagner the future of art was in the fusion and synchrony of all its different branches (music, visual arts, performing arts) with the aim of conceiving an immersive and extra-sensorial experience. "Scenic painting, lighting effects, and acoustical design, were intended to render an entirely believable 'virtual' world, in which the proscenium arch serves as the interface to the stage environment." (Ibid.). Wagner erased all the all the unnecessary architectonic elements from the theatre room, in a way so that the audience would not be distracted and could be completely immersed in an intense experience (Dixon 2007, 41). For him this was the only way to push the art further, as for him all the branches had achieved their maximum progress, and possibilities of exploration (Daniels 2004).

Seeds from Wagner's *total artwork* ideas can be found in many multidisciplinary stage performances along history. A good example is the play *Rossum Universal Robots* by Karel Capek (1921). The architect and artist Frederik Kiesler was commissioned to design the stage and created an "unusual elecro-optical-mechanical scenography" (Salter 2010, 30). A stage equipped with electrical mechanical structures, moving sceneries and film projections, including a projection over a waterfall, led to a mutant theatrical space continuously in motion, from the beginning to the end of the play (Dixon 2007, 75).

The use of the projected film in the stage environment allowed the creation of a new wide range of possibilities, a new era of dynamic scenarios was being built. "No more stage painting!… The stage is not a buttonhole that should be decorated. It is a completely independent organism with its own theatrical laws of its time" (Kiesler quoted in Salter 2010, 30).

The integration of the space with dynamic scenographies shaped by light and sound aligns closely with Wagner's total artwork ideas, as both look for the creation of an immersive and artificial environment (Sterken 2001, 263). A pioneer case were the *Polytopes* series developed by Iannis Xenakis during the 1960s and 1970s, that can be considered the "starting point for many contemporary researches in multimedia performances and immersive environments"[26]. From the agglutination of Greek words *Poly* (several) and *Topos* (place) it was a series of large scale immersive multimedia installations where Xenakis using speakers and flashing lights shaped specific architectural places with several layers or light and sound (Sterken 2001, 267). The abstract and geometrical vocabulary from Xenakis architecture background was transposed to the domains of light and sound, overlapping the physical characteristics of the place building this way a superimposed and immaterial space. The integration of the specific characteristics of each space was therefore a fundamental parameter (Ibid.), *Polytopes* was installed in different locations (Montreal, Persepolis and Cluny) and each version had different configurations and different characteristics with a specific system of Cartesian coordinates, related to each space, composed by points of sound and light[27] (Ibid.).
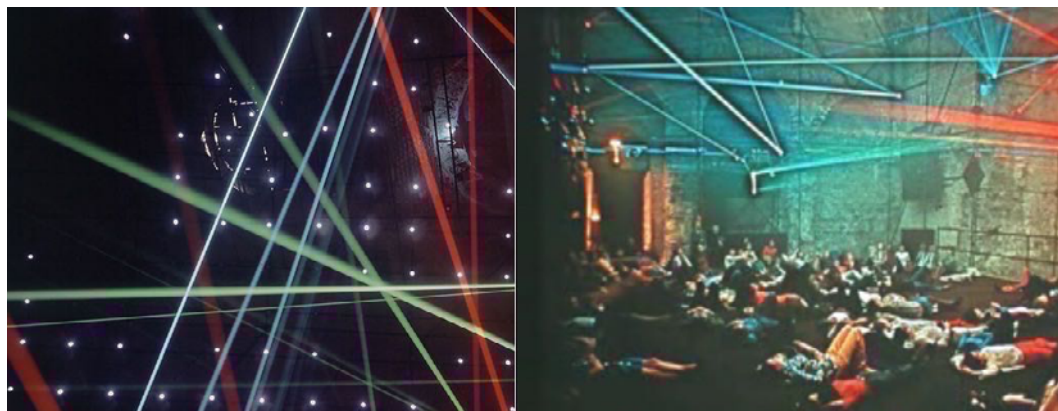
Fig. 16: Lasers setup and audience in the *Polytopes of Clunny* (Xenakis 1972)

In 2012 Chris Salter led a rebuilt of *Polytones* series with a new version named *N_Polytope*. It was exhibited first in Gijon at LABoral[28] followed by Basel, Berlin, Paris and Montreal. According to Salter project description[29] "*N_Polytope* is based on the attempt to both re-imagine Xenakis' work with probabilistic/stochastic systems with new techniques as well as to explore how these techniques can exemplify our own historical moment of extreme instability". In *N_Polytope*, like in the original version, the audience is surrounded by an immersive light and sound dynamic system that alternates between "order and disorder, tranquillity and thundering chaos", evolving its behaviour and changing the experience over time.

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26 Fabrizi, MarianaBruna. (2014) Yannis Xenakis' Polytopes: Cosmogonies in Sound and Architecture. <http://socks-studio.com/2014/01/08/yannis-xenakis-polytopes-cosmogonies-in-sound-and-architecture/>. Accessed 2015.05.27

27 Description of each *Polytope* versions can be consulted on Sven Sterken article "Towards a Space-Time Art: Iannis Xenakis's Polytopes" (2001)

28 LABoral Centro de Arte y Creación Industrial Gijón, Spain. <http://www.laboralcentrodearte.org> Accessed 2015.05.19

29 "N_Polytone" project description. <http://chrissalter.com/projects/n-polytope-behaviors-in-light-and-sound-after-iannis-xenakis/> Accessed 2015.05.19

The quest for immersive and alternative audiovisual spaces had a great relevance in the 1960s with the explosion of rock concerts, light shows and psychedelic culture. Analog light effects, illusions and liquid projections were performed at the same time as the music, to provide visual correlation and create an immersive environment, "dissolving the boundaries between audience and performers, between mind and body, between the different senses, and between individual and communal identity" (James 2009).

A historical case was the multimedia performance *Exploding Plastic Inevitable* created by Andy Warhol in 1966. An experimental hyper-sensory alternative show composed by a concert of the *Velvet Underground*, multiple film and slide projections, stage lights and several other performances (Branden 2002). This immersible visual and sound ambient created a semi-autonomous zone, a parallel space to the reality, an autonomous temporary zone described by Marshall McLuhan as "the auditory space of electronic media" and "multidirectional, synaesthetic and interactive" (Ibid.).

Another pioneer example was *Glimpses of the USA*, a multi-projection media space created by Charles and Ray Eames for the first USSR-USA cultural exchange in Moscow in 1959. It was composed by seven supersize screens placed inside a geodesic dome where in which of them were projected fast image sequences portraying various scenes from the daily life in the United States (Colomina 2001).

Some years later, in 1964-65, the Eames as curators of the IBM Pavillon on New York World's Fair took the multi-projection media space a few steps forward, using this time 22 screens (shaped in circles, squares, triangles, and rectangles)[30], in a setup that reminds Herbert Bayer's *Diagram of the field of vision* (1930), as it was arranged in a way "the eye cannot escape the screens and each screen is bordered by other screens "(Colomina 2001, 49). The film, composed by several fragments interconnected by ideas and associations together with the involving media space was able to wrap the audience in a mixed reality and play with their perceptions.
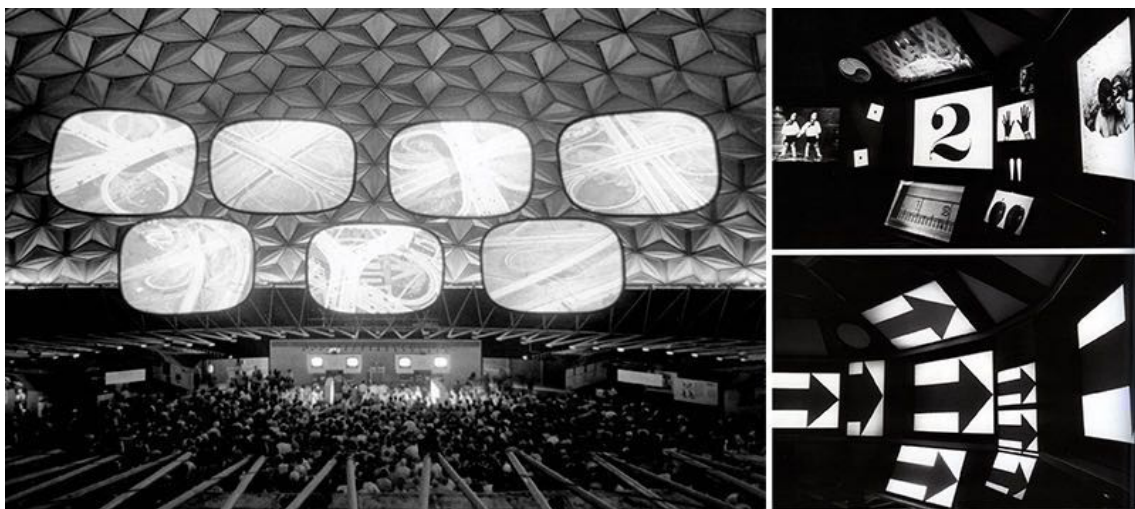
Fig. 17: *Glimpses of U.S.A.* (Eames 1959), left; *Think* (Eames 1964), right.

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30 From Eames Office Official site. <http://www.eamesoffice.com/the-work/think/> Accessed 2015.05.05

There is an instant connection between Eames's multi-projection spaces and nowa-days mapped projected ones. Like in *Daydream* (Nonotak 2014) an audiovisual installation where a series of projected semi-transparent screens build a physical connection between the real and the virtual space "blurring the limits and submerging the audience into a short detachment from reality"[31]. The screens are placed around the visitors, wrapping them in a distorted reality made of minimalists geometric imaginary with endless dimensions.

The increasingly use of domes as space for audiovisual environments also triggers a connection with Eames's media spaces. In projects like *O (Omicron)* (AntiVJ 2012) or *Domos* (Maotik 2011) the spherical surface of a dome ceiling is used for an evolving 360° mapped projection. The audiences in the center of the space are immersed in a stream of synesthetic audiovisual narrative and just like in Eames's multi-projected spaces the content is designed to fit on the architectonic features of the space creating a "space within the space" (Colomina 2001, 40). A simulated space where physical and digital-data space are overlapped and share complex interrelations. By one hand the physical space can be simulated inside the digital one and by other the flow of data itself "create their own forms of spatiality" (Kwastek 2013, 105). The digital-data space also known as "Cyberspace", a term coined by William Gibson in *Neuromancer* (1981) to describe a place defined by a three-dimensional digital matrix where data is materialized in space. A place where "we jack in" our neurons directly into an immaterial world (Murray 1998, 22) where we visualize "graphic representation of data abstracted from the banks of every computer in the human system. ... Lines of light ranged in the non-space of the mind, clusters and constellations of data," (Gibson 1981).
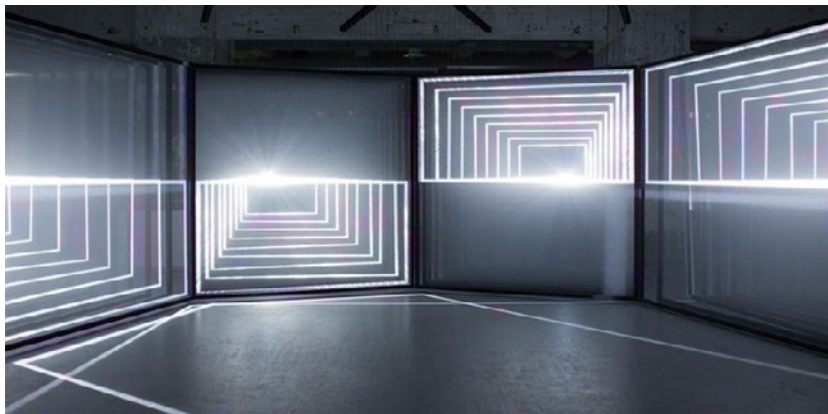
Fig. 18: *Daydream* (Nonotak 2014)

Alice passing through the looking-glass is a recurrent metaphor to describe these spaces. In the paper *The Ultimate Display* Ivan Sutherland described the possibility of accessing places with "concepts not realizable in the physical world," places with "forces in non-uniform fields, non projective geometric transformations, and high-inertia, low friction motion... It is a looking glass into a mathematical wonderland" (1965). Places that do not intend to simulate the real world, but to augmented it.

Another interesting conceptual parallelism is the *Zone* from Andrey Tarkovsky's film *Stalker* (1979). In Stalker there is a place called "The Zone" which is a restricted area, closed and guarded by the government. It is known to be a very dangerous and

31 From Nonotak project description. <http://www.nonotak.com/_DAYDREAM-V-4>. Accessed 2015.05.05

unpredictable place, where space and time are unstable. In this place if you walk in a straight line, it is possible that you return to the same place where you started. Or if you try to go back to the same place where you were some minutes ago, that place will not be there any more.

Like the *Zone* these spaces have magical features and do not obey to the laws of physics as we know them in the real world. They represent a mathematical wonderland where Alice jumped into (Sutherland 1965). They represent the primal desire of being transported into another world (Packer and Jordan 2001, XVI), a desire that exist in the human conscience ever since. "This visual pageantry links computers culture to ancient forms of entertainment" (Murray 1998, 112), from ancestral rituals in dark and deep painted caves, where the audiences were immersed into another domains and triggered into altered perceptions and higher states of consciousness (Packer and Jordan 2001, XVI), to the optics and lights devices by della Porta and Kircher, Roberson's phantasmagoria, Gibson's *Cyberspace* until nowadays *mixed reality* spaces.

2.6 AUDIOVISUAL INTERACTIVE SYSTEMS

> *An interactive system is a machine system which reacts in the moment, by virtue of automated reasoning based on data from its sensory apparatus (Penny 1996).*

This chapter approaches computer mediated systems that allow the interaction with sound and image in real time. These systems may be built for a diversity of applications and situations, in this research the focus is on experimental interactive art installations and music and stage performances.

Interactive systems allow the communication between a human (performer, user or audience) with sound and image in real time. They can also be used to connect different media, running and interacting without the interference of a human. They should provide instant feedback, so the user can perceive it as a real-time response. The time of response is essential for the system to be perceived as interactive by the users, "interactivity implies real time, now" (Penny 1996). If the response is to slow or to fast it will not work, it must match the time frame of physiological reaction to be perceived as "real-time" by the users (Ibid.). It is a commitment to real-time interaction, a medium that includes perception, display and control systems, and that sends and receives inputs to and from the participants (Krueger 1991, 85). The system can be programmed to react to movement, sounds, location, gestures or many others possibilities, the artist programs it to achieve the desired and meaningful interactions, but "it cannot respond to what it cannot perceive" (p.86).

These systems are typically built to activate, control or channel an action, that usually is manifested by the "physical movement of the recipients or the dynamic of the process and configurations" (Kwastek 2013, 149), and they should involve the audience in a relation that they can understand, and in which they may easily identify its behaviors and procedures (Krueger 1991, 102). The goal of these systems should not be only to reproduce exactly the real world, but they are an opportunity to create new and augmented realities. "...In the long range it augurs a new realm of human experience, artificial realities which

seek not to stimulate the physical world but to define arbitrary, abstract and other wise impossible relationships between action and result." (Krueger 1977, 119).

The categorization of a system as *interactive* often generates doubts and discussions related to its levels of interactivity, or if it is reactive instead of interactive. In fact "many interactive systems in new-media art are in fact reactive systems. Ideally, interaction between a human and a system should be mutually influential." (Bongers 2000, 44) It should be a two-way process, a dialogue, where an action creates a feedback from the system that influence the next user action. A wide range of sensors and interfaces allow the translation of signals from the real world to the machine one, so the system can process the information and display it back, in a way the "interactive loop" is completed and user perceives the feedback from the machine (Ibid.).

There are different perspectives to approach and classify the interactivity, "they are the topic of dozens of conferences, books and dissertation" (Laurel 1993, 29). Many authors have described and classified them in different ways depending on their approach, needs or specific use of interactivity.

One of the earliest classifications was made by Stroud Cornock and Ernest Edmonds in a paper approaching the changes in the creative process that the advent of computers brought to art (1973) and the appearance of dynamic artworks mediated by a processing machine. Cornock and Edmonds based their classification on the relation between audience and artwork to differentiate static and non-static art, and categorised the systems as: *Static system, Dynamic passive system, Dynamic interactive system*, and *Varying System.* Another interesting approach is the one given by Kurt F. Lauckner in the article *Microprocessors and Intelligent Sculpture* (1976) where systems are divided in *Reflected Intelligence* and *Internally Intelligent.* Both classification are discribed with more detail in section *4.3 Existing Classification of Interactive Systems*.

Myron Krueger in *Responsive Environments* (1977, 116) defined the interaction with responsive spaces in eight different categories:

1) A *dialogue system*, the system expresses itself with sounds and visuals and the user with physical motion. In this dialogue between human and machine, the user activates triggers and the system answers with audio and visual;

2) A *personal amplifier*, the system acts like an amplifier of actions from the user. The user's actions in the space are amplified an enhanced;

3) An *environment with sub-environments* that hold different types of interactions;

4) An *amplifier of physical movement* in the artificial space. A movement around the environment can represent a much larger distance in the virtual one. The position and movements can be mapped to different scales.

5) The *interactive space as an instrument.* By moving around the space, users control and trigger different interactions;

6) The *body as an instrument.* The gestures and movement from a user can be mapped to be used as an instrument;

7) A *game* between the user and the environment;

8) An *experimental parable.*

These categories emerged after a series of prototypes of interactive spaces developed by Krueger in the 1970s and 1980s (1991). His work on computer vision, silhouette extraction, responsive environments and research on interactivity with digital realities are a landmark for interactive art and a base reference for most of technology and interactive systems used up till now, as Levin states "he practically invented the vocabulary of interaction" (2012, n.p.).

Brenda Laurel states that interactivity is a continuum, and describes three different variables to classify it: *Frequency*, related to the periodicity of interaction; *Range*, related to the number of choices available; and *Significance* ranking how much the choices from users affects the experience (1993, 29). These variables measure the magnitude of the dialogue between the user and the computer, but besides these, Laurel refers other features that can help the users to feel the interactivity like *sensory immersion* or the "tight coupling of kinesthetic input and visual response" (Ibid.).

Steve Dixon in his comprehensive research on *Digital Performance* defined four different levels of interactivity (2007, 563): *navigation*, where the audience chooses paths like in a multimedia CD-ROM or in an interactive movie; *participation*: where the audience explores an active environment; *conversation*: where users have dialogues with avatars in virtual words; and, *collaboration*: where the audience contributes with creative inputs to the artwork.

Frieder Weiss[32], in a talk narrating his experiences designing interactive system for dance performances in the last two decades, describes three different approaches to interactivity that have evolved along the time.

1) *Reactive System*: used in the early stages of interactive art. The system was used mostly as a control tool to trigger events;

2) *Interactive System*: a system with a feedback loop with the user;

3) *Contemplative Systems*: more complex systems containing a level of artificial intelligence and autonomous agents abled to provide a more diversified outcome.

Also related to interactive stage performances, Klaus Obermaier [33]describes a similar approach, also with three levels of interactivity:

1) *Triggering*: where a specific action triggers audio or visual events. A use for this case can be in a stage performance where the body of the dancer is being tracked by a computer vision system, every time that the hand of the performer is higher than a particular range a sound sample is played;

2) *Controlling*: where parameters are modified dynamically over time, like when the movement of a body directly modulates a sound filter;

3) *Communication between Digital and Human*: where an autonomous digital system is a performing partner in stage and both the human and the digital interact and mutually influence each other. An example is the case where visual media is composed by a particle or flocking system and the presence and movement of the dancers in stage will influence the parameters and characteristics of the system inducing different visual shapes which in turn influences the dancer's choreographies.

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32 Frieder Weiss talk at Scope #16, Berlin 2013. "Intermedia Dance Performances with Motion Sensing". <https://vimeo.com/52208994>.

33 Klaus Obermaier talk at Instint, Minneapolis 2014. "Interactive Installations vs. Interactive Performing < https://vimeo.com/124767899 > Accessed 2015.05.20

These three typologies arise from Obermaier's work on stage audiovisual interactive performances and have been evolving and being explored in each new work. One of the most important features that Obermaier stresses is the fact that the digital system must by a performative partner and not just a background or wallpaper. Sound, image and movement must be created together as one.

From all these different classifications and perspectives on interactivity we can identity two different approaches. One more related to the mechanics of the interactive system, focused on the inputs and outputs, and technical processes (Obermaier, Weiss, Lauckner, and Cornock and Edmonds). And another focused on the intensity and dimension of the interaction (Dixon and Laurel). We can consider Krueger's approach as an hybrid between both.

An important landmark that Cornock and Edmonds (1973) stressed in the explanation of their classification was the change in the role of the audience, they are no more just a *viewer* or an *observer* but a *participant*. The audience becomes an integral part of the artwork. This new concept is in part strongly influenced by Allan Kaprow who in the 1960s coined the term *Happening*, to describe art performances where the audience was an integral part of the artwork, interacting in group in composed environments where every action would influence the performance (Packer and Jordan 2001, XXI). "He was particularly interested in the blurring of the distinction between artwork and audience. (...) The ultimate integrated art." (Ibid.).

According to Manovich (2001, 49) the audience appears now as co-author of the interactive artworks. Audience members are an essential element as they provide a direct performance of the experience, they affect the results and the narrative of the piece. The audience has now new responsibilities, they are no longer only observing the artwork, they are also co-creators. "Their own action complete the piece. (...) the participants also become creators" (Krueger 1991, 92), the audience is "both a live performer and his own public" (Kwastek 2013, 26). Instead of a fix artwork there is a *dynamic situation*, from which the audience is also part, the artwork is a trigger to drive the audience into an open-ended situation and stimulate to interact with an unpredictable behavior (Cornock and Edmonds 1973). To my knowledge, one of the earliest interactive artworks involving actions from the audience was the *SAM (Sound Activated Mobile)* by Ihnatowicz (1968), a kinetic sculpture that through microphones captured the presence of the audience and reacted to their movements. It was first presented in the *Cybernetic Serendipity* exhibition in London in 1968 (Reichardt 1968).

Besides the change in the role of the audience, the functions of the artists also changed, a new concept of artist was also born, an artist that acts at a meta-level (Krueger 1977). The artist creates the mechanism, the instrument, and defines the parameters, the rules, the sequences and the possibilities, often being surprised by unexpected results that were not planned. Authorship is now procedural, the artist establishes "the properties of the objects and potential objects in the virtual world and the formulas for how they will relate to one another. The procedural author created not just a set of scenes but a world of narrative possibilities." (Murray 1998, 152). The artist has also the challenge to make sense of the interactions and technologies by establishing a clear language in interaction and a recognizable gestural coherence, and by keeping a level of surprise and unpredictability avoiding just visualizing mimetic illustrations of the movement (Weiss 2013). The experimental interdisciplinary feature embedded on the field of interactive audiovisuals led to

the breaking of borders of conventional arts and to break down barriers between performer and audience, maker and viewer. (deLaHunta 2010c)

Also, the integration of media screens, and interactive audiovisuals in the performative stages and exhibitions spaces allow artists to "experiment with techniques that at times fragment and dislocate the bodies, time and space, and at others unify physical, spacial, and temporal significations" (Dixon 2007, 336), having this way a huge potential in the building of metaphors, constructing narratives, augmenting bodies physicality and explore new performative expressiveness. As Davies write: "such environments can provide a new kind of ´place´through which our minds may float amont three-dimensionally extended yet virtual forms" (1997, 295).

2.7 TRANSMUTABILITY OF DIGITAL DATA

> *A significant theme in many audiovisual software artworks is the transmutability of digital data, as expressed by the mapping of some input data stream into sound and graphics. For these works, the premise that any information can be algorithmically sonified or visualized is the starting point for a conceptual transformation and/or aesthetic experience. (Levin 2009)*

One of the characteristics of the digital medium is the fact that everything can be transformed from one format to another. Digital data is made of streams of numbers, of structures of numerical representations. Manovich identified this characteristic as the first basic principle of new media (2001, 27), and he named it as *Numerical Representation*, meaning that every digital object can be described using a mathematical function, and therefore everything can also be subject to algorithmic manipulation and programmable. This takes us to another of Manovich's basic principles, *Transcoding*, that states that everything can be transformed into another format (2001, 45).

 The term *Transmutability*, that by definition means the change of form from one condition into another, is closely linked with the concept that in the digital medium we can map any kind of data set into another, or any kind of medium into another, this is in fact "one of the most common operations in computer culture, and it is also common in new media art." (Manovich 2002). This term emphasizes certain qualities of the digital data that due the fact of being represented by a numerical code, forms a measurable system of quantitative and abstract information that can be mapped one into another and transformed due it *polymorphism*, *mutability* or *malleability* features (Ribas 2011, 210).

Transmutability encompasses a number of other close terms with some different specificities as *Transmediality*, *Transcoding* or *Translatability*. *Transcoding* is used specifically for a conversion from one type of data into another, from one format into another, while *Translatability* is used in the case of a translation of information across different media languages and *Transmediality* refers to the transform of media from one media. (Ibid.)

The ability to transform is also one of the aesthetic principles that Murray uses to define digital environments. "Computers offer us countless ways of shape shifting" (1998, 154) and transformation reflects that "anything we see in digital format - words, numbers, images, moving pictures - becomes more plastic, more inviting of change." (Ibid.)

Due to these characteristics *Digital Data* is mutant and can be mapped, shifted and shaped between the different domains of an interactive system. Movement data from a dancer can be transformed into visual shapes, images can be transformed into sound, sound can analyzed and used to define the movement of a kinetic sculpture among many other configurations. Many times the transmutability of data is not the main purpose of an artwork, but yes a strategy to "enabling some data stream of interest to be understood, experienced, or made perceptible in a new way." (Levin 2009)
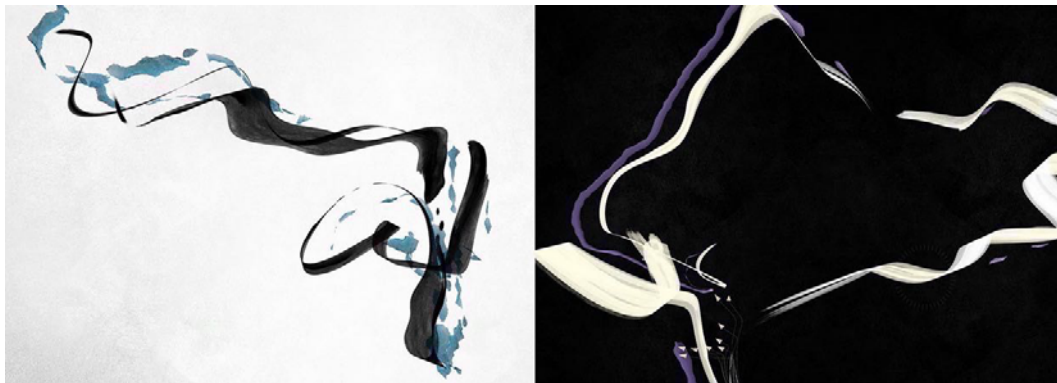
Fig. 19: Different visual outputs from *Paint With Your Feet* (YesYesNo 2011)

On the project *Paint With Your Feet* (YesYesNo 2011) movement data from a group of runners is visualized in a series of generative artworks. The participants, equipped with devices made for runners that collects metric data, were invited to record their runs. Later Zack Lieberman and Theo Watson downloaded their data and developed a software to visualize it based on a set of parameters like speed, consistency and unique style of each person's run. In the end runners' movement data was mapped into color, textures and visual shapes creating this way a unique visual output of each one of the participants' runs[34].

With a similar approach, Aaron Koblin on *Flight Patterns* (2009) collected 24 hours of flight data from airplanes flying between the United States and Europe and used it to create a series of animations and graphic prints of flight patterns and density[35]. In the case of *Reading My Body* (Vtol 2014) the direction of the mapping was reversed, and visual shapes are transformed into sound. The artist built a robotic device that is attached to his arm and moves along it. Through black line sensors, it reads his tattoos and uses its data as a music score. The device is equipped with a 3-dimensional Wii remote controller communicating with through OSC[36] protocol so it can give additional expression while being used as a performative instrument on stage[37].

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34 Paint With Your Feet, project description.
<http://www.yesyesno.com/nike-collab-paint-with-your-feet/>. Accessed 2015.06.04

35 Flight Patterns, project description.
 <http://www.aaronkoblin.com/work/flightpatterns/index.html>. Accessed 2015.06.04

36 OSC stands for Open Sound Control. Networking protocol to connect computers, software, and other multimedia devices

37 Reading My Body's project description. < http://vtol.cc/filter/works/reading-my-body>. Accessed 2015.06.03
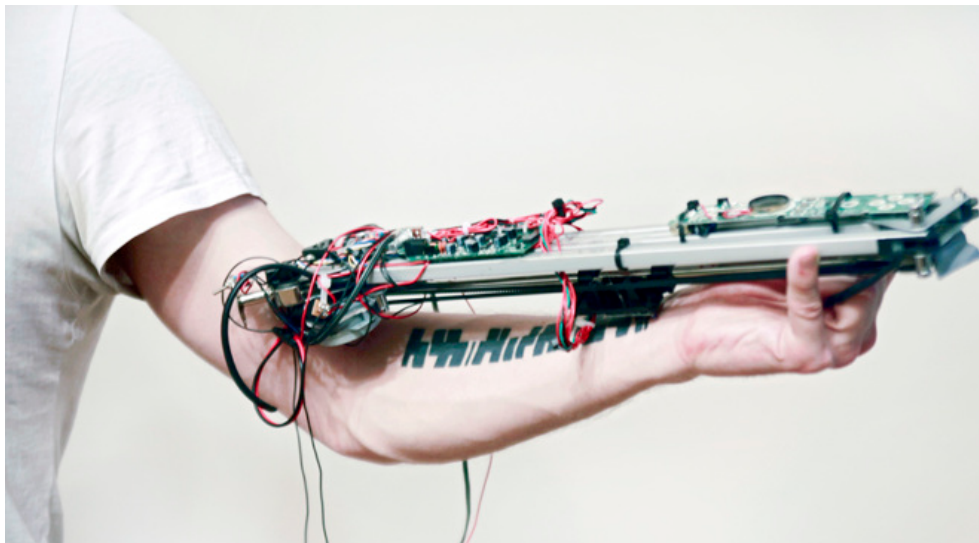
Fig. 20: *Reading my Body*'s device (Vtol 2014)

The practice of mapping data *from one domain into another* was referred by Phillip Galanter as one of the rules for *Generative Art* (2006), he also stressed the fact of this practice being a popular technique in contemporary generative art. The transformation from one domain to another is an easy task for a computer due to the fact that all digital data is represented by a numerical code. The biggest challenge is in the search of interesting mapping and relations between dataset and domains. It is the way that the data is mapped to a certain domain, that gives the meaning and the interpretation to the metaphor of the artwork. The "search for such new mappings ... represents one of the most fruitful research direction in new media art" (Manovich 2002), therefore, defining the mapping strategy is one of the most crucial tasks in the development of an interactive system.

We can see *mapping* as a correspondence between control parameters, that will influence the way the users and audience will interact or interpret the system. A simple mapping provides a quick learning, but will provide little control over the interaction, a complex mapping will allow the possibility to control complex parameters of the system (Rovan et al. 1997).

In an article categorizing gesture mappings strategies for music performances Rovan, Wanderley, Dubvon and Depalle distinguished three different mapping strategies: *One-to-one*, *One-to-Many* and *Many-to-One* (Ibid.). Besides of the categorization being meant for gestural mappings for music performances it can be applied to different systems and configurations for mappings between sound, visuals and movement data.

The strategy *One-to-One* happens when an individual parameter is assigned to another correspondent parameter. Like when the brightness value of an image is directly assigned a sound parameter (like pitch); On *One-to-Many* an individual parameter is assigned to many simultaneous parameters. As an example the position in space of a dance performer can be controlling the speed of a video playback and at the same time modulating different sound filters; on *Many-to-One* many inputs are controlling at the same time one single parameter. It allows more control and expressivity over that parameter but at the same time is more complex. As an example in an interactive dance performance the movement of the dancer's arms and legs in simultaneous controls one musical parameter.

The mapping provides the dictionary of correspondences to that allow the shifting of media from one domain to another, to materialize it in a new form and context. Each option is exclusive and can be combined with the others. We can have a *one-to-one* strategy using a dancer position in space to control the movement of a group of particles in a virtual world, and at the same time, use his arms gestures to control multiple parameters that influence that group of particles *velocity*, *color*, *size* or *gravity*. Digital data appears as the invisible element that flows around the 3 elements of the system. It is the signal,"that is imperceptible in and of itself. Signal maps to the perception through the contingencies of both media technologies and sensor boundaries" (Whitelaw 2008).

2.8 CONCLUSION

The six topics addressed represent the core areas and the groundworks for this research. They put in perspective the point of view of this work over the wide range of topics that overlap around the interactive art field, and also shaped the work developed in the artistic practice and theoretical research of this dissertation.

In section *2.2 Seeing Sound* we should highlight the historical review on the visual music pioneers and the quest for the perfect synchrony between sound and image. Their focus on abstract imaginary and non-narrative structures had a big influence on the practice-based artworks, as we can see on the visual work on *Boris Chimp 504* and *Non-Human Device series*, as an example (see chapter 5.2). It should also be pointed out the importance of the *Time* as a key element on the relations between sound and image, stressed by Whitney (1985, 37), as it connects, structures and gives new dimensions to both domains. We can also find a similar concept on Kandinsky's ideas on visual shapes, spatial relations, rhythm and structures of time. *Time* is again an essential element on section *2.3 Visualizing Movement* where the exploration of visual shapes in a time-structured design is addressed. It is was established a relation between the work of Etienne-Jules Marey and Braune and Fisher in the 19th century capturing the human movement in visual-trails of motion events, and nowadays motion capture systems and artworks as for example *Forms* (Akten and Quayola 2012) or *Invisible Things of the Past* (Art+Com 1996). The exploration of this topics can be found also in some of the artworks created, as *The Interpreter* (Carvalho, de Quay and Jun 2014) on section 5.3.4, or the explorative work developed at *Creative Coding Lab* (Carvalho 2013), described on Appendix .

Section 2.4, *The Computer*, addresses Cybernetics and the emergence of the computer as a tool for creativity and expressivity, shaping new paradigms, aesthetics and processes in art. The computer became a universal machine, being able to deal with different media at the same time (Daniels, 2004). All these concepts are fundamental for the approach of this dissertation work on digital artworks and interactive systems, as on the building of the theoretical definitions and groundwork for the *S+V+M framework* (see *4.2 Sound, Visual And Movement Interactive Systems*).

Section *2.5 Audiovisual Spaces* approaches the quest for immersive and magic spaces that blurry the lines between real and virtual spaces, and wrap up the audiences into and distorted realities and hyper-sensorial experiences. It draws a pathway relating Wagner's total artwork ideas, Eames's multi-screens (1959), Xenakis's Polytopes , ending with

recent contemporary interactive artworks as Daydream (Nonotak 2014) . This search for augmented spaces between real and virtual worlds can be found on the stage performances developed in this research discussed on chapter 5.3, as *Breakdown* (Carvalho, de Quay and Jun 2014), *With Oui* (Carvalho et al. 2015) and *Ad Mortuos* (Carvalho et al. 2015b).

The last two sections, *2.6 Audiovisual Interactive Systems* and *2.7 Transmutability Of Digital Data*, compile the core concepts and theory references that helped to build the *S+V+M framework* proposed in this dissertation. Section 2.6 states different views and definitions on interactive systems and levels of interaction by artists and scholars as Obermaier (2014), Weiss (2013), Lauckner (1976), Laurel (1993, 29), Dixon (2007,663) or Krueger (1977,116). And section 2.7 approaches a key definition in the digital media, which is the fact that everything can be transformed from one medium to another. Digital data can be translated, mapped and shaped between the different domains of the interactive system. *Movement* data from a dancer can be transformed into *Visual* shapes, parameters from the *Visual* domain used to generate *Sound*, and *Sound'*s parameters used to control the *Movement* of a kinetic sculpture. These concepts and references had a great importance for the definition of Sound, Visual and Movement interactive systems on section 4.2, as to collet the set of different classifications on *4.3 Existing Classifications Of Interactive Systems*, and to build the framework proposed on *4.4 S+V+M, A Framework For The Classification Of Interactive Systems*.

3. STATE OF THE ART

3.1 OVERVIEW

This chapter addresses current state of the art on audiovisual interactive artworks.

It starts by approaching a group of pioneers on the interaction with sound and visuals in real time, which form the groundwork for the work presented on this dissertation.

It then presents the blog *S-V-M (Sound+Visual+Movement)*, where the baseline for the study of the interactions between the three domains was created. The blog archives an informal list of projects catalogued according to theirs processes of domain transformations, which provides the foundations for this work.

Finally it presents the artworks that will be used as case studies in the building of the framework for classification of audiovisual interactive artworks, proposed on the next chapter.

3.2 PIONEERING WORK ON THE INTERACTIONS BETWEEN *SOUND*, *VISUAL* AND *MOVEMENT* DOMAINS

The following section compiles a selection of pioneering authors on the development of digital technologies and interactions with sound and visuals in real time systems for interactive art. These projects are landmarks that laid the groundwork for the work presented in this dissertation, both in the literature and state of the art research, as on the projects developed as part of the practice research.

In this shortlist we must highlight Myron Krueger who "made some of the most fundamental developments in the connection between interaction and computer graphics" (Levin 2000, 33), defining the interactive metaphors, language and paradigms used until the present day on interactive works. Krueger developed extensive work on computer vision, silhouette extraction for human computer interaction and responsive environments during the 1970s and 1980s. He was the first "to systematically explore the potential of digital technology for interactive art" (Kwastek 2013, 29). On *Artificial Reality II* (Krueger 1991), which compiles his research, we can observe a series of techniques and approaches for human computer interactivity that are still used nowadays in most camera based interactive artworks. His research helped to define the vocabulary of the digital mediated interactions that are being used today, techniques like the silhouette extraction, first viewed on *Videoplace* (1975), have become a standard in interactive art (Kwastek 2013, 29).

Krueger's most recognizable work is *Videoplace* (1975) which connected in the same virtual space people that stood in different rooms. Participants' silhouettes were tracked

and displayed on screens, and they were able to interact with each other through gestures, and play together with a set of applications that Krueger developed for the system (1977, 113). Another of Krueger's works was *GlowFlow* (Krueger et al. 1969), a dark space filled with glowing tubes of light that defined a virtual space (1977, 106). The floor was equipped with pressure sensors that, when stepped on by the visitors, would trigger lights and change the sound generated by a synthesizer (Ibid.).

It was in *GlowFlow*'s exhibition communication material that the term *interactive art* appeared for the first time (Kwastek 2013, 8), but it was not until 1990, when it was included as a prize category in Ars Electronica Festival[1], that it became an important field in new media art (Ibid.). Krueger, a pioneer in exploring the digital technology for technology art also "*coined the term 'artificial reality' to denote an art form resulting from a blend between aesthetics and technology* (Kwastek 2013, 29).
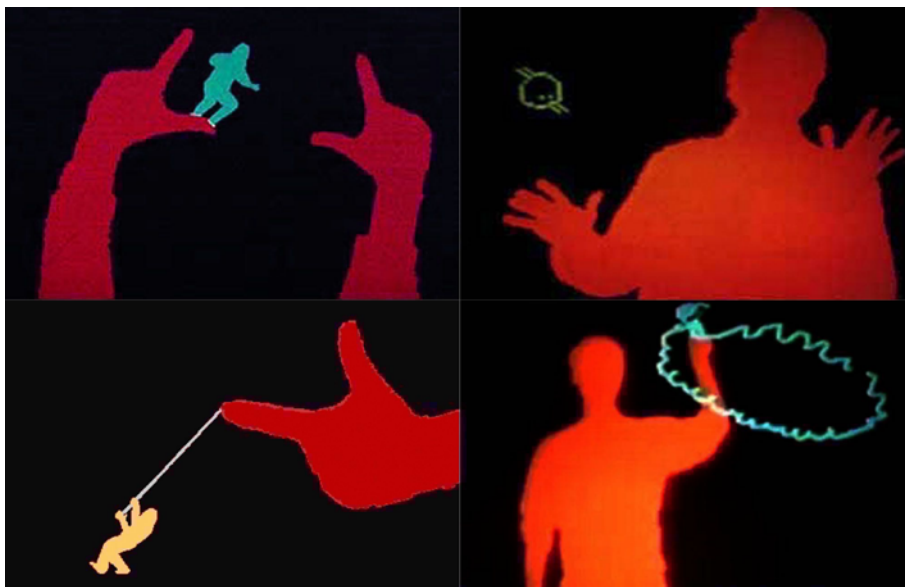
Fig. 21: Different interactive scenes on *Videoplace* (Krueger, 1975)

Later in 1971 Krueger created *Psychic Space*, an interactive environment that detected the movements of the visitors in a touch-sensitive grid on the floor (1977, 109). Like *GlowFlow* it was a responsive space where the participants would become involved in a dialog with the environment. By walking around they triggered sounds on the system and navigated on a virtual maze projected on the wall (idem).

Apart from Krueger, we should also highlight the pioneering work of Iannis Xenakis, Erkki Kurenniemi, David Rokeby, Rolf Gehlhaar or Jeffrey Shaw. Each with different approaches to the media, and with very important roles in the development of systems to interact with sound in real-time. The idea of translating visual shapes into sound can be tracked back to the 1930s and 1940s, with creators like Oskar Fischinger, Evgeny Sholpo or Norman McLaren, where by reversing the principle of the sonogram, visual information was interpreted and sonified. Xenakis's *UPIC* (1977) was the first real-time system that directly sonified visual forms, it confirmed Fishinger's prediction of a future where music would not be written on a score but painted in a free and expressive way (1932). On *UPIC*

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1 *Ars Electronica*: Art, technology, society Festival. <http://www.aec.at/>,. Accessed 2015.04.17.

visual shapes are drawn on a graphic pad and their graphic features are mapped into pitch and tone variations (Kwastek, 2009). It was a visual based sound instrument where the user would freely draw waveforms that would create expressive sound compositions.

DIMI-O (Kurenniemi, 1971) was also a pioneering breakthrough. Using a video camera and an electronic interface, a performer was able to instantly generate sound by triggering notes on an electronic organ through body movements. To demonstrate the use of his instrument Kurenniemi created the video performance *DIMI-BALLET* (1971a) where he explained the features of the instrument and demonstrated its use with a dance performance (1971b). Apart from the use in dance, Kurenniemi imagined some other uses for *DIMI-O* such as live instruments to perform with orchestras; a studio instrument, to read graphic music, and record sounds through the video input; or in experimental films, where the pictures would be transformed into music.
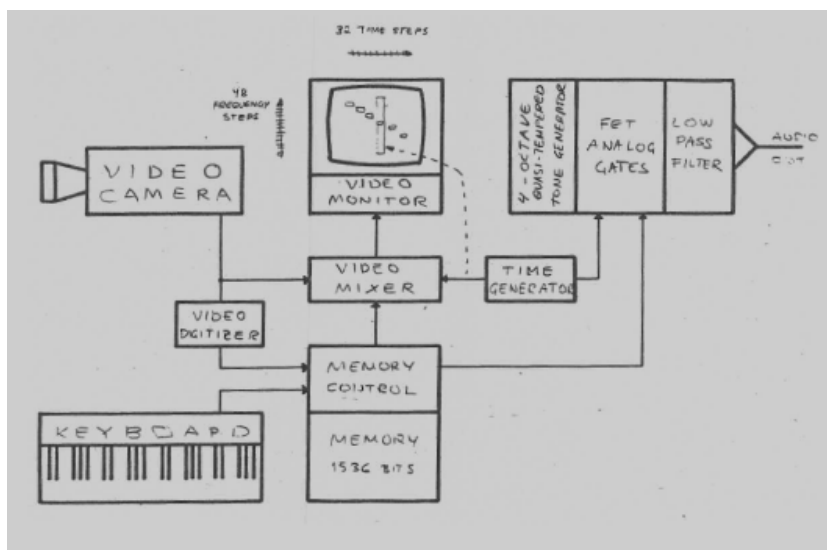
Fig. 22: *DIMI-O*'s operation schematics (Kurenniemi, 1975)

Also with the goal of translating body movements into sound, Rokeby created the interactive installation *Very Nervous System* (1986), a motion tracking based interactive system were gestures and movements were captured through a video camera and translated in real time into an improvised music system that reflects and reacts to the qualities of the movements. In the project description Rokeby writes, "I use video cameras, image processors, computers, synthesizers and a sound system to create a space in which the movements of one's body create sound and/or music".

The user's body was transformed in an instrument, and his postures would have a direct sound feedback. Different parts of the body controlled different parameters of the sound (Kwastek, 2009), the visitors become an active element of the interface, "*the audience becomes the performer*" (deLaHunta, 2010b, 128).

Very Nervous System was not Rokeby's first experience generating sound with body movement, in fact, it is an evolution of a previous interactive sound installation called *Reflexions* (1983). The installation had a similar setup and used an 8x8 pixel video camera sending images to a computer software that digitalizes images to detect the areas with movement and use it to trigger manipulate sound in a *Korg MS-20* synthesizer and trigger

water sound loops from an audio tape[2]. More recently Rokeby presented the *International Feel* (2011), a telematic and updated version of *Very Nervous System*. Presented at the *Strategic Arts Initiative 2.0*[3] in 2011, the installation was placed in Toronto at Inter/Access[4] and in Rotterdam at V2_[5]. The interactive spaces were scanned by a Kinect sensor, and all the activity in each one was transmitted to the other via the Internet and visualized in a screen. Users in both locations meet telematically in the virtual space and create sound compositions in collaboration[6].
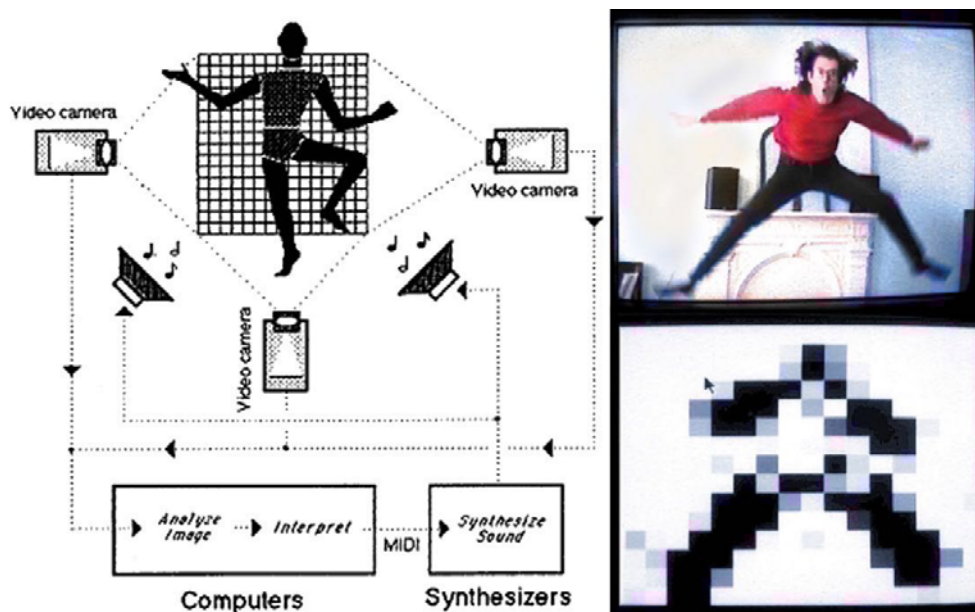
Fig. 23: *Very Nervous System*'s operation schematics (Rokeby 1986), and a frame from the computer-vision

With a similar goal of creating sound compositions with the body movement, but more focus on interacting in more spatial dimensions and on collaborative creation, Rolf Gehlhaar developed and presented *SOUND=SPACE* (1984)[7] as an output of an artistic residence at the IRCAM[8] center in Paris. In this installation an interactive space is scanned by a series of ultrasonic sensors aligned in two arrays on two perpendicular sides of the space, creating a grid that senses the space and provides specifics coordinates of motion activity.

The presence and activity of visitors in the space is translated by the computer system into controls used to interact with synthesizers, trigger sounds and control different parameters in real time (Gehlhaar 1991). The system also presented different modes of interaction with the space for sound creation. Varying from triggering sounds related to

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2 Reflex, project report. <http://www.davidrokeby.com/reflex.html>. Accessed 2015.06.17

3 *Strategic Arts Initiative 2.0,* a re-installation made in 2011 of the telepresence exhibition *Strategic Arts Initiative* from 1986. A collaboration between V2_ in Rotterdam and Inter/Access in Toront*o*. <http://v2.nl/events/strategic-arts-initiative-2.0>. Accessed 2017, 09.11.

4 *Inter/Access* is a gallery, laboratory and festival for art and technologies in Toronto. <http://interaccess.org/>.Accessed 2017.09.11

5 V2__, Lab for the Unstable Media is an interdisciplinary center for art and media technology in Rotterdam. <http://v2.nl/>. Accessed 2017.09.11

6 International Feel, project report. <http://www.davidrokeby.com/int_feel.html>. Accessed 2015.04.17

7 SOUND=SPACE video documentation <https://www.youtube.com/watch?v=tJyutKQEpLk>

8 Institut de Recherche et Coordination Acoustique/Musique. <http://www.ircam.fr/>. Accessed 2016.04.11

the space coordinates where the visitor was placed, to more complex and dynamic modes where sequences of sound were build and there were a series of parameters being modulated by the activity on the space like pitch or rhythmic complexity (Ibid.).
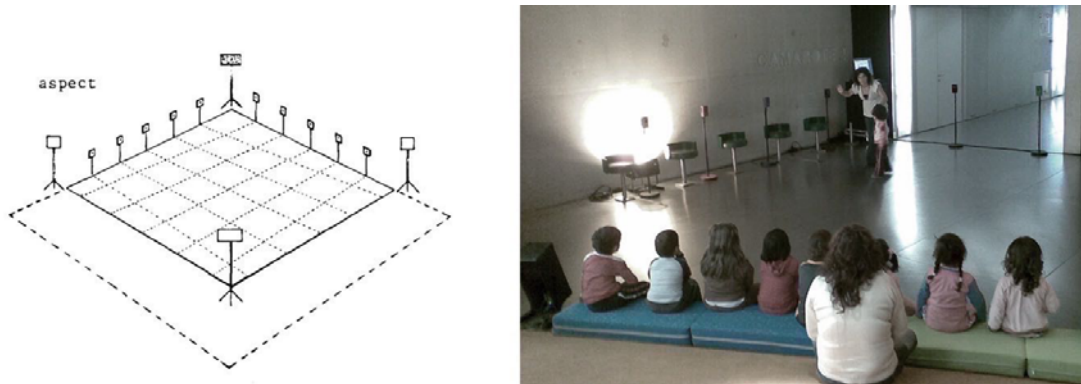
Fig. 24: SOUND=SPACE's (Gehlhaar 1984) installation scheme (left). A renewed version of SOUND=SPACE, installed at Casa da Musica (right)

The Legible City (1989), one of the Jeffrey Shaw's most recognized works, merges real world with the virtual one through a physical interface that connects both dimensions.

Like in the previous examples it provides a system of interacting with audio or visual content in real time. A bicycle fixed to the floor is used as a physical interface to allow visitors to ride around a virtual city that is projected in a big frontal screen. The virtual city is a three-dimensional computer generated environment that used the maps of real cities (Manhattan, Amsterdam and Karlsruhe) but replaces its real architecture by text compositions. The pedals and handlebar of the bicycle provide to the users the device that connects the real world with the digital one, allowing a control over the direction and speed of travel in the virtual world and providing the visitors with a drive around the city through streets full of buildings made of letters.[9]

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9 *The Legible City,* project report. <http://www.jeffrey-shaw.net/html_main/show_work.php?record_id=83>. Accessed 2015.04.17

Fig. 25: *The Legible City* (Shaw 1989)

These projects present interactive techniques, approaches and paradigms that have been replicated, evolved and merged with new technologies over the time. They present a variety of interactive systems where users are able to interact with sound and image in real time through diverse techniques, from gestures and movements captured by a camera, or walking around in a space tracked by sensors to interact through a physical device that connects the real with the virtual world.

3.3 COLLECTING *SOUND+VISUAL+MOVEMENT* RELATIONS

As part of a daily research process, on searching and collecting transformations of digital data between different domains, the blog *S-V-M (Sound+Visual+Movement)[10]* was created. It works as an informal list of projects with the main goal of compiling and organizing interactive audiovisual projects. The projects were selected from the daily feeds of specialized sites as *Creative Applications[11], Creators Projects[12], Create Digital Motion[13],* from the many *Vimeo[14]* channels focused on interactive art and interactive audiovisuals, as from the literature review, online journals as *Leonardo Electronic Almanac[15]* and from the proceedings of academic conferences as xCoAx[16], ICLI[17], SIGGRAPH[18] or NIME[19].
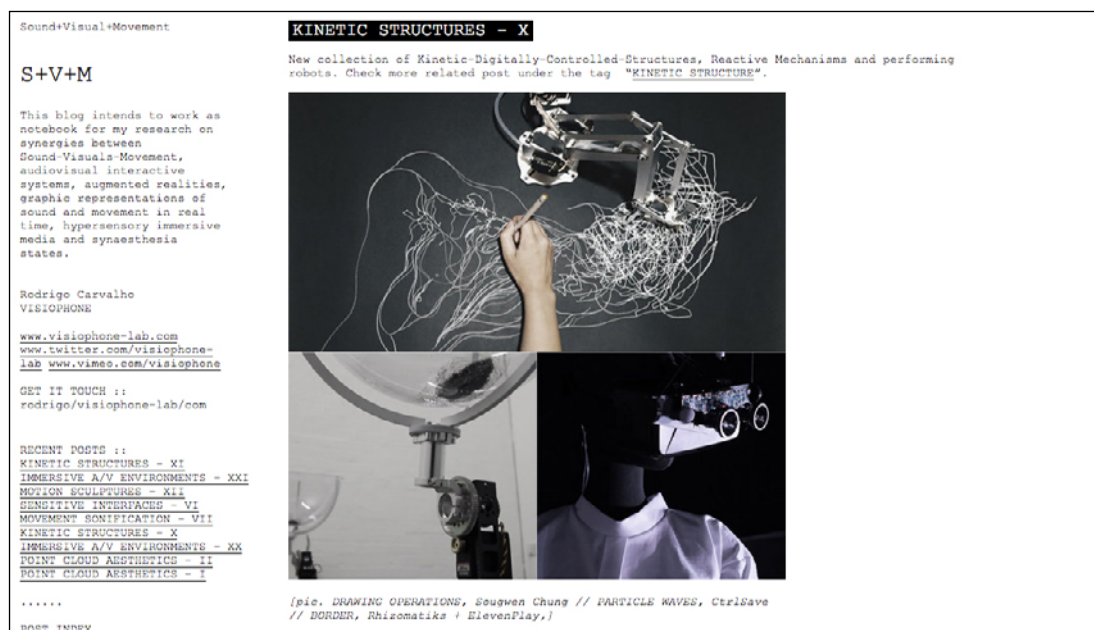
Fig. 26: Printscreen from *S-V-M* blog.

The blog is divided in six main categories, grouping projects with similar characteristics and technologies, in which the main focus is on the transmutability of digital data and the input/output relations between *Sound*, *Movement* and *Visual* domain on interactive

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10 <http://s-v-m.tumblr.com/>. Accessed 2016.04.17

11 <http://creativeapplications.net/>. Accessed 2016.12.28.

12 <http://thecreatorsproject.vice.com>. Accessed 2016.12.28

13 <http://createdigitalmotion.com/>. Accessed 2016.12.28

14 "Controllerism": <https://vimeo.com/groups/controllerism>; "Creative Technology": <https://vimeo.com/groups/creativetechnology>; "Real time / Generative / Interactive art collective": <https://vimeo.com/groups/308518>; "Alphaville": <https://vimeo.com/groups/alphaville>. Accessed 2016.12.28

15 Leonardo Electronic Almanac <http://www.leoalmanac.org/>. Accessed 2016.12.28

16 xCoAx, Conference on Computation, Communication, Aesthetics & X.
 <http://www.xcoax.org/>. Accessed 2016.12.28.

17 ICLI, International Conference on Live Interfaces. <http://www.liveinterfaces.org/>. Accessed on 2016.12.28

18 SIGGRAPH, Special Interest Group on GRAPHics and Interactive Techniques. <https://www.siggraph.org/>. Accessed on 2016.12.28

19 NIME, New Interfaces for Musical Expression. <http://www.nime.org/archives/>. Accessed on 2016.12.28

systems. The categories are: (1) *Motion Sculptures* where motion is transformed into visual shapes and forms; (2) *Sound Sculptures* where sound is mapped into three dimensional physical shapes; (3) *Graphic Sound Visualizers* where sound is visualized graphically; *(4) Shaping Sound* where sound is generated from shapes and graphical features; (5) *Movement Sonification* where sound is generated from movement and (6) *Kinetic Structures* where movement is generated, setting in motion digitally controlled mechanisms and performing robotic agents. Other categories were later added by collecting not only cases related to transformations of data but also by covering topics that in some way are connected or overlapped with audiovisual interactive systems: *Early Computer Graphics* for pioneers on computer art; *Color Organs* for visual music and color organs; *Sensitive Interfaces* for experimental interfaces for audiovisual creation and *Immersive Audiovisual Environments* for responsive and immersive spaces.

The purpose of the collection was to create an informal catalogue of *Sound+Visual+Movement* relations that could be used as a reference to identify artworks, trends and new approaches on contemporary interactive art to be used as case studies for the research project.

3.3.1 MOTION SCULPTURES

The section *Motion Sculptures* collects projects where motion data is used as input to trigger, manipulate or generate visual shapes and forms. *Movement data* (like *position*, *velocity*, or *direction*) is captured along the time and mapped into visual metaphors.

Using the human body as data source is one of the most common cases, where sequences of movement are captured through motion capture systems and then translated over time into visual metaphors in a smooth trail of motion events. We can see that approach on projects like *Aeolus* (Ersinhan 2014), *Tai Chi* (Universal Everything 2012) or *Nike Flyknit* (Universal Everything 2013) where motion-capture data is translated into motion visualizations composed by a variety of points, lines, forms and textures drawing abstractions of the bodies' silhouettes over time. On these cases we can observe an identifiable influence from Duchamp's *Nude Descending a Staircase, No2* (1912) where a body is painted several times along different moments of time, portraying a sequence from a subject descending a staircase. The representation of all the different moments of the movement results in a final dynamic shape, an abstraction representing the movement along the time. Also *Unnamed Soundsculpture* (Franke & Kiefer, 2012) or *Reincarnation* (Akten, 2009) are good examples of the use of the human body. In both, a dancer's body is translated into fluid particle simulations revealing an inconsistent and indefinite form, generating abstract layers and revealing subtle visualizations of human movement and forms.
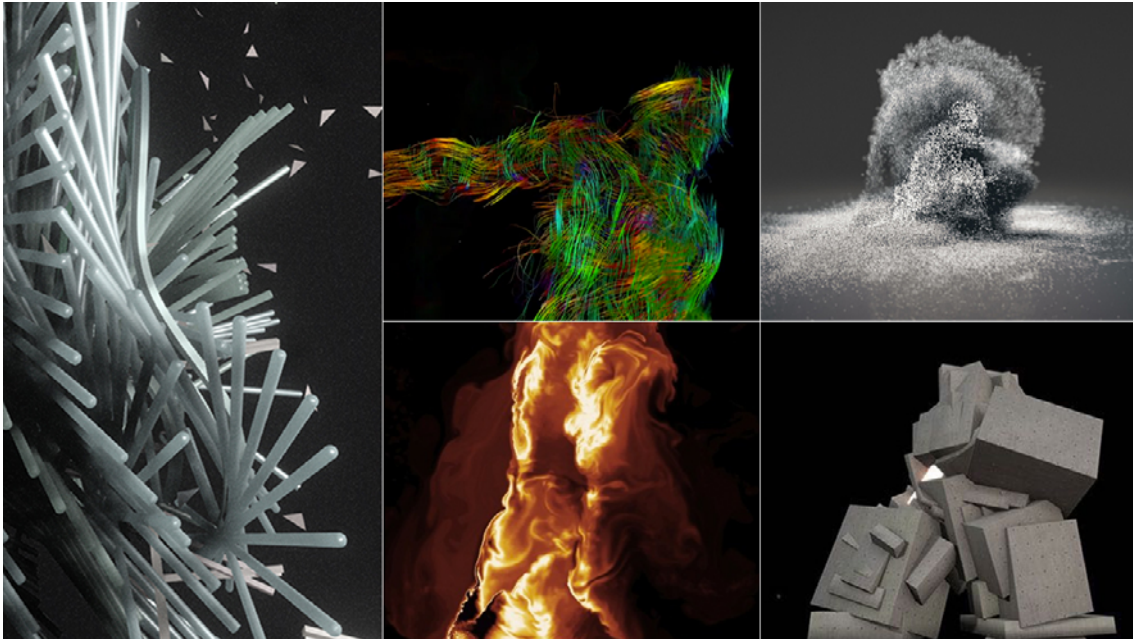
Fig. 27: *Aeolus* (Ersin Ersinhan 2014); *Nike Flyknit* (Universal Everything 2013); *Unname Soundsculpture* (Franke & Kiefer 2012); *Reincarnation* (Akten 2009); *Tai Chi* (Universal Everything 2012).

Another set of projects explore the movement of a variety of elements in a physical/ geographical space sharing in the same way the goal of exploration and generating visual patterns. Many of them use data collected from different sources from transportation and vehicles sources to animal and natural events tracking.

On *IQ Font* (Lieberman et al. 2009) a typographic font was built by tracking the movement of a car. A top camera grabs a car entering an empty space where a pilot drives it in a series of rehearsed sequences in a way that it draws in the space each one of the letters of the alphabet. On *Art Made by Insects* (Edhv 2010), a top camera tracks the movements of ants inside a box and its movements in space are used to generated graphic patters and later printed in posters.
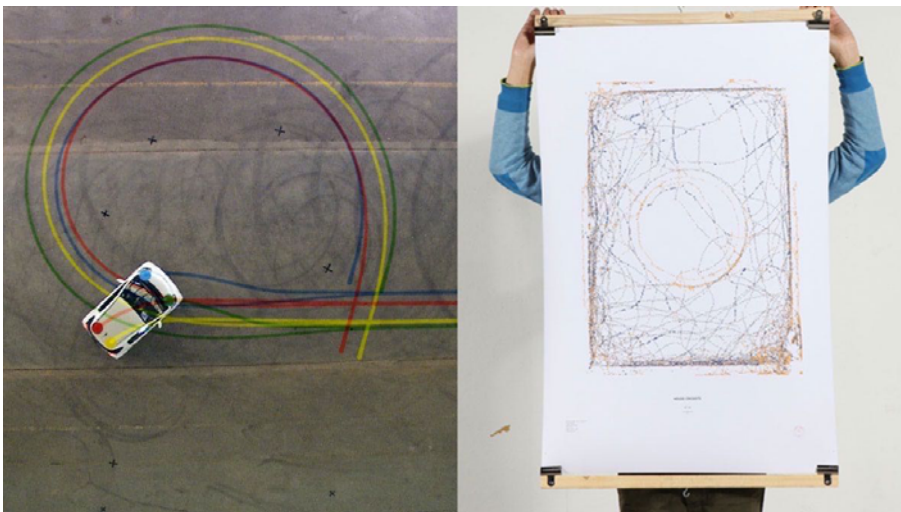
Fig. 28: *IQ Font* (Lieberman et al. 2009); *Art Made by Insects* (Edhv 2010)
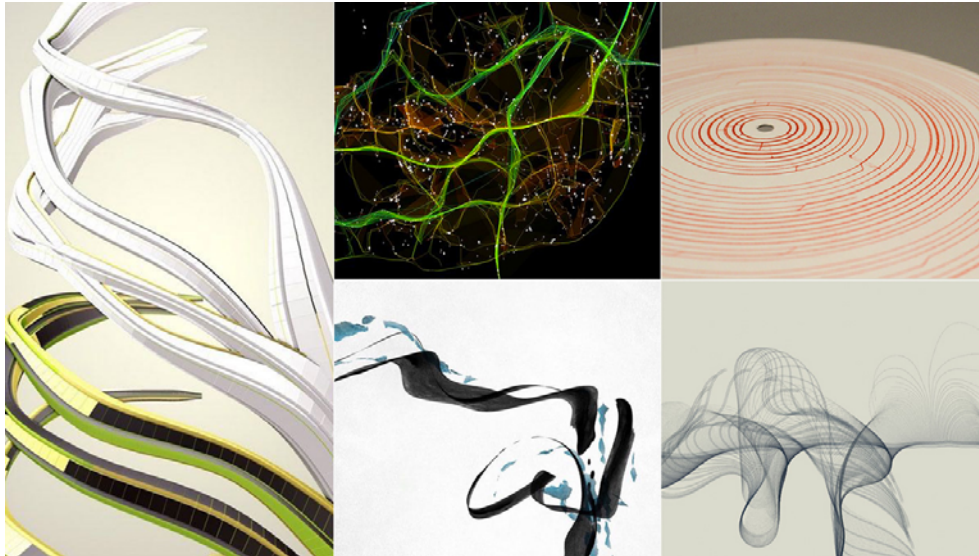
Fig. 29: Fibers (Variable 2014); *Traffic in Lisbon Condensed in One Day* (Cruz 2010); *The Circular Space Visualization Device* (Mahal, Zaza et al. 2012); *Paint with your Feet* (YesYesNo 2011); *Whale* (SmartCitizenProject 2013)

On *Fibers* (Variable 2014) and *Paint With Your Feet* (YesYesNo 2011) data is collected from runners while they are performing theirs training and parameters like the running route, velocity or time are used to generate a unique a personalized visual output for each runner. The same strategy is used by *Traffic in Lisbon Condensed in One Day* (Cruz 2010) wich visualizes traffic information from Lisbon, captureb from cars GPS data, highlighting levels of density and speed over the city map. *The Circular Space Visualization Device* (Mahal, Zaza et al. 2012) is another case that explores the occupation of the space to generate abstract drawing. The device is a mechanical drawing tool that through an ultrasound sensor receives data of movement in a specific area. It is composed by a rotating mechanism that turns a paper circle around, on the top a robotic arm holds a pen. The sensor detects presence in the space, then the area is active, the pen drops down and paints lines on the disc. By the end of day it will produce a visual and physical recording on the history of the activity of the space.

Finally, *Whale* (SmartCitizenProject 2013) presents an interesting visual approach on environment data. *Whale* is an output from the Smart Citizen project[20] a community based platform for collecting and sharing environment data in different cities. In this specific case it used data from sensors placed on a buoy in the Mediterranean sea. Visualizations are then generated based on a series of parameters, like motion of waves and weather conditions, representing each one of them the state of the sea on a particular day.

3.3.2 SHAPING SOUND

Shaping Sound collects artworks where visual shapes are translated into sound. Graphic features (like size, curves, form, silhouette or colors) are used as input data to generate and modulate sound. The roots of these practices come from the first half of the 20th

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20 Smart Citizen Project. <http://smartcitizen.me/>. Accessed 2014.06.04.

century from the pioneers on optical synthesis and graphical sound. As refered on the section *2.2 Seing Sound*, pioneers like Oscar Fischisger or Evgeny Sholpo developed techniques of drawing sound that are used until nowadays in may of the comtemporary artworks.
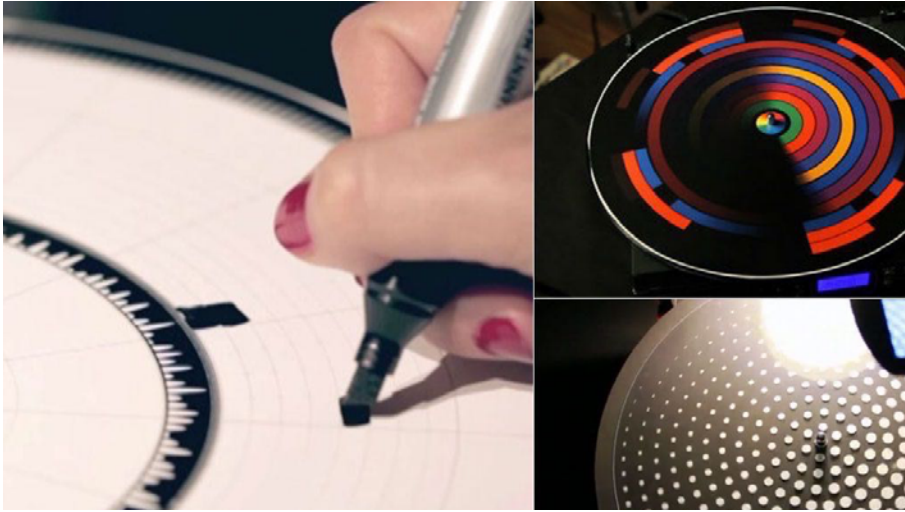
Fig. 30: *Dyskograf* (Avoca 2012); *Light Turnable* (Things Happen 2012);
Graphics Speak (Nam Yap 2012)

On *Dyskograf* (Avoca 2012) we can observe a direct link with the *Variophone* (Sholpo 1930) and Fischinger's idea of drawing the sound by hand. This project uses cardboard disks where different patterns are drawn by users and placed on top of a turntable. Then with the turntable on, the disks rotate, a top camera reads the previously drawn shapes and the system translates these sounds. Besides the *Dyskograf* we can find many similar cases, as *Graphics Speak* (Nam Yap 2012), or *Light Turntable* (Things Happen 2012), that use circular cardboard disks on turntables to create music sequences and patterns, establishing a direct link to Sholpo's *Variophone* and corroborating its expressive capabilities.
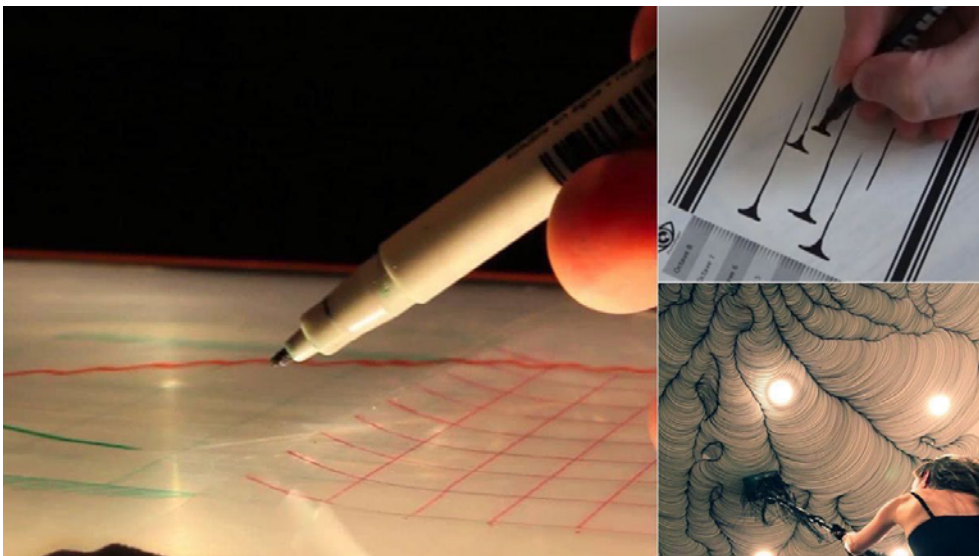
Fig. 31: *Color a Sound* (Neal 2010); *Phono Paper* (Zolotov 2014); R*esonance Reader* (Marcus 2015).

On *Color a Sound* (Neal 2010) the users draw on an acetate sheet roll. The acetate is placed on an overhead projector with a camera on the top. The acetate can then be rolled along the device, shapes and colors are captured by the camera and sounds are triggered in a piano style. Red, green and blue define different octaves or different samples sets from the system. The acetate can then be rolled forward and backward in a way that previous compositions can be played. Following a similar method of directly drawing the sound with on sheets the *Phono Paper* (Zolotov 2014) is a mobile application where users draw sound in a paper, the device's camera captures the drawing and in real time the application translates it to sound. Also aiming to translate drawings into sound the *Resonance Reader* (Marcus 2015) is a "mystic wand" equipped with a custom barcode reader that converts black and white lines to midi messages. It was first presented during the art exhibition *The Hollow* (in Brooklyn, New York in 2015) for the sonification of a massive black-and-white ceiling painting by the artist Tatiana Zaragoza. By moving the device along the painting "*haunting echoes* and *vibrations*" are created.[21]
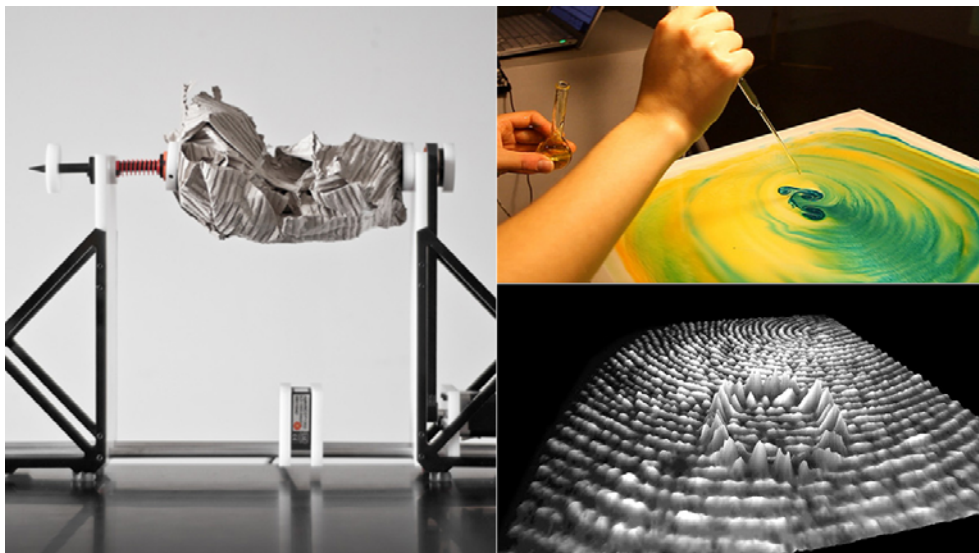
Fig. 32: *An Instrument for the Sonification of Everyday Things* (Paul 2012); *Liquid~do* (Borovaya et al. 2011); *Digiti Sonus* (Chung Han 2013)

An Instrument for the Sonification of Everyday Things (Paul 2012) is similar but differs from all the other artworks presented before in one particular aspect, as it produces sound from three-dimensional shapes. Random everyday objects are mounted on the device, a mechanism rotates it and a sensor scans its silhouette. The scanning is made by a laser that measures the distance to the surface of the object. By rotating the object and moving the laser along it, the shape features of each object are exposed and the distance values are transformed into audible frequencies, notes and scales. Focused on the sonification of a specific set of images *Digiti Sonus* (Chung Han 2013) proposes to transform human finger-prints into sound. Presented as an interactive sound installation, it captures the individual fingerprint of each visitor and sound is generated algorithmically from its patterns creating this way a unique sound identity for each visitor.

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21 Exhibition report at The Creators Project. <http://thecreatorsproject.vice.com/blog/custom-instrument-turns-black-and-white-drawings-into-sound>. Accessed 2015.06.09

Finally, *Liquid~do* (Borovaya et al. 2011) presents a device used for an interactive live audiovisual performance that generates sound from colorful fluids. During the performance an artist generates fluids by adding chemical reagents to a liquid on a surface. The reagents led the liquid to dynamic and colorful changes creating this way abstract shapes and textures that are captured by a top camera. Through the features of the captured images the interactive system algorithmically generates a continuous soundtrack.

3.3.3 MOVEMENT SONIFICATION

This section collects projects where movement data is used as input for sound generation. Many of the projects found use the human body as an input and use different techniques and approaches like computer-vision or electronic sensors to track the body motion and use it to generate and control sound.

One of the earliest examples found is the *Terpsitone* (Theremin 1932) an adaptation of the famous gesture based instrument by Leon Theremin. Like the original this was an electronic instrument that used the capacitance of the bodies to cause variation on the pitch of an oscillator, but this version was intended to be used with the entire body. It had a metallic conductive platform on the floor, where the dancer would stand and move to generate sound compositions. Vertical movements would change pitch and volume was controlled by the distance from the back of the platform. (Smirnov 2013 63).

Already in the computer era two of the most known pioneers were David Rokeby and Erkki Kurenniemi who developed camera based solutions for body detection and movement sonification, as described on section *3.2*. Following the legacy of Rokeby and Kurenniemi we find a wide variety of projects that use similar approaches in the creation of interactive installations and systems for stage performance were body movements can create and modulate sound. One example is *We Are Waves* (Chavarri and Gonzalez 2009) an interactive installation that uses a camera and a computer vision system to extracts the silhouettes of its visitors in real time. The silhouette's points are used to create a dynamic wave that is then converted into sound. Also based on camera tracking but focused on stage performance *Seine Hohle Form* (Weiss and Rovan 2000) uses real-time sound synthesis fed by data coming from video tracking. The choreographic movements of the dancers are tracked and shape the live generated sound.

Following similar aproaches we should also hightlihgt the work of Pablo Palacio and Muriel Romero, who under the name of *Sonic Dance* have developed a series of different body motion instruments for dance performance. The instruments are camera tracking based and on each one of them new interactions with the body are explored. One of the instruments developed is the *Interactive Dynamic Stochastic Step Size Modulator,* an interactive version of the *Dynamic Stochastic Synthesizer* created by Iannis Xenakis that uses simulated brownian motion[22] to generate sound. The dancer manipulates individual sound samples and step sizes of random movement with her body motion. Another instrument is the *Interactive Stochastic Swarm Synthesis Sextet* based again on the *Dynamic Stochastic Synthesizer* and combined with simulations of swarm behaviors. It is a dialogue between a dancer and five artificial intelligent agents which stop moving when the dancer is in

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22 Brownian Motion: Random motion of particles suspended in a fluid.

motion and move frenetically when the dancer stops. Both instruments were used in an interactive dance performance called *Stocos* (Palacio and Romero 2011) which explored stochastic processes combined with artificial intelligence simulations in the creation of a responsive stage where dancers, automated agents, music and visuals where connected and interacting with each other. Palacio and Romero have created other explorative instruments used in different performances like the *Blink Morpher* an interactive instrument manipulated by the dancer's eyes; or *Ataxia* where the dancer's motions controls the rhythm of pulses of percussive sounds.[23]
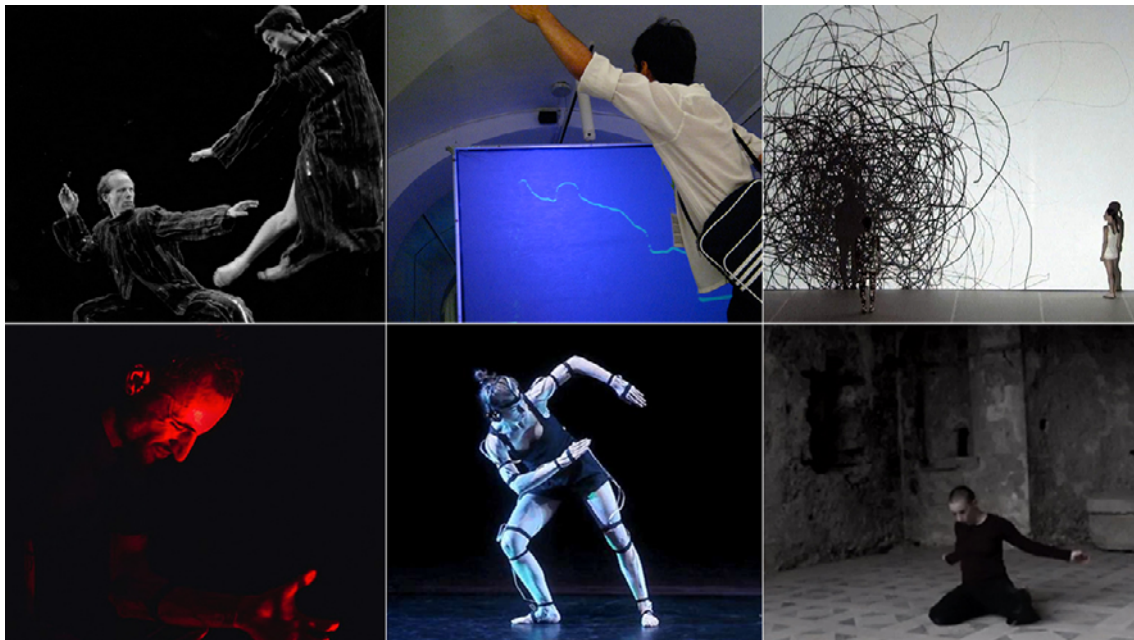
Fig. 33: *Seine Hohle Form* (Weiss and Rovan 2000); *We Are Waves* (Chavarri and Gonzalez 2009); *Stocos* (Palacio and Romero 2011); *Ominous* (Donnarumma, 2014); *Audift* (Klimowski, Lichota, Romaszkan 2014); *Epi::Akten* (Novell, Rijekoff and Dauri 2012).

Besides from the camera based solutions there are a vast number of body interactions and stage performances that use body sensors for movement tracking. *Xth Sense* (Donnarumma, 2011) is a biophysical sensor that captures the sound of body's muscles, hearth and blood[24] with the purpose of using the body internal mechanisms as an augmented instrument, a generator of raw sounds for music performance. Marco Dunnaruma has used it in a variety of stage performances like *Ominous* (2014) where the sound of his muscles contractions are processed, amplified and manipulated in stage as a unstable sonic sculpture. *Audift* (Klimowski, Lichota, Romaszkan 2014) is a dance costume built for dance stage performances that reads dancer's movements and positions in real time. A number of motion detectors and accelerometer read the body movements and its data is converted into sound that is then broadcasted in three different channels. The audience equipped with headphones tunes to one of three radio channels and hears different versions of the performance. In *Epi::Akten* (Novell, Rijekoff and Dauri 2012) a combined solution of

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23 Body instruments descriptions at the author's website <http://www.pablopalacio.com/instruments.html>. Accessed 2015.06.10.

24 *Xth Sense*, project description. <http://www.marcodonnarumma.com/works/xth-sense> Accessed 2015.06.10

camera tracking and body sensors were used. SenseStage's[25] micro-controller boards capture the acceleration of joints and sends their data through a wireless network, in addition a frontal camera was used to determine the position of the skeleton's joints in the stage space. This gives to the performer a higher level of expressivity, since it combines two different tracking dimensions, a small scale one specific for the body and tracking small scale movements and another one related to the space tracking a bigger scale.
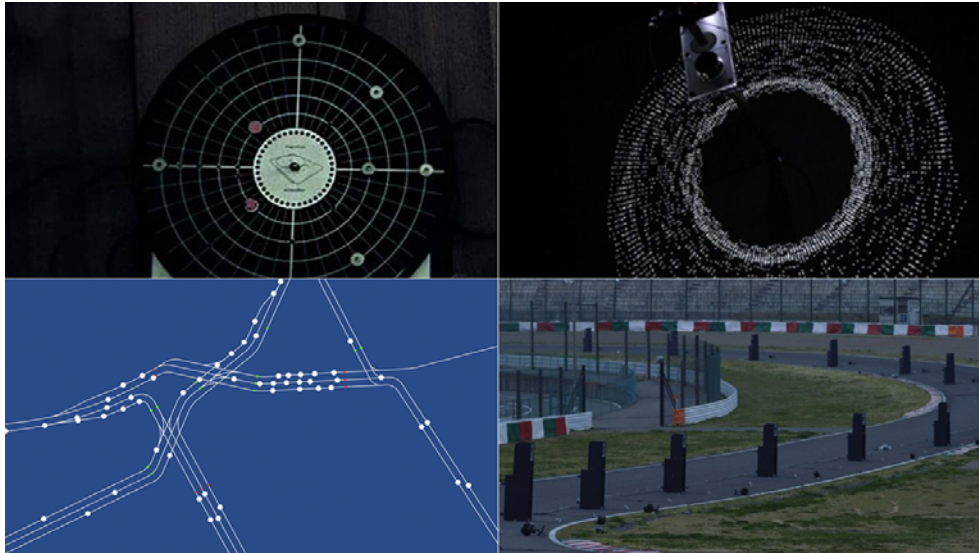
Fig. 34: *Sound Radar* (Wedelstädt 2013); *Radius Music* (Henderson 2010); *City Symphonies* (Mckeague 2012); *The Sound of Honda* (Dentsu Tokyo Agency 2014)

Beyond systems that use body movement to generate sound there are variety of instruments and experimental sonification approaches that use movement from other different sources. *Sound Radar* (Wedelstädt 2013) is a custom MIDI controller based on a turntable equipped with six magnetic sensors. The interaction is made by placing magnets over records and make them spin on the turntable. The data collected by the sensors generated by the magnets moving over the turnable is sent as MIDI to a music software to create rhythms and patterns. On *Radius Music* (Henderson 2010) an autonomous device equipped with an ultrasonic distance sensor is continuously rotating and scanning the space around looking for the presence of other objects. The device measures the distance between itself and the objects found and uses that data to create a sonic frequency soundscape. *City Symphonies* (Mckeague 2012) uses a traffic simulation of vehicles to generate data from the movement of these vehicles through London roads network. The traffic along the streets and the interactions between vehicles create endless and unique city soundtrack where the city and its streets are the music score.

Finally *The Sound of Honda* (Dentsu Tokyo Agency 2014) is a sonification of telemetry data from the race driver Ayrton Senna's fastest lap on the F1 Japanese Grand Prix in 1989. It is a sound and light installation with 5807 meters and an array of sound speakers displayed along the track. From the collected data and sound samples from the car's engine a soundtrack was created with the sound traveling from speaker to speaker around the track, recreating in the physical space Senna's famous lap.

25 SenseStage a Low Cost, Open Source Wireless Sensor Infrastructure for Live Performance and Interactive, Real-Time Environments by Marije Baalman. <http://sensestage.hexagram.ca>. Accessed 2015.06.10

3.3.4 GRAPHIC SOUND VISUALIZERS

The section *Graphic Sound Visualizers* collects artworks where sound is visualized graphically, in which sound is used as source to generate or manipulate visual content. It gathers projects in diverse formats including audiovisual live acts with real-time projections or physical structures, generative screen work, or analogue devices. The strategies to visualize sound also vary from direct visual feedback coming from analogue signals, to representation of sound frequencies or experimental visualizations with various mapping strategies. Despite the differences in technical approaches and formats, all of them share the same goals and explore relations between sound and image and create hyper-sensory and synesthetic experiences to their audiences.
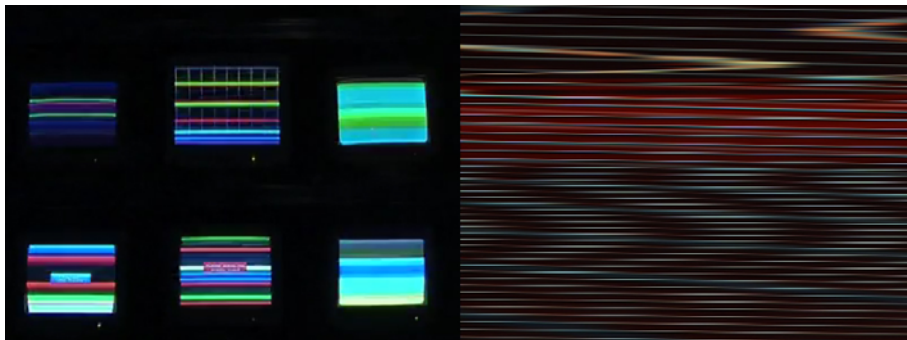
Fig. 35: *NoSignal25* (Luthiers Drapaires 2009); *Synchronator* (Van Koolwijk and Prins 2009)

The legacy from visual music of the 20th century and specifically the video artists from the 1970s have a strong influence in contemporary sound-visualizations artwork. We can draw a connection between the works of Steina and Woody Vasulka and others early video artists, refered on section 2.2 *Seeing Sound,* and the audiovisual instrument *NoSignal25* (Les Luthiers Drapaires 2009). *NoSignal25* is composed by an array of 25 recycled VGA computer screens that receive independent electrical pulses (from witch the audio is also generated). The video signal is not being directly transformed from the audio but it is being created in synchrony from the same source and transmitting a visual output from the generated sounds. On the same line of analogue signal, the *Synchronator* (Van Koolwijk and Prins 2009) is a portable device that transforms audio into video signals. It takes up to three audio inputs, that will generate the RGB colors, and translates them to one video output of audio sync pulses. The device has been widely used in audiovisual live performance delivering direct visualizations of sound frequencies.
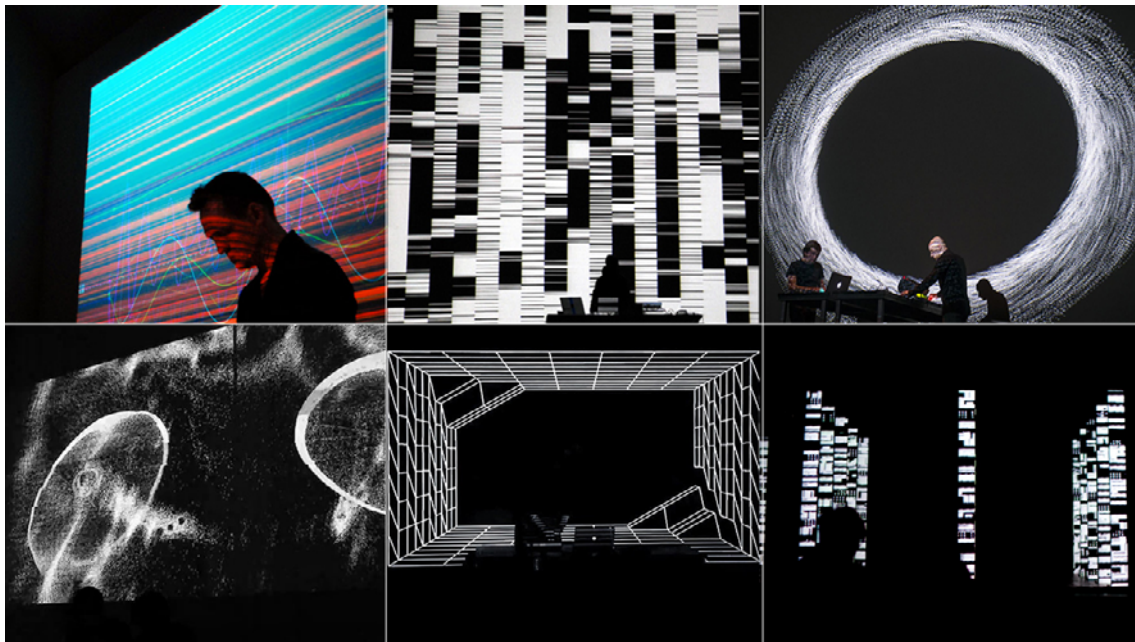
Fig. 36: *Unitxt, Derivative Version* (Noto 2009); *Test Pattern* (Ikeda 2008); *Tempest* (Vigroux and Schmitt 2012); *STM~ Duality* (Sanz and Barandun 2015); Alpha (Bayle 2014); *Imposition* (Schwarz and Edisonnoside 2012)

The artist Alva Noto in a recent video interview expresses his interests in exploring various "graphic analyzers, different ways to analyze frequencies"[26] and in fact he holds a long line of work exploring visual characteristics of sound. In his live audiovisual performance *Unitxt (Derivative Version)* (Noto 2009) the audience is immersed along the performance in a sequence of different real-time sound visualizers in total synchrony with highly rhythmic music and building together an audiovisual language suggesting rhythmic graphic grids, glitches and mathematical units. Noto, together with Ryoji Ikeda, published the book *Cyclo. Id* (2011), an extensive catalogue of visual patterns generated by specific sound frequencies. Along more than 300 pages are displayed thousands of sound driven figures with the correspondent audio frequencies. In the preface the artists declare that they have "abandoned the idea that the image acts only as a functional accompanist to sound and instead subordinated the audio element for our desire of the image" (Ikeda and Noto 2011, 3).

Many contemporany audiovisual performances share similar aproaches, setups and goals to the ones described by Noto. As *Test Pattern* (Ikeda 2008), where Ikeda presents an audiovisual live performance where audio signal is converted in real time into barcode patterns on the screen. The black and white and fast flickering aesthetics associated with it and the high level of audio and image synchrony takes the audience's perceptions to the limits and takes them inside an imaginary ambience of fast digital processes and infinite multidimensional data matrixes. Or *Tempest* (Vigroux and Schmitt 2012) a combination of analogue instruments and visual algorithms create a chaotic system of millions of particles that cab be seen and heard.

We can also hightlihgt *STM~ Duality* (Sanz and Barandun 2015) where a particle system is used as a visual and audio resource in the creation of a synesthetic performance. Also *Alpha* (Bayle 2014) which explores sounds and visuals generated by algorithmic sequences

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26 Carten Nicolai aka Alva Noto interviewed by Juliana Mori for the Tugobot project. < https://youtu.be/KsilVMw3N9Q > and <http://www.tugobot.com>. Accessed 2015.06.10.

controlled in real-time. Or *Imposition* (Schwarz and Edisonnoside 2012) where a matrix of rods in a vertical position are placed around the stage and used as projection surface creating a three dimensional space, distorting the perception and merging the virtual and real spaces.

Lumière (Henke 2013) is an audiovisual performance where instead of using video projection as visual output, it uses high power lasers drawing points, lines and shapes in space. The dark space, where the performance takes place, is filled with haze that enables the laser lights to become visible, not only in the projection surface, but also in the air, shaping this way a three dimensional space and involving the spectators in an "highly synchronized immersive experience". On *Frequencies, Synthetic Variations* (Bernier 2013) the visualization of the sound is not made by means of projecting light in space but through a physical structure made of a succession of acrylic frames, each one of them being illuminated in the edges by an individual light. When the performance is running, sequences of tight synchrony of sound and light are delivered "bringing a sense of extreme precision where one can either hear the light or see the sound"[27].
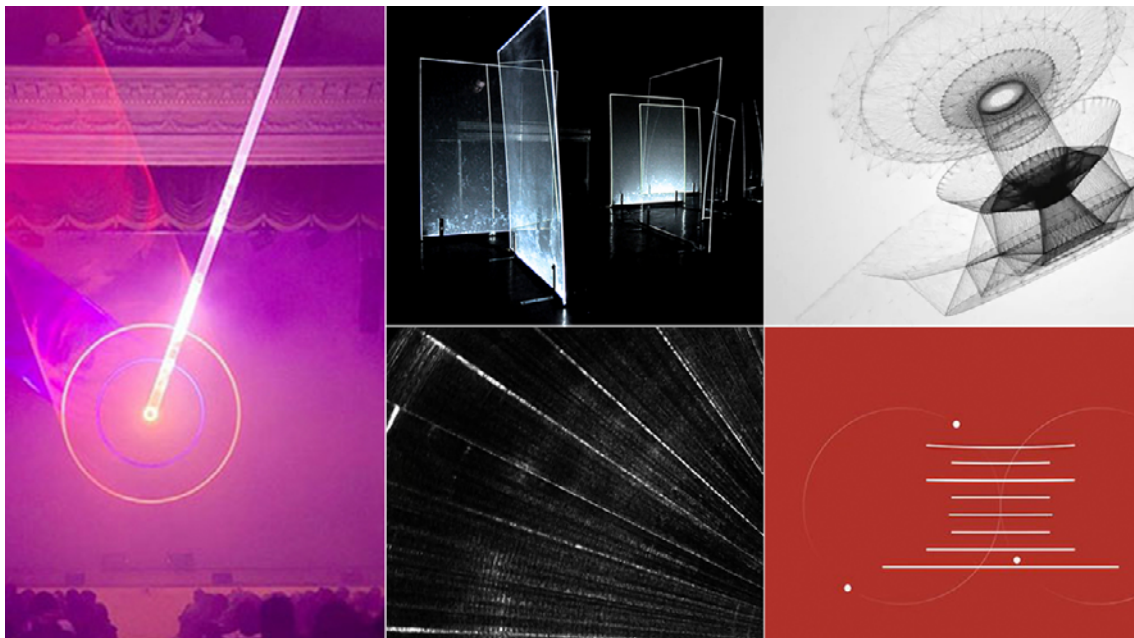
Fig. 37: *Lumière* (Henke 2013); *Frequencies, Synthetic Variations* (Bernier 2013); *Audio Generated Objects* (Lange 2010); *Periskop* (Peterson 2012); *Bach* (Chen 2011)

And finally a selection of examples of sound visualizations that are not presented as a live performance but as a screen artwork, as an interactive application, or video render. Like the live performances they are the outcome of different software processes, approaches and mappings on visualizing the sound, where audio is analyzed and the data from its frequencies is used to create, manipulate and deform structures of points, lines, meshes and colors. *Audio Generated Objects* (Lange 2010) is a series of sound visualization explorations by Diana Lange where different three dimensional shapes are deformed using with data from audio analysis. Audio waves, beats, peaks and frequencies are visualized on each object shape in synchrony with the music track creating ephemeral digital sound objects reflecting the features of each track. *Periskop* (Peterson 2012) is a sound

27 *Frequencies, Synthetic Variations*, project description by the author. <http://www.nicolasbernier.com/page/works.htm>. Accessed 2015.06.10

visualization video using data from sound frequencies mapped on rows around a circle as a dynamic texture, on every frame of the video the rows moves one step further creating a progressive circular motion. Presented in the format of an interactive online application, *Bach* (Chen 2011) visualizes the first prelude from Bach's Cello Suites*.* All the notes are presented as strings emphasizing the music structure shape and a number of spheres flow around and trigger sounds every time they cross over a string. The application runs autonomously following Bach's notation, but users can drag the spheres to play their own compositions, after released the spheres slowly return to their path to get in track with the original Bach's score.

3.3.5 SOUND SCULPTURES

The data transformations gathered in *Sound Sculptures* are similar to those in *Graphic Sound Visualizers,* dedicated to the visualization of sound, but in this case this section specifically collects projects where sound is mapped into three dimensional shapes. The output of all these artworks are physical objects that are the materialization of data extracted from sound analysis. In each moment of time the sound features are taken and shaped into physical matter (by 3D printing, laser cutting or other techniques), this instance is accumulated with the following ones building this way in the end a physical sound object.
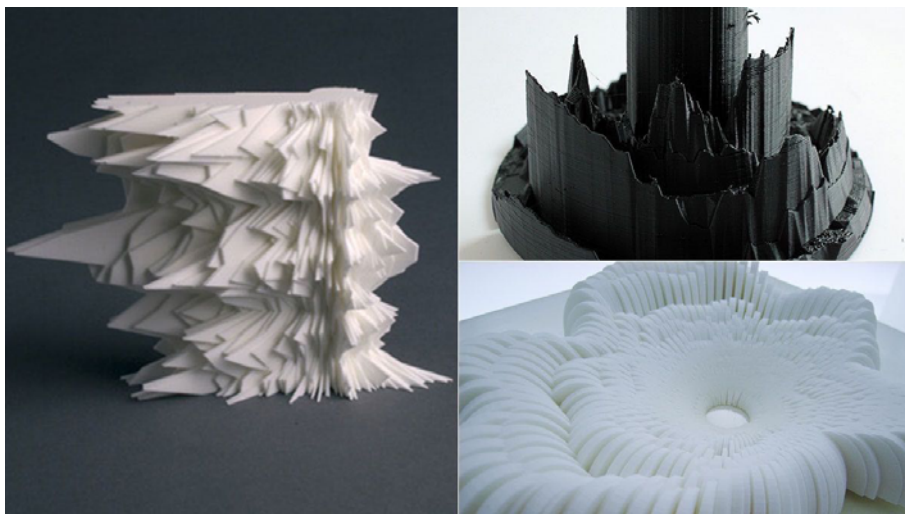
Fig. 38: *Cylinder* (Huntington and Allan 2003); *Microsonic Landscapes* (Realitat 2012); *Sound Memory* (Watz 2008)

In *Cylinder* (Huntington and Allan 2003) instances of sound frequencies were taken from sound samples, cut in paper layers and mounted in cylinders. The titles of each sculpture (like *Seahorses, Breath or Market*), are directly related to the origin of the sound that was used to build the piece.[28] The cylinder or circular shape is easily related to time based structures. A similar strategy can be found in other artworks like *Microsonic Landscapes* (Realitat 2012) where a cylinder shape is used as materialization of a series of music

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28 *Cylinder*, project description. <http://andyhuntington.co.uk/2003/cylinder/>. Accessed 2015.06.10

albums, including *Third* by Portishead or *Für Alina* by Arvo Pärt. The sound waves of each album are translated into spatial coordinates placed in a circular shape and printed with a 3D printer[29]. The final result is a metaphoric object materializing the soundscape of each album. A similar approach was also used by Marius Watz on *Sound Memory* (2008) where a series of three dimensional shapes, visualizing instances of the song *Oslo Rain Manifesto* by Alexander Rishaug, are disposed in a circular shape building an organic wavy sculpture.
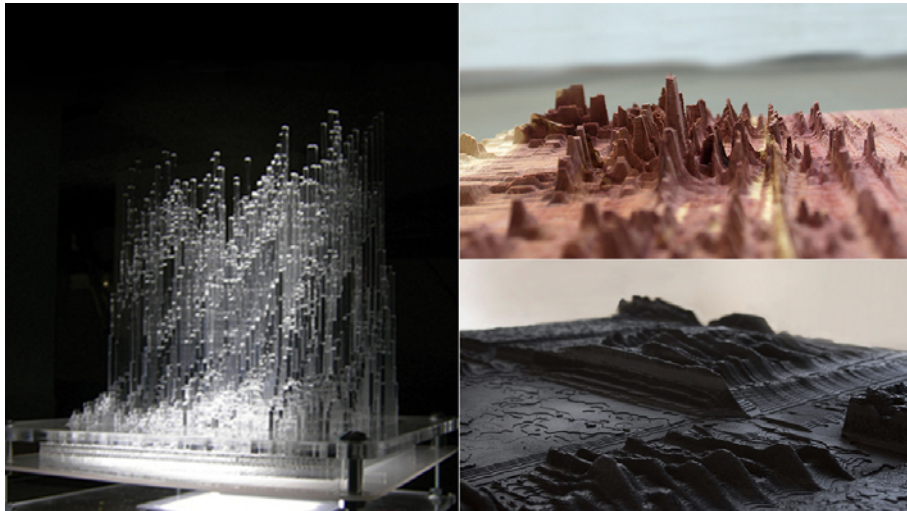
Fig. 39: Nightingale Bird Song (Huang 2010); Spectral Density Estimation (Fischer 2013); *Refletcion* (Fischer and Maus 2008)

Nightingale Bird Song (Huang 2010) uses a plane matrix instead of a circular shape, but the main idea remains. From an audio capture of a bird singing, independent instances of the sound frequency visualizations were take in regular time intervals. Those shapes were then traced and cut on acrylic layers and sequentially assembled together into a physical sculpture. Also represented on a plane *Spectral Density Estimation* (Fischer 2013) visualizes two performances from the *Winston-Salem Symphony* orchestra. The recordings were analyzed and the shapes of its sound frequencies were extracted over time and organized sequentially in space. The final shape was then carven in a block of wood.

On *Refletcion* (Fischer and Maus 2008) an identical strategy is used to visualize the spectrum analysis from a musical piece, *Reflection* by Frans de Waard, in a sequence of sample silhouettes along a plane of a MDF board. Years later a remake of this project, named *Reflection II* (Fischer and Maus 2010), brought a new dimension to the visualization. A video projector on the top creates animated white lines over the sculpture symbolizing a light scanner and at the same time the original audio-track was being played. The video projection and the audio-track were in synchrony in a way that the shapes where the light was projected matched the sound that was being played building this way an augmented data sound sculpture.

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29 *Microsonic Landscapes*, Project desciption <http://www.realitat.com/microsonic>. Accessed 2015.06.10
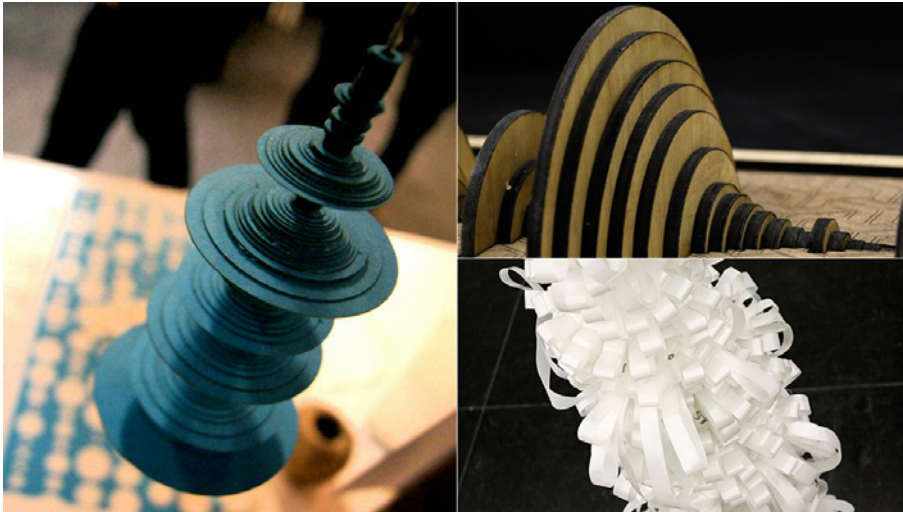
Fig. 40: *Paper Note* (Spitz and Nip 2012); *Amen Break Waveform* (Hendee 2015); *Frozen* (Herzon 2008)

Paper Note (Spitz and Nip 2012) is an application that lets users upload sounds and messages and translates each moment of the corresponding waveform into the form of a circle. The circles are then printed, cut with laser and connected with a rope passing through the center of all circles. In the end the user gets a tangible paper sculpture representing the audio waveform where each slide, or circle, represent a moment in the sound file[30]. *Amen Break Waveform* (Hendee 2015) also uses circles slides to map audio frequencies, this time laser cut pieces of wood. *Amen Break*[31] is one of most famous drum breaks in the recent history of electronic music, being extensively sampled across several genres of electronic music, particularly in drum&bass, hip-hop and jungle genres. Hendee's artwork, a wooden base where the circles slides are mounted, works as a statue or a monument that preserves the memory of the drum sample and its role in the music's history.

All the previous sound sculptures maintain a strong visual connection with the sound produced, both due to its assembly in temporal sequence or its exact reproduction of the sound wave. But in the case of *Frozen* (Herzon 2008) its final shape is completely disconnected with the original sound, and explore an aproach more connected with design speculations and abstract visualizations. *Frozen* is a data sculpture where the artist uses a data stream from Ryoji Ikeda's *Data-Matrix*, and cuts plastic ribbons according to the amplitude of each data instance, all the ribbons are then assembled in one piece, and an abstract sound object is created.

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30 *Paper Note*, project description. <http://www.soundplusdesign.com/?p=4946>.Accessed 2015.06.10

31 Video by Nate Harrison (2004) narrating the history of *Amen Break* can be watch on the following link: <https://www.youtube.com/watch?v=5SaFTm2bcac>. Accessed 2015.06.10.

3.3.6 KINETIC SCULPTURES

Kinetic Sculptures collects artworks where movement is generated. It includes physical digitally manipulated mechanisms with reactive, interactive, algorithmic or pre-sequenced behaviors where the domain *movement* is an output in the digital system. The input source is not distinguished, it can come from different sources and domains like sound frequencies, image or event capture of movements, and the data produced is used to generate movement in kinetic sculptures, interactive structures or robotic mechanisms.

Fig. 41: *Standards and Double Standards* (Lozano-Hemmer 2004); *Audience* (O'Shea 2010)

Standards and Double Standards (Lozano-Hemmer 2004) falls into a group of projects that can be consider as *responsive environments,* such as Krueger defined (1977) a responsive environment where the participants enter and get involved and in dialog with the room. The exhibition space is filled with a matrix of fastened belts suspended by ropes to the ceiling. For each belt a step motor on the top is used to control the direction to where the belt is pointing. When a visitor enters the space a video camera and a tracking system are used to trace its position triggering the motors to rotate in a way that the belts' front side is facing the visitors. When a visitor walks around the space the belts automatically follow him. When several visitors enter the space, chaotic patterns and non-linear behaviors emerge and the belts rotate in unpredictable ways.[32] Using a similar setup *Audience* (O'Shea 2010) is a responsive environment composed by 64 head-size mirrors, each one mounted over a structure controlled by two stepper motors. The mirrors are constantly rotating around mimicking a scanning behavior. A camera in the top tracks the space looking for movement, when a moving visitor is found all the mirrors synchronize and rotate towards that position[33].

32 *Standards and Double Standards*, project desciption.
<http://www.lozano-hemmer.com/standards_and_double_standards.php>. Accessed 2015.06.17

33 *Audience*, project description. <http://www.chrisoshea.org/audience>. Accessed 2015.06.17
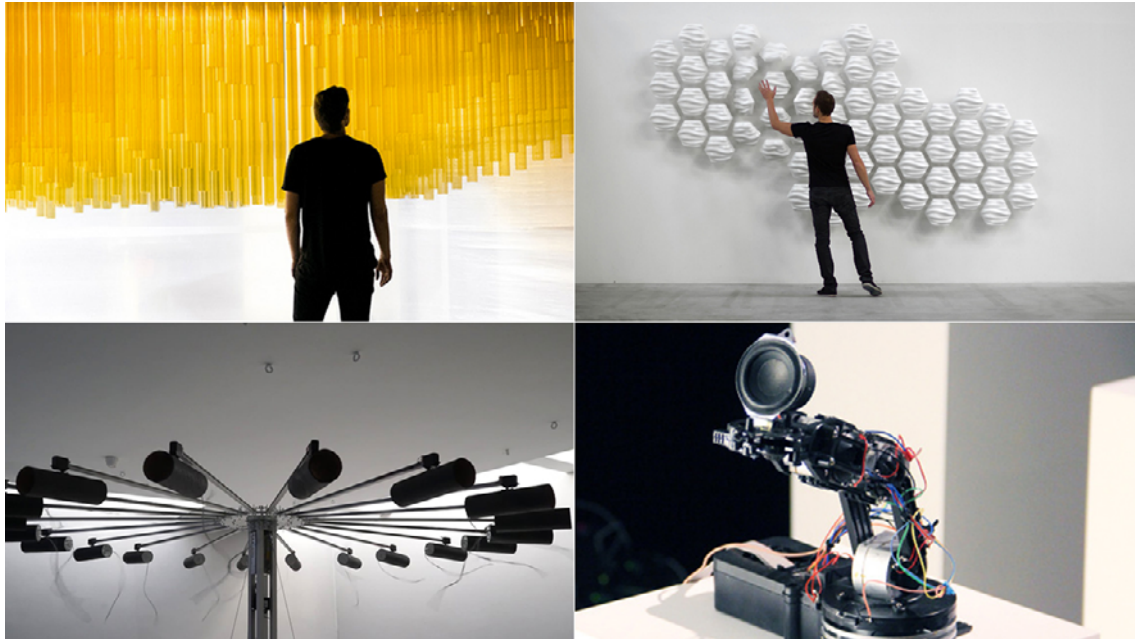
Fig. 42: *Breaking the Surface* (Scandinavian Design Group and Ctrl+N 2014); *Hexi Wall* (Thibaut Sld 2013); *R x2* (Vtol and Alekhina 2015); *Nayral-ro* (Vtol 2014)

Breaking the Surface (Scandinavian Design Group and Ctrl+N 2014) is also a responsive space where a sculpture reacts to visitors' movements. The space is filled with a matrix of 529 acrylic pipes mounted vertically on the ceiling, each one of the pipes is controlled by motors that make them move up and down. A combination of cameras and a sensitive floor senses the presence of visitors and the pipes sculpture responds by changing its shape. All the pipes in the matrix move together as one organic wave and move in a way that it wraps the visitors underneath in a protective dome shape[34]. On *Hexi Wall* (Thibaut Sld 2013) a similar approach is used on a wall instead of the ceiling. A series of tiles are placed in the wall attached to servo motors, a depth camera senses the space and when presence is detected the tiles rotate in that direction, morphing the shape of the wall and mirroring the visitor's motion.

R x2 (Vtol and Alekhina 2015) is a kinetic sound installation that uses scientific earthquake data to move a robotic performative sculpture. Custom software collects data from the internet related to the movements of the planet's crust searching for earthquakes above 0.1 on the Richter magnitude scale, which happens around 200 times a day. Data related to the power and depth of shocks is converted in to signals and used to move the sculpture. The physical structure is composed by a series of mechanical arms arranged in circle and suspended around a central pole. On the edge of each arm an electric motor rotates and moves a Thunder Drum, an instrument composed by a cylinder and a suspended string, when it rotates the spring vibrates, hitting the cylinder and producing sound. By the same artist *Nayral-ro* (Vtol 2014) is an interactive orchestra composed by a series of robotic performers, each one made of a motorized mechanical arm, able to rotate and pan. Also each one of them is equipped with a sound speaker and all of them combined form a multi-channel electronic orchestra. Twelve robotic arms are placed over white

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34 *Breaking the surface*, project description.
<http://www.creativeapplications.net/openframeworks/breaking-the-surface/>. Accessed 2015.06.17

podiums and in front a stage with a leap-motion device allows the users to interact with the orchestra with hand gestures in the air, which controls the sound and interacts with the robots movements. Making similar gestures to an orchestra conductor, the user waves his hands and the robotic arms turn and bend changing this way the positions and rotation of the sound speakers, pointing the sound to different directions and creating this way dynamic and spacial soundscapes[35].
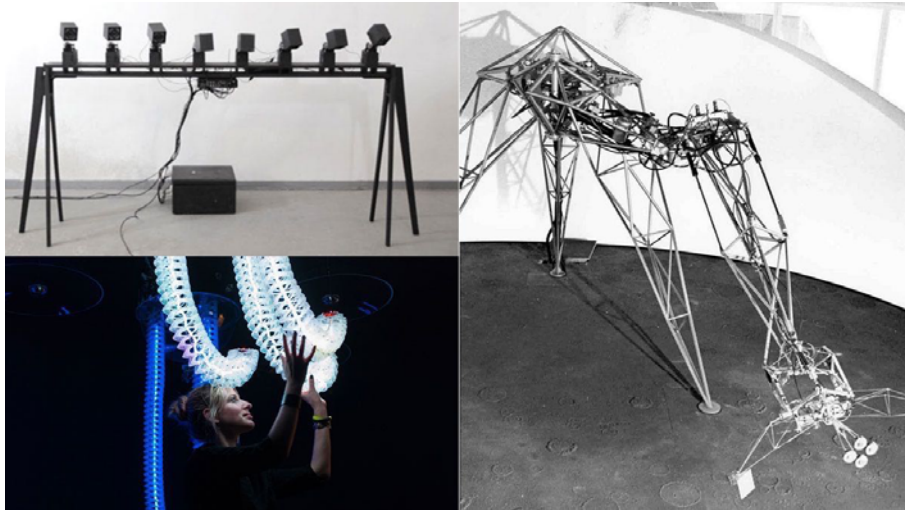
Fig. 43: *ECHOOOOOOOO* (panGenerator 2014); *Senster* (Ihnatowicz 1970); *Petting Zoo* (Minimaform 2013)

Also using motorized mechanical arms but presented as robotic performers, *ECHOOOOOOOO* (panGenerator 2014) is a robotic choir that receives as input the performer's voice to generate sounds and movement. The voice of the performer is processed and used to generate a composition that is played in each one of the robotic arms, and its movements are generated from the frequency and amplitude of the sounds. The use of robotic mechanical arms, that react to the actions of humans around it can be traced back to the work of Edward Ihnatowicz, who created *S.A.M* (1968), a reactive moving sculpture presented at the *Cybernetic Serendipity* exhibition (Reichart 1968). A few years later a new and bigger version called *Senster* (1970)[36] was also created by Ihnatowicz. A similar strategy was also used in the *Petting Zoo* (Minimaform 2013), an interactive robotic environment where a group of speculative robotic creatures are hanging from the ceiling and interacting with the audience. The creatures are controlled by artificial intelligence algorithms which provide them with a variety of personalities, behaviors, and range of movements to interact with the audience[37].

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35 *Nayral-ro*, project description. <http://vtol.cc/filter/works/nayral-ro>. Accessed 2015.06.17.

36 *SAM and Senster* descriptions by the author. <http://www.senster.com/ihnatowicz/index.htm>.Accessed 2015.06.17.

37 *Petting Zoo*, authors' description. <http://www.minimaforms.com/petting-zoo-frac>. Accessed 2015.06.17.
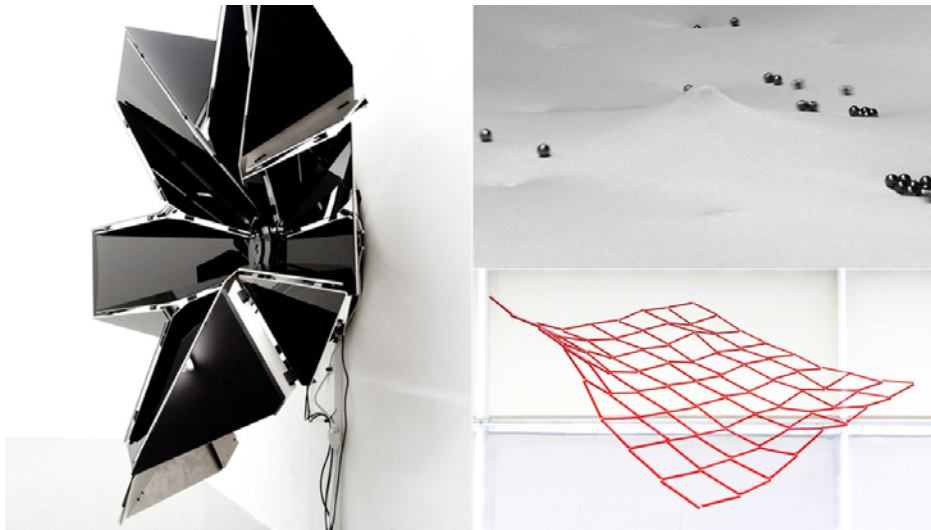
Fig. 44: *Versus* (Letillier 2011); *Aerosol* (Born 2013): *Tele-Present Water* (Bowen 2011)

Besides the robotic mechanical arms approach, there is a wide range of alternative reactive structures with different shapes, that react to present, sound, or other inputs. *Versus* (Letillier 2011) is a kinetic and sound sculpture composed by two facing moving mechanisms that react to each other. Each sculpture is made of triangular panels controlled by motors, each one with a sound speaker and a microphone. Periodically each sculpture produces a sound that is then recorded and analyzed by the opposite sculpture, which in turn reacts by moving and changing its shape according to the analyzed sound frequencies. Later it emits also a sound in response, creating this way an endless feedback loop. On the other hand, also exploring different moving shapes, *Aerosol* (Born 2013) is a physical particle system composed by a surface made of a malleable and elastic fabric that is shaped and warped by a series of servo motors placed under it. The *up and down* movement of the motors create a hilly landscape on the fabric where a set of small iron balls are placed, which are naturally set in motion due the unevenness of the terrain and the gravitational forces. Over the time with the continuous changing of the terrain shape, patterns and groups emerge on the endless movement of the balls.

Exploring different types of movement, *Tele-Present Water* (Bowen 2011) is a kinetic installation where a suspended dynamic surface, controlled by strings and motors on the ceiling, is shaped according to ocean waves' data, by the USA National Oceanic and Atmospheric Administration, captured with a scientific buoy station placed on the Pacific Ocean 205 nautical miles southwest of Honolulu. Intensity and frequency of the waves are translated to the motors, giving shape and movement to the structure and simulating waves activity from a distant location[38]. With many similarities with *Tele-Present Water* is *Underwater* (Bowen 2012) where, instead of using scientific data collected from a buoy, it is used a *Kinect* camera placed on a tripod pointing to the sea and capturing three-dimensional data from the water surface. This data is them used to give motion and shape to a grid dynamic suspended surface, also controlled by strings and motors on the ceiling[39].

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38 *Tele-Present Water*, author's description. <http://www.dwbowen.com/telepresentwater> Accessed 2015.06.17.

39 *Underwater*, author's description. <http://www.dwbowen.com/underwater> Accessed 2015.06.17.
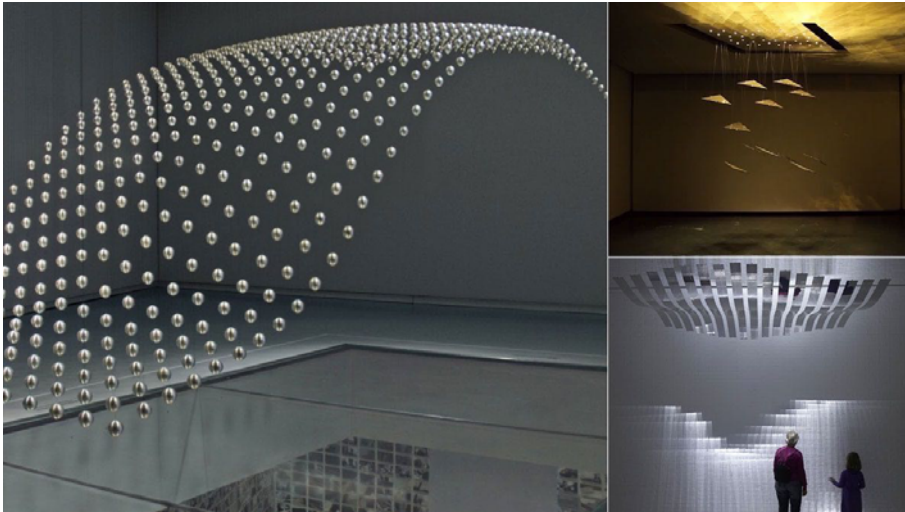
Fig. 45: *The Shape of Things to Come* (Art+Com 2008); *Resonance* (Art+Com 2012); *Tri* (Art+Com 2013)

The dynamic suspended grid structures used by Bowen have been widely use by many artists to create kinetic sculptures and express movement. Some of the most well-known are the ones created by the studio Art+Com[40], where *The Shape of Things to Come* (2008), *Resonance* (2012), *Tri* (2013) are good examples. In all of them a structure made by a grid composed by independent objects (sphere, squares and triangles) is suspended in the ceiling by strings, and each one of the objects act like a three-dimensional pixel that works together with all the other objects to shape an unified form. Motors on the top control the length of the strings giving motion, tension and expressivity to the sculpture. Unlike Bowen's sculptures that were moving according to captured data and could achieve unpredictable results, the motion of these ones are pre-defined and sequenced, delivering precise three-dimensional dramatic and abstract choreographies.

Fig. 46: *Straight & Arrow* (Manabe 2012)

Finally, on *Straight & Arrow* (Manabe 2012) a series of electrical wires are placed on specific locations over the skin of human performers. Then in synchrony with the music electrical shocks are triggered causing uncontrollable body reflexes and the movement of that specific body part, creating this way an human sound visualizer.

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40 <http://artcom.de>. Accessed 2015.06.17.

3.4 SELECTED CASE STUDIES

This section collects a selection of projects that explore different *input* and *output* relations and different transformations of digital data between *Sound*, *Visual* and *Movement* domains. The selected projects cover a wide range of possible setups and configurations within the three domains, and they were selected with the aim of serve as case studies for the development of the framework for classification of audiovisual interactive artworks.

The main rule for selecting the artworks as case studies is the focus on projects with interactive systems made for dance performances, performing interfaces, installations and immersive spaces, where the three domains are present, and where processes of transformation and translation occur between them in real-time.

Most of the artworks were selected from the projects on the *S-V-M*[41] blog. The selection process varies from case to case, but the main focus was to cover the maximum possible number of variations and combinations on the relations between *Sound*, *Visual* and *Movement* domains, in a way to gather a wide range of different interactive systems' configurations. Some projects — as *Soft Revolvers* (Bleau 2014), *Quadrotor Show* (Marshmallow Laser Feast 2012), *Laser Forest* (Marshmallow Laser Feast 2013) or *Epizoo* (Antúnez Roca 1994) — were selected due to their rare or unique interactive configurations and relations between domains. In the cases of more common setups and technical approaches (as in dance performances), the selection of these cases over other similar ones was made due to the fact that they stood out on their conceptual, artistic or visual outcomes, or had a more strong proximity to our artistic practice and research interests.

Messa di Voce, *Manual Input Sessions* and *Apparition* were the first projects to be selected, due to the fact that they are important references and inspirations to our artistic practice. As they were key triggers that guide our path on the interactive art field, and helped to trace and define the groundworks of this research.

All the artworks contain the three domains in the system and are divided in two different groups: *Interactive Spaces/Installations* and *Stage Performances*. Some of them are hybrid and can be presented in both forms, as performance works used by experts*,* or with a explorative approach presented in an exhibition and being used by visitors. Both places, stage and exhibition space, provide the opportunities for interaction with audiovisual systems. Due to their characteristics these spaces can be easily transformed into mixed reality places with total synchrony of movement, sound and light with huge potential to engage the audiences and build alternative virtual worlds. According to Dantes (1997): "Such environments can provide a new kind of place through which our minds may float among three-dimensionally extended yet virtual forms".

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41 <http://s-v-m.tumblr.com>. Accessed 2016.04.17

3.4.1 STAGE PERFORMANCES
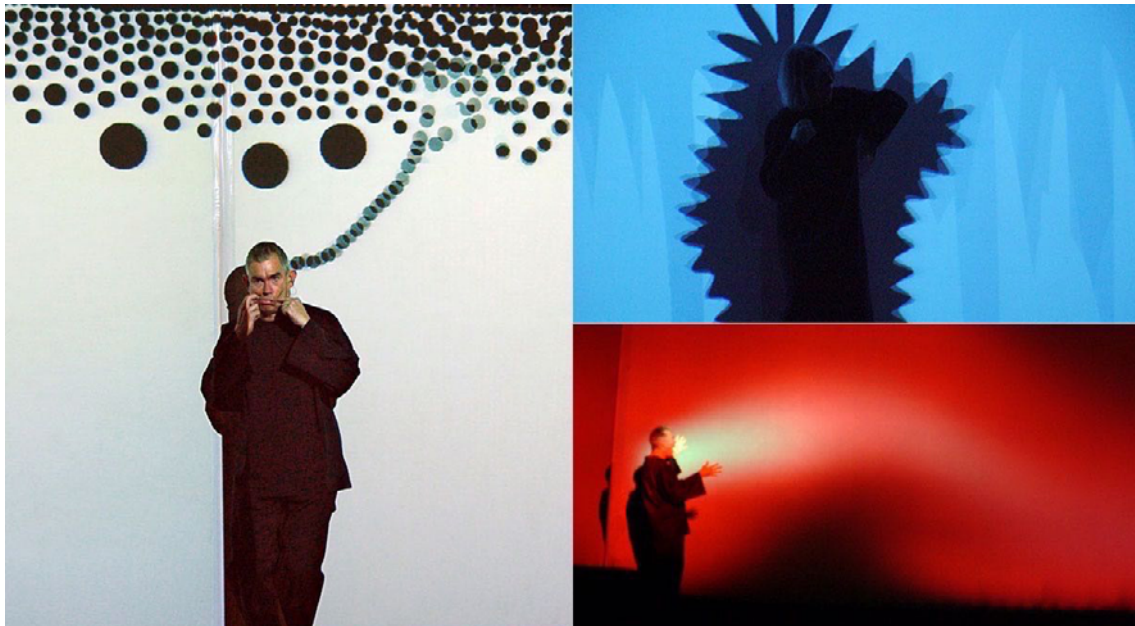
Fig. 47: Different scenes from *Messa di Voce* (Levin et al. 2003): *Bounce, Insect Nature Show and Fluid.*

Messa di Voce (Levin et al. 2003) is an audiovisual performance where sounds from singers' voices are augmented into a virtual space. The space of the interaction is composed by a big projection in the back of the stage where the interactions are visualized. A frontal camera detects the performer's silhouette and uses this information to interact with the virtual elements.

The performance is divided in twelve diferent scenes, which one with a different interaction between the vocal sounds of the performers and the visual methafors. After being vocalized the sounds are materialized into a virtual world in the screen, and performers can interact with them. In scene number four, titled *Bounce*, the performer emits vocal sounds that are visualized as black floating bubbles with sizes proportional to the emitted sound's amplitude. The bubbles are created in a position coincident with the performer's mouth and will flow around and fill the space. After some time, they become unstable and start to fall, colliding with the performer's body and the floor.

In scene number six, *Insect Nature Show*, the performer's silhouette is visualized in the screen and the border of the silhouette is audio reactive, creating shapes that look like strange animals. In the following scene, *Fluid*, a glowing fluid grows in the mouth of the performers when they speak, giving a physical form and visualization to the speech. Along all the scenes different metaphors and interactions are explored creating this way a set of different relations between physical bodies, movement, sound, virtual elements and graphic shapes.[42]

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42 *Messa di Voce*'s online documentation.
<http://www.flong.com/storage/pdf/reports/messa_report_600.pdf>. Accessed 2015.05.22

Fig. 48: *Manual Input Sessions* (Levin and Lieberman 2004)

Manual Input Sessions is another project developed by Levin and Lieberman (2004), an audiovisual instrument developed for a live performance (and later presented as an installation). In this performance, hand gestures are used for audio and visual creation (Levin and Lieberman 2005). The user's hands are analyzed by a computer vision system and their silhouettes are extracted and used to create graphic forms which are in turn used as data for sound synthesis.

On top of this system the authors have created several different instruments (or playing modes), where each one of them has different rules and operating modes. As an example, in the instrument *NegDrop,* the interior contours (or negative shapes) of the performer's hands create virtual objects. When the performer opens the hands the negative shape is destroyed and the object falls into the button of the projection area, emitting a sound when colliding with the border. The sound is generated according to a series of parameters: the area of the shape determines the pitch, the collision energy the volume, the horizontal position determines the stereo pan location and the compactness/pointiness the timbral brightness. In other mode, the *Inerstamp* instrument, a shape is also defined by the negative shape of the performer hands. But the shape, instead of being released, is held in the performer's hands. While he is holding the shape, the sound is generated and the user is able to modulate it in real time (Ibid.).
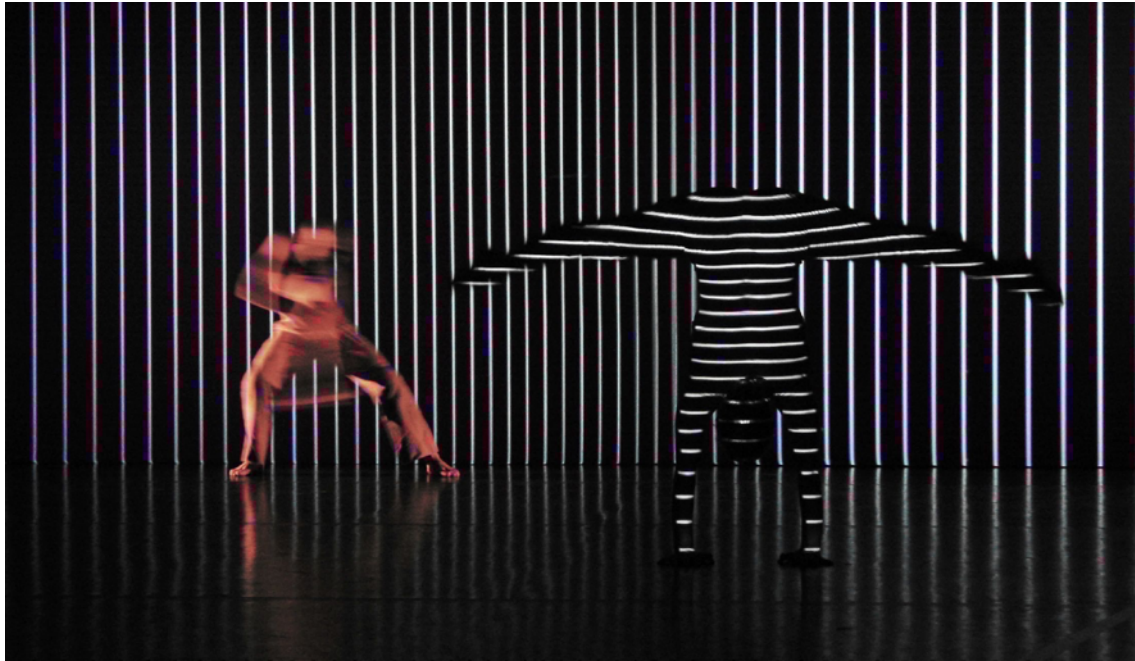
Fig. 49: *Apparition* (Obermaier 2004)

Apparition (Obermaier 2004) is an interactive dance performance where performers in front of a big projection interact with different dynamic and abstract virtual spaces. The movement of the dancers is tracked by a computer vision system and different motion parameters (like speed, direction, intensity and volume) are extracted and used to interact with different minimalistic graphic elements along a set of diverse scenes.

In one of the most recognized scenes of this performance, the body of the performers is used as surface for mapped projections. Their presence blends with the stage, physical body and virtual world can barely be distinguished. A computer vision system tracks the dancer's silhouette through a frontal camera, then their shape is used as a mask for the mapped projections, and a kinetic projection surface is achieved. Aside from being actors in this mixed reality, the performers are also layers of the virtual space itself and their body dynamics and features are transferred to the architecture of the space, which can be expanded and contracted and made fluid or rigid depending on the performer's movement.

Obermaier seeks a "kinetic space where the beauty and dynamics of the human body and its movement quality are extended and transferred into the virtual world"[43].

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43 *Apparition*'s online documentation.
< http://www.exile.at/apparition/project.html >. Accessed 2015.05.22

Fig. 50: *Anatta* (Delev and Gruberska 2014)

Anatta (Delev and Gruberska 2014) is an interactive dance performance where an interplay is created between movement, sound and an immersive projection space composed by a floor and back projection. The movements of the dancer are tracked by a laser ranging device and a set of parameters (position, velocity and some specific actions like jumps) are extracted and sent via OSC into the system to manipulate sound and visuals. The projected visuals are set in an abstract, minimal and black & white imaginary and depending on the scene are deformed and shaped by the dancer's movement. In some scenes the dancer is moving around and leaving a white path behind, in others a white shape is drawn around the dancer extremities changing its dimensions according to the dancer positions, or in other a set of horizontal lines crossing the stage are positioned according to the dancer. In the sound domain the movement data is used to triggers sound samples and manipulate filters, effects and synthesizers. The performance is divided in different scenes where the type of interactions, mappings an audiovisual content vary.

Besides the established influence that the dancer's movements cause on the sonic and visual domains, these last two also are interconnected. The generated sound is analyzed and its frequency data is sent back to the visuals domain and used as parameter for the creation of visuals. This way the visual domain is affected by the movement and sound at the same time. The dancer, on stage, is in control of the interactive system that defines the performance's audiovisual content, being able to trigger and manipulate sound and visuals and change its scenes. But at the same time, an off-stage operator is also able to change and manipulate certain parameters, creating a dialogue and relation between the exterior manipulator and the internal performer. The control that the performer holds allows him to improvise and play in between the established cue points in the performance's script, generating and simultaneously interacting with the visuals, creating this was a feedback loop of creating and reaction.[44]

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44 *Anatta*, informations and technical details from the performance taken from a conversation by email with the author Viktor Delev, on September 2014.

Fig. 51: *BioMeditation* (Beira and de Quay 2014)

BioMeditation (Beira and de Quay 2014) is an audiovisual performance that uses an electroencephalography (EEG) brain interface as a sensor for live interaction. It connects the body to brain activity, merging the physical world with the psychic dimension and translating the performer cognitive and emotional signals into sound and visual compositions in real-time.

From the continuous stream of brainwaves, a series of data mappings are extracted like *concentration* and *meditation* levels or *eyes blinking*, and specific actions like *levitating an object*. These are used to manipulate sound and visual effects parameters creating a perfect synchrony between body, brain, sound and visuals. Besides the brain waves, the EEG interface has a gyroscope which allows to extract data related to the rotation and orientation of the performer's head.

The visual content is generated in real time through a Kinect depth camera, producing a three dimensional mesh visualization of the performer's body. A virtual camera, also controlled by the EEG data, travels around the performed virtual representation and zoom in an out. The audio, also generated in real time, is created trough granular synthesis and modulated by the brainwaves using different mappings strategies along the structure of the piece. At the same time some visual details also react to sound analysis delivering this way a continuous control and relation between the performer, physical and brain activity, sound and image.

During the piece the performer is trying to achieve a high level of focus and meditation, but at the same time he is being exposed intense light and sounds, creating a biofeedback loop where both, the performer's brain data and the audiovisual environment are affecting and reacting to each other.

Fig. 52: Performer interacting with floor projection in *Gameplay* (Schmitt, Matos and Holst 2005)

Gameplay (Schmitt, Matos and Holst 2005) is an audiovisual interactive dance performance where the language and structures of video-games are explored as narrative and blended with the choreographic language.

The piece is divided in twelve scenes, or levels, with different audiovisual content and different rules for the interaction. In each one the dancer faces a semi-autonomous environment that react and evolves with his presence and actions. A camera on the top tracks the performer movements and its data is used as input into the audiovisual system influencing and interacting with it, the dancer sees and hears the interaction that he has created and reacts to it. The performance is a mix of prewritten movements and sequences with improvisation, that besides the clear game rules in each level has a great importance in the piece. The improvisation comes from the interactive system, that is semi-autonomous and in a way unpredictable and the improvisation from the dancer who has to find a way to face the challenges of each level. System and dancer create an interactive dialogue that evolves along the performance and makes each presentation unique.[45]

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45 *Gameplay's* informations and technical details from the performance taken from a conversation by email with the one of authors Antoine Schmitt, on September 2014.
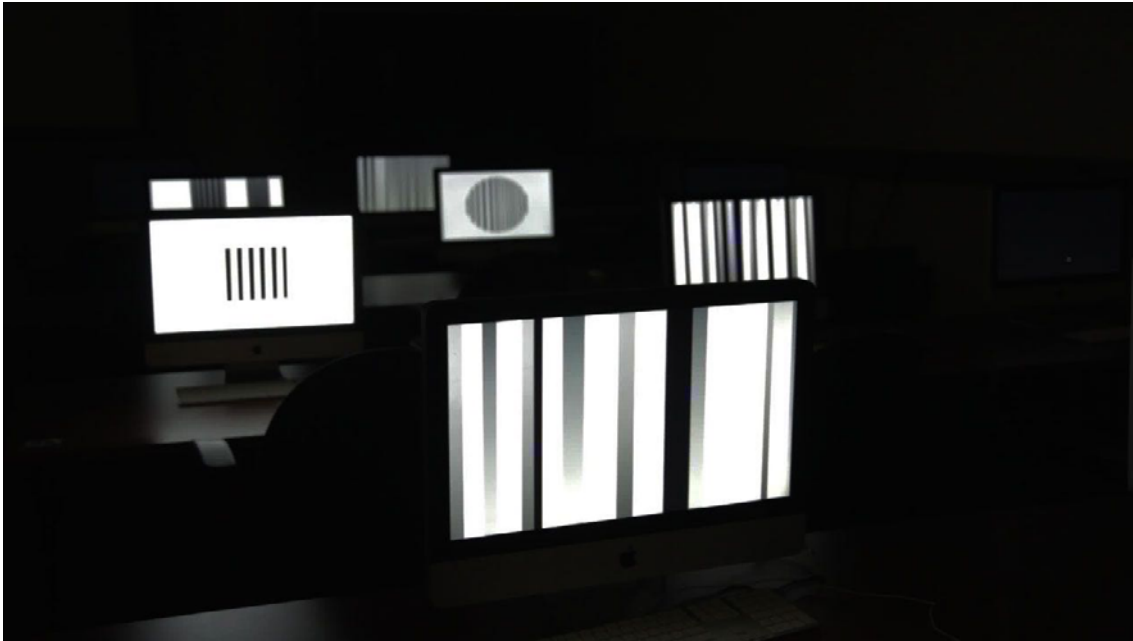
Fig. 53: *(Glitch) Music For a Computer Classroom* (Maheu 2013).

(Glitch) Music For a Computer Classroom (Maheu 2013) is an interactive audiovisual performance where the movement from hand gestures is used to manipulate sound and visuals. The performer is standing in front of group of computers and screens and acts like a maestro making hand gestures in the air that are captured by a Kinect camera and sent to the audiovisual system.

The computers are placed around the room and each one acts as an autonomous machine with a predefined programmed algorithm for the sound generation and tuned in different pitch and frequencies. When the performer makes gestures in the air, the position and speed of each hand are tracked. The position defines which computers are activated in every moment and the speed influences the frequency and volume of each one. The *Kinect* camera is looking for a virtual square area in front of the performer, when he moves his hands its position in the virtual square are mapped to a position on the real space and matched with specific computer. This way the performer is able to choose and activate the desirable machine with its specific sounds and visual compositions[46].

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46 *(Glitch) Music For a Computer Classroom,* informations and technical details from the performance taken from a conversation by email with the author Serge Maheu, on September 2014.

Fig. 54: Myriam Bleau performing *Soft Revolvers* (2014)

Soft Revolvers (Bleau 2014) is a live performance where four spinning tops act as interactive device to manipulate sound and visuals in real time. The performer makes the tops spin and their rotation is used for generating light and sound. The tops are equipped with gyroscopes and accelerometers to capture their rotation, the motion data (speed, unsteadiness at the end of a spin, acceleration spikes in case of collisions) is sent wirelessly to a computer where a custom software generates and controls the sound. During the performance, different mappings and approaches are used, so it allows a wide range of flexibility and expressiveness. In the first section of the performance the rotation controls the pitch of different sound samples, much like scratching loops, on this approach the relation between the spinning and the sound output is very explicit, helping this way to transmit the function of the device to the audience. Later on the performance other approaches are used, like using the speed of the rotation to control the tempo of a percussive element, creating rhythmically unstable moments or using the top to playback pre-recorded sound, much like a vinyl.

The tops are also equipped with a strip of LEDs that reacts with the sounds that are being generated creating this way lightning effects, sound visualization and hypnotic shapes due to the rotation patterns. The lights are controlled by the amplitude envelope of the sounds, creating this way a direct visual and aesthetic response. Also, a camera on the top of the stage captures the performance and its video feed is projected behind the artist, in a way the audience can watch a visual feedback during the performance.[47]

47 *Soft Revolvers'*s descriptions and technical details from a conversation by email with the author Myriam Bleau, on January 2016.
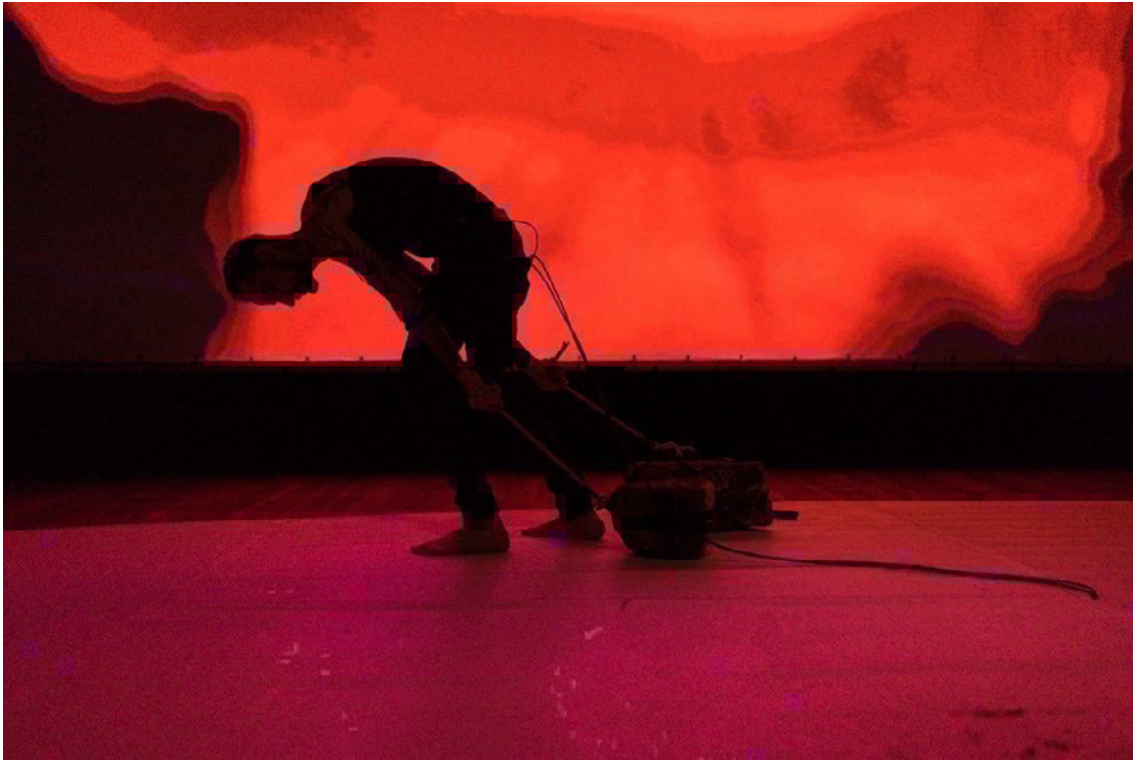
Fig. 55: Performer pulling the 50kgs concrete blocks on *Hypo Chrysos* (Donnarumma 2011b)

Hypo Chrysos (Donnarumma 2011b) is an audiovisual performance that uses bioacoustics signals as input to generate sound and visuals. On stage, a performer equipped with Xth Sense sensors (a biophysical sensor capturing the sound of muscles, hearth and blood (2011), pulls two concrete blocks in a circle.

The physical effort and body movements, made by the performer to hold and pull the concrete blocks, which weighs about 50kg, is the central point of the performance, and it is dramatized and expressed into real-time audiovisuals. The sound of muscles contracting, of blood flowing and other bodily sounds are captured by the sensors and sent to the system where they are amplified, distorted and manipulated, generating the performance's soundtrack. At the same time, the data from the Xth Sense sensors is also used to generate real time visuals, feeding swarming particles, lights' parameters, and organic forms.[48]

48 *Hypo Chrysos*' online documentation.
<http://marcodonnarumma.com/works/hypo-chrysos/>. Accessed 2016.02.19

Fig. 56: Performer interacting with the visuals on *Luxate* (Beira 2015)

Luxate (Beira 2015) is an audiovisual dance performance that explores body movement together with light and space perceptions. On stage an array of video projectors throws light beams in space creating multiple geometric dimensions and shaping various space perceptions. The video projectors are not used to project images on a screen but to create volumes in space. Inspired by the work of Anthony McCall, specifically *Line Describing a Cone* (1973), Beira uses the sculptural qualities of light beams, with the help of smoke and haze, to create volumes in the three-dimensional space.

The performer's body is tracked by a Kinect camera, and its motion data used to control in real time graphic visual parameters. During the performance the narrative goes through a series of different generative visual shapes, and the performer's body is mapped with simple interactions to different visual parameters, like controlling the rotation of lines through the arms rotation.

The performance soundtrack is predefined, and the different visual sequences and scenes are synchronized with it in a timeline. However specific sound effects and audio mappings are controlled by the body movement.[49]

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49 *Luxate*'s descriptions and technical details from a conversation by email with the author João Beira, on January 2016.

Fig. 57: Three-dimensional shape formed by digitally controlled balloons on *Atom* (Henke and Bauder 2007)

Atom (Henke and Bauder 2007) is an audiovisual performance where sound is mapped into mechanical movement, modulating shapes on kinetic sculpture. The space is filled by an eight-by-eight array of helium balloons. Each balloon is attached to a cable controlled by a motor, in a way that the balloon can go up and down depending of the amount of cable that is released by the motor (the helium gas pushes the balloon up, and the motor controls its height by releasing or pulling the cable). The sound played by the performer is mapped into commands to the motors, moving the balloons vertically and producing dynamically patterns and shapes in the air.

At the same time LEDs light inside the balloons are triggered driven by MIDI notes sent from the sound synthesis in Ableton Live. A Max path receives the MIDI notes and through different cloud and movement statistical algorithms defines synchronous mapping between the incoming music events and the light patterns, transforming the space and giving new dimensions to the sound sculpture.[50]

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50 *Atom*'s online documentation. <http://www.roberthenke.com/concerts/atom.html>. Accessed 2016.02.16
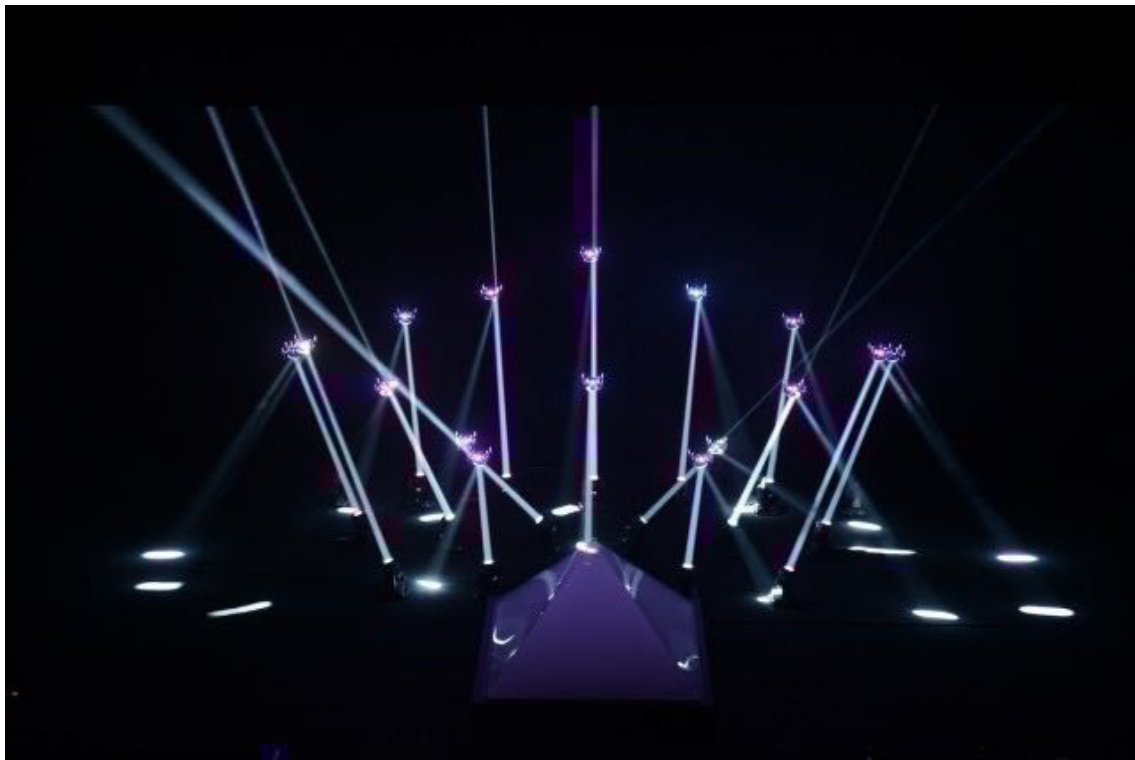
Fig. 58: Dancing drones on stage from *Quadrotor Show* (Marshmallow Laser Feast 2012)

Quadrotor Show (Marshmallow Laser Feast 2012) is a live audiovisual kinetic show performed by drones, motorized mirrors and moving head spotlights. It explores relations between movement, form and sound using the drones as programmable vertices in space. On stage a group of sixteen semi-autonomous computer-programmed UAVs (Unmanned Aerial Vehicles) perform choreographed patterns in the middle air. Each one of them has on its body a LED light and a mirror (controlled by a mechanic arm).

On the floor, and array of sixteen moving head spotlights receive the drone's position data and point a light beam to each one. When the light beams touch the drones it is reflected away by its mirrors, which can be pointing down or sideways, creating this way three-dimensional shapes in the middle air.

Each drone has a precise choreographed path to follow, however while in the air many events can cause disturbances to their flight, like network delays and specially wind caused by others drones. This causes as chain reaction effect with each one trying to self-correct they position in order to follow the pre-defined path. The result is that the precise paths defined by the humans gain organic and expressive features as a result of the machine's behaviors.[51]

51 *Quadrotor Show*'s online documentation.
<http://www.memo.tv/meet-your-creator/>. Accessed 2016.02.16
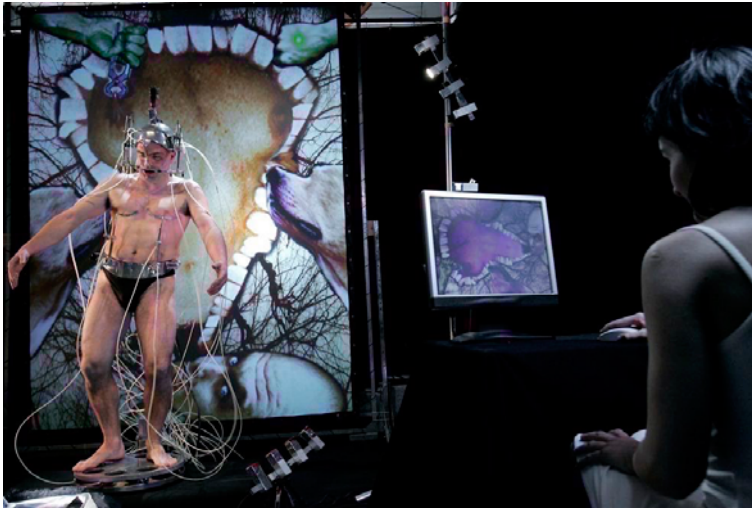
Fig. 59: *Epizoo*'s performer, Marcel.li Antúnez Roca on stage with
the exoskeleton, and in front a spectator interacting with a computer mouse.

Epizoo (Antúnez Roca 1994) is an interactive mechatronic performance, where a pneumatic exoskeleton is attached to a performer's body[52]. Through a mouse and a graphic interface, the audience is able to control the different mechanism of the robotic exoskeleton and thus also to manipulate the performer's body.

The different mechanisms that compose the exoskeleton are able to move the performer's nose, buttocks, pectorals, mouth and ears and through a series of eleven interactive scenes the audience is able to control different parts of the performer body as well as lights, video projections and sound. In this way each performance is decided by the spectators, the performer and all the interactive content and standing on stage, waiting for the spectators inputs to be triggered.

Fig. 60: The stage of *Symphony #2 for Dot Matrix Printers (The User 1999)*

Symphony #2 for Dot Matrix Printers (The User 1999) is an audiovisual music performance executed by fifteen personal computers and fifteen dot matrix printers.[53] The printers work as audiovisual instruments controlled by an orchestra of computers. They play

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52 *Epizoo'*s online documentation. <http://marceliantunez.com/work/epizoo/>. Accessed 2016.08.05

53 *Symphony #2 for Dot Matrix Printers*' online documentation <http://www.undefine.ca/en/projects/symphony-for-dot-matrix-printers/symphony-2/>. Accessed 2016.08.05

by printing and moving its mechanisms, its mechanical sounds are captured with micro-phones and used as textures, tones and rhythms for music creation. Each printer also con-tains video cameras to capture its motion patterns, which are them projected on screens, on stage behind the machine orchestra. The printers movements are scored on ASCII text compositions that are sent in real time through a network server as a serial command to each one of the computers controlling the correspondent printer. The movements pro-duced by the printers are used an aesthetic resource on this audiovisual performance.

3.4.2 INTERACTIVE SPACES / INSTALLATIONS

Fig. 61: One participant, inside one of telematic space from *The Trace* (Lozano-Hemmer 1995)

The Trace (Lozano-Hemmer 1995) is an audiovisual installation that takes place in two different rooms at the same time, which invites the participants to share a telematic virtual space[54]. Both interconnected spaces are equipped with a rear-projection on the ceiling, robot lamps on the ceiling, a small side monitor and an array of speakers spread around the space. Each participant holds a wireless sensor that transmits his/her position on space. The robotic lights, projections and screen react to each participant movements revealing their position and behaviors, in a way that each participant has a visual and sonic feedback of the participant in the other room. The goal of *The Trace* is to lead both partici-pants to *telembody,* in other words to make them occupy similar positions in space.

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54 *The Trace*'s online documentation. <http://www.lozano-hemmer.com/the_trace.php>. Accessed 2016.08.05
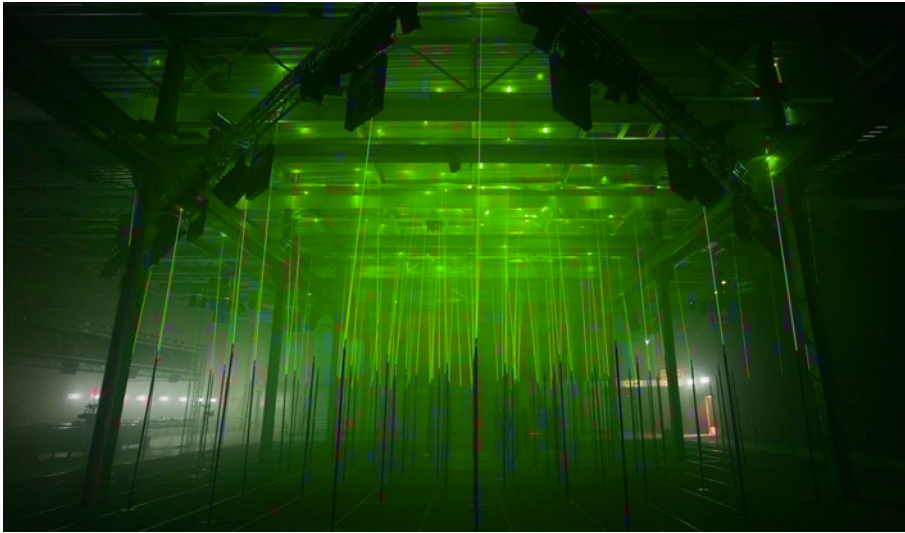
Fig. 62: Immersive environment on *Laser Forest* (Marshmallow Laser Feast 2013)

Laser Forest (Marshmallow Laser Feast 2013) is an interactive space filled with one hundred and fifty trees made of flexible rods with green lasers on the top. The space works as a big light and sound instrument where visitors are invited to walk around and play with trees by shaking them, creating oscillations and swings that will originate light and sound vibrating patterns.

The laser emitter on the top of each tree is connected to the rods by a spring that besides causing the oscillating of the laser beams also holds a sensor measuring the amplitude of each oscillation and uses it as an envelope for the sound. The relation between the movement of the trees and the sound and light compositions produced is very tight, and it is strictly related with the mechanical representation of the vibration. So the strength with which the tree is shaken influences the output produced, allowing this way a huge range of expressive possibilities. When the space is empty a very subtle sound is produced, triggering random notes suggesting the wind blowing in the middle of the forest. Each tree has a specific tune creating this way a spatialised sound composition.[55]

Besides being an interactive responsive space waiting for the visitors to revel itself, the *Laser Forest* was also used in the form of a stage performance at the STRP Biennale 2013, where a group of children was choreographed to move around the space with specific paths and time cues delivering an audiovisual concert of lasers beans and futurist forest sounds.

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55 *Laser Forest*'s informations and technical details from the project taken from a conversation by email with one of the authors Memo Akten, on September 2014.
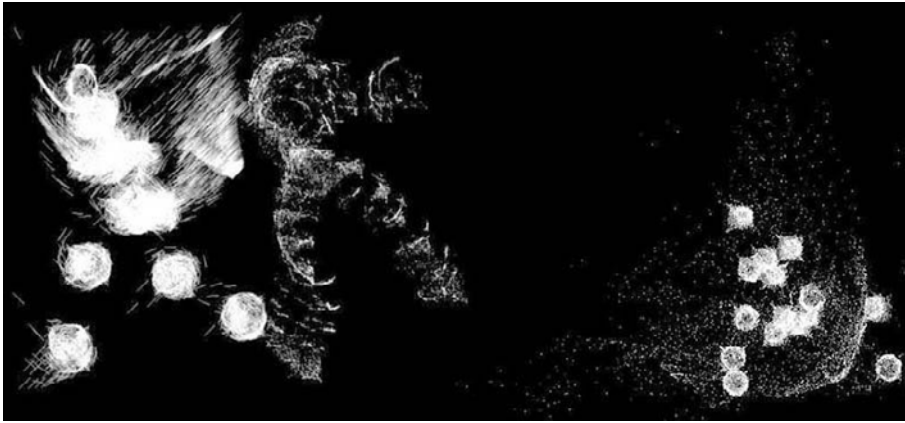
Fig. 63: Swarming particles visualizations from *Will.0.W1sp* (Woolford and Guedes 2007)

Will.0.W1sp (Woolford and Guedes 2007) is an interactive installation that explores the "ability to recognize human motion without human form" (Woolford 2007), and uses body movement to control the behavior of a particle system and generate sound.The motion data comes from two sources, one captured in real time from the installation visitors, and the other from pre-recorded motion captured sequences. The installation is constantly working and the particle system flows around the projection, the particles, fed by the pre-recorded motion data, form the shape of the human body. Sometimes the particle system loses the human shape, others it presents a very close human shape and it also jumps from sequence to sequence. These behaviors are defined by the presence and movement of visitors in the interactive space.

The motion data used to feed the particle system is also used to generate sound. Melodies, crickets, goat bells, and scruffing sounds are generated and mixed live using the data from the recorded sequences that determines the flow and position of the particles and also the real time motion from the visitors in the space (Ibid.).
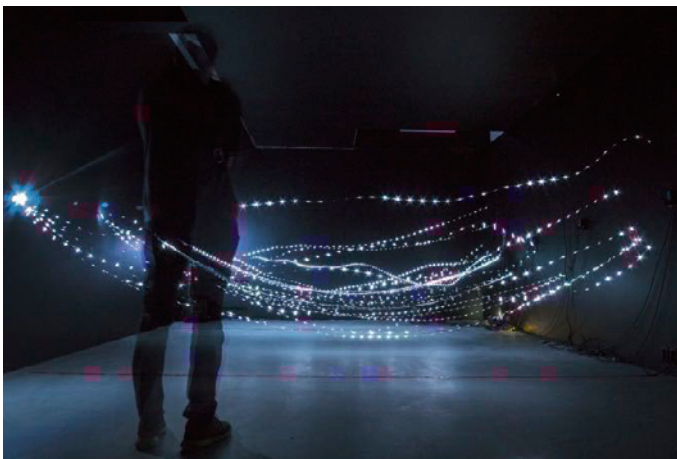
Fig. 64: *Wave is My Nature* (Vtol 2015)

Wave is My Nature (Vtol 2015) is a kinetic spatial installation, a responsive space where a robotic light structure reacts to the audience's presence and creates an autonomous robotic, sound and light composition. The kinetic structure is composed by stretched cables with LED strips on the tops, and it is moved by a system of servo motors.

The installation explores the concept of *Waves*, both as sound, light and tangible waves. Through its kinetic system the stretched cables, with the lighting tops, are moved and rotated around the space with precise velocity and amplitude creating physical waves in the space. A series of infrared motion sensors detect the presence of the audience in the room, using its data as input to generate movement through the motors and sound. A soundtrack relating to the waves' movement is also generated in real time, creating this way an immersive audiovisual space where sound, physical movement and light connected and delivering a synesthetic environment where sound and movement are visualized and light and movement are sonified.

Fig. 65: *AXIAL* (PlayMID 2014)

AXIAL (PlayMID 2014) is an audiovisual immersive space where a group of sixteen motorized light beams, a series of RGB fixtures, plus strobe lights and smoking machines are choreographed with a synchronized soundtrack, creating a dynamic dance of light in space. The audiovisual space has the shape of a corridor or tunnel, where on each side of the space a row of eight motorized light beams is placed. It is a passage through which the audience crosses and is involved by a synesthetic audiovisual and spatial composition.

Dynamic movements on the beams' motors and lights' behaviors are developed in sync with the sound design, creating this way an evolving soundtrack and light architectures. The use of smoke helps to give physicality to the light beams, creating three dimensional lines in the air, shaping the space and redefining its geometry.

Axial's audiovisual system is driven by a digital timeline where all the parameters are scored and triggered in real-time (motor pan and tilt positions, light intensity, RGB values for the lights and audio parameters for the sound synthesis).

The audience also has the power to interact with the audiovisual creation through an interactive device placed on a desk inside the space. Through hand gestures the audience can manipulate movement and light parameters, as well sound, turning *Axial*'s "in a 21st century fully playable audio-visual instrument."[56]

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56 *Axial*'s online documentation.<http://playmodes.com/web/wp-content/uploads/2014/04/axial_document_4.pdf>. Accessed 2015.05.22

Fig. 66: *Spectra-3* (Field 2016)

Spectra-3 (Field 2016) is an audiovisual light installation based on a kinetic physical sculpture. The sculpture, mimicking the shape and movements of a radio telescope, is the protagonist of choreography of movement, animated light an spatialised sound. It is a score driven piece where, despite being running in real-time, all the movement, sound and light events are predetermined on a timeline. A custom software controls a timeline where all the events are specified accurately over the time. This way the parameters to control movement, lights and sound are triggered synchronously developing the piece's narrative that relates to communications, and metaphors of traveling into space and through time. Vera-Maria Glahn, one of authors and founders of FIELD studio, explains on an interview why it was chosen to present the piece as a score-driven performance: "We are trying to get it very synchronized – a very tight experience to make it a really immersive piece, as if you were watching theatre"[57]. However, despite the tight control on every parameter of the physical/digital sculpture the output has a certain level of unpredictability and serendipity on how the light reflect on the environment. The real-world conditions and the place where the piece is installed changes dramatically the output of the light reflections.

Fig. 67: *Cloud Piano's* mechanism (Bowen 2014)

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57 Vera-Maria Glahn (FIELD studio) interviewed for Creative Review UK<https://www.creativereview.co.uk/cr-blog/2016/january/lumiere-2016-field-studio-discuss-their-audio-visual-sculpture-spectra-3-as-the-light-festival-arrives-in-london >Accessed 2016.01.22

Cloud Piano (Bowen 2014) is an autonomous mechanical installation that uses as input images from the sky and the shapes of clouds to play a piano. A camera is pointing to the sky and grabbing images in real-time that are then mapped, by a custom software, over a representation of the eighty-eight piano keys. When the sky has clouds, its shape will be visualized overlapped with the representation of the keys of the piano, and the keys with clouds will be played as long as the cloud stays over it. A robotic mechanism with eighty-eight robotic arms was built over a piano and is waiting for orders from the software, when a key is activated the mechanisms moves and the desired key is pressed.

The system works by continuously grabbing and sonifying the sky ambience, when the clouds move and change shape different keys are played resulting in different patterns and music compositions representing the soundscape of the sky[58].

Fig. 68: *Deep Web's* immersive audiovisual space (Henke and Bauder 2016)

Deep Web (Henke and Bauder 2016) is an immersive audiovisual installation where a three-dimensional structure of floating lines and spheres moves in synchrony with and array of lasers and a 8 channel surround soundtrack. Resembling Xenakis's *Polytopes,* it is equipped with twelve high power laser systems and a luminous architectural structure with 175 motorized spheres placed 10 meters off the ground. The audience, on the floor, contemplate the choreography of movement, sound and light, where with a precise synchrony the spheres move up and down and are illuminated by blasts of laser beams that shape the architectural space and create luminous analogies of nodes and connections on digital networks.

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58 *Cloud Piano*'s online documentation. <http://www.dwbowen.com/cloud-piano> Accessed 2015.06.22

3.4.3 NOTES ON THE SELECTED CASE STUDIES

Table 1, presented at the end of this section, gathers all the projects collected in this section and describes their relations of input and output of data between the _Sound, Visual_ and _Movement_ domains.

The most common situation are the ones where data from _Movement_ is used to generate or control _Sound_ and _Visuals._ We can observe that configuration mostly on stage performances, where the movement of dancers is tracked and motion data is used to interact with the audio and the visual system, like in _Anatta_, _Apparition_, _Gameplay_, _BioMeditation_, _Luxate, Hypo Chrysos, The Trace_ or _(Glitch) Music for a Computer Classroom._ But despite the similarities between them, each one has differences in its configuration which results in distinct outcomes and interaction expressivity. In _Gameplay_, motion tracking data from the performer flows from the _Movement_ domain and is used as an input in the _Visual_ and _Sound_ ones. _Anatta_ has a similar configuration but with the addition that the _Visual_ and _Sound_ also have a relation between them. Motion data is used as input to control parameters in the visuals and sound but additionally sound is analyzed and visuals are constantly reacting to its frequencies. In _Apparition_ motion tracking data is also captured and sent to the Visual domain for live interaction but there is not a direct connection with the _Sound_ domain inside the system. Sound is out of the interactive system, it is used to sequence and choreograph the piece and during the live performance it influences the dancers movements but there is not any digital interaction. _Luxate_ is similar to the previous one. Body movement is tracked and used as input to manipulate visuals and the soundtrack is already predetermined, used as a timeline to choreograph and synchronize visuals and movement. However parameters from specific sound effects are manipulated live with the dancer's movements.

BioMeditation although being a stage performance it is not a dance performance like the previous examples. The performer is sitting on the stage floor, his body shape is captured and used to create a 3D mesh on the screen, and his brain activity's data and body gestures are used to manipulate sound generation and visual parameters. At the same time some visual parameters are also reacting to sound frequencies.

In _(Glitch) Music for a Computer Classroom_, although not being performed live on a stage but videographed, a performer's gestures data is sent to the system for sound and visual creation. _Hypo Chrysos_ shares the same _Sound_, _Visual_ and _Movement_ relations of the previous projects, but in this case the performers movement's it is not capture through the use of cameras and computer tracking but with biophysical sensors. Placed on the performer's body the sensors capture the sound of his muscles, hearth and blood while moving, and uses this bioacoustics signals as input into the interactive system to manipulate and generate sound and visuals. And on _The Trace_ the position tracking is made with a wireless sensor that each participant holds on his hand.

There are another set of projects as _Will.0.W1sp, Laser Forest_ and _Wave is my Nature_ that also share the same data-flow configuration (where movement is used as an input on _Sound_ and _Visual_ domains) but they are not performances but interactive installations. Using not the motion data from performers trained on that interactive system, but the audience who is most of the times exploring the system for the first time. On _Will.0.W1sp_ motion data from two different sources, pre-recorded and live, is used to define the

behaviors of a particle system on screen and its dynamic soundtrack, on *Laser Forest* the oscillations of a physical interface shape the visual space and modulate the sound, and on *Wave is my Nature* the presence and behaviors of the audience on the space triggers and manipulates kinetic movement, sound and lights.

On *Atom* the domains of the interactive system are inverted. The *Sound* domain acts as the input of data to manipulate kinetic movement and light control.

Messa di Voce presents a different configuration from the presented cases above. Instead of using data from one domain to feed two domains, it uses data from two different domains that converge into one. *Movement* and *Sound* are used as input to interact with the visuals on the screen.

On the other hand the following ones also present a different approach, where the configuration of the domains is sequential. They do not converge from two domains into one, or diverge from one into the other two, but they are transformed in sequence, data from one domain is transformed into another, and from that to the other one. On *Manual Input Sessions* hand gestures form shapes on the screen which are then used to generate sound. On *Soft Revolvers* movement generates sound that creates reactions on the visual side and on *Clouds* images from the sky trigger mechanical arms to play sounds on a piano. All three projects have their data transformation in a sequential structure, but each of them have the domains in a different order. Changing from: *Movement* to *Visual* to *Sound*; *Movement* to *Sound* to *Visual* and *Visual* to *Movement* to *Sound*.

Epizoo has slight different system from all the previous ones, where the input of the audience on a computer interface, what we can call external data, triggers mechanic and body *Movement*, *Sound* and *Visuals*.

Finally in *Axial*, *Spectra-3*, *Deep Web*, *Quadrotor Show* and *Symphony #2 for dot matrix printers* the interactive systems are following a predetermined timeline of events. Besides of being real time interactive system, its data does not come from real-time movement tracking, or sound and visuals parameters, but yes from a score where all the audiovisual and movement events have been stabilized. However on *Axial* and *Quadrotor Show* cases, beyond the predetermined timeline events, there are interactions in real-time between the domains. Such as the gesture's device on *Axial* with whom the audience can play with the installation as an instrument, and the movement tracking system that leads the moving head lights on *Quadrotor Show,* which can result on unanticipated actions due to the drones unexpected behaviors.

When mapping all this system configurations and data-flow layouts we can observe that *Movement* is a key and hybrid domain, as it can be presented in many different ways and interpretations. From human bodies dancing on stage, hand gestures or physical objects motion to robotic mechanisms. Also the different alternatives of configurations and domain transformations presented on each system define the interaction and artistic outcomes of each project and are used as a tool for improvisation and creative expressivity.

Table1: List of all the selected case studies and their correspondent relations between the *Sound*, *Visual* and *Movement* domains.

ARTWORK	DESCRIPTION
Epizoo **(1994)**	Audience controls through a computer's interface a mechanic exoskeleton and the performer's body. Also triggers sound, visuals and lights.
The Trace **(1995)**	Participants movements are tracked and used as input into sound, video-projection and lights.
Symphony #2 for Dot Matrix Printers **(1999)**	A score is sent by network to the printers. Printers' mechanisms respond and its movements are captured by microphones and videocameras and transmitted live
Messa Di Voce **(2003)**	Vocal sounds and body tracking generate and interact with visuals on the screen
Manual Input Sessions **(2004)**	Hand gestures create visual shapes that are then translated into sound
Appariton **(2004)**	Performers dance along the sound. Bodies are tracked to interact with the visuals
Gameplay **(2005)**	Performer's movements control/generate sound and visuals
Will.0.W1sp **(2005)**	Motion data (prerecorded and live) generates/controls sound and visuals
Atom **(2007)**	Sound that is being played is mapped into motors commands and lights to shape the sculpture
Hypo Chrysos **(2011)**	Bioacoustics signals by the performer's motions used as input to sound and visuals
Quadrotor Show **(2012)**	A predetermined timeline controls the drones' and sound. Moving head lights follow the drones through motions tracking
(Glitch) Music For a Computer Classroom **(2013)**	Performer acts like a maestro. Hand gestures, control and sound and visuals
Laser Forest **(2013)**	Trees' oscillations generate sound and shape the space with laser lights
Anatta **(2014)**	Performer's movements control/generate sound and visuals. Visuals react to sound
Axial **(2014)**	A predetermined timeline controls sound, lights and moving heads movements
Biomeditation **(2014)**	Performer's movements and brain signals manipulate and generate sounds and visuals
Cloud Piano **(2014)**	Pictures from the sky are mapped to play different notes on a mechanical piano
Soft Revolvers **(2014)**	Rotation and acceleration are generating sound, lights' color an intensity react to sound
Luxate **(2015)**	Body motion tracking manipulates projected light and sound effects
Wave Is My Nature **(2015)**	Presence of audience in the space triggers kinetic movement, sound and lights
Deep Web **(2016)**	A predetermined timeline controls sound, lights and moving heads movements
Spectra 3 **(2016)**	A predetermined timeline controls sound, lights and moving heads movements

4. SOUND + VISUAL + MOVEMENT

4.1 OVERVIEW

This chapter addresses the main topic of this dissertation: the relations between the *Sound*, *Visual* and *Movement* domains in interactive systems. It starts by explaining the perspective of this research on interactive systems and on the limits and boundaries of the domains. Due to the multidisciplinary of this field, this is a vital task, that leads to different definitions and approaches to similar terms.

After this it discusses a set of classifications of interactive systems collected from the literature on interactive and computer arts, each of the classifications are presented with different approaches and definitions, and tested with the selection of case studies presented on chapter 3.

Lastly, it is proposed a new classification, named *S+V+M*, a framework for classification of audiovisual interactive artworks based on the flow of data through the interactive system, specifically across the *Sound*, *Visual* and *Movement* domains. The *S+V+M* approach, goals, definitions and methods are presented and explained, and then each case study is then classified under the framework, along with a visualization of the flows.

4.2 *SOUND*, *VISUAL* AND *MOVEMENT* INTERACTIVE SYSTEMS

> *Thus, for example, participants' physical movements can cause sounds, or their voices can be used to navigate a computer-defined visual space. It is the composition of the relationships between action and response that is important. The beauty of the visual and aural response is secondary. RESPONSE IS THE MEDIUM! (Krueger 1991, 86)*

The artworks studied in this research are focused on digital systems for interactive installations and on stage performances where the three domains of *Sound*, *Visuals* and *Movement* are present. Our focus is on the processes of transformation, and interactions that occur across the domains (movement into sound, sound into visuals, movement into visuals, etc.) in each different system. Each of these domains can be either an input and/or an output of data on the system, and different articulations between the three can be explored, determining how the data flows through the system, the type of interaction and the expressivity of the artwork.

For the purpose of this study the term *interactive system* refers to digital systems where processes of interaction occur in real-time between the three domains, regardless to diferent levels of interaction or the presence of human input.

The idea of classifying an interactive artwork based on its configuration or the behaviors of its system can be traced to the beginnings of interactive art. In 1973, Stroud Cornock and Ernest Edmonds predicted the important role of the computer "defining the specification of the art work and also managing the real-time result of that specification" (Edmonds, Turner and Candy 2004, 1). An artwork could be described not only by its content but also by its system and the characteristics of their interactions, therefore, in interactive art it is useful to "think in terms of 'art systems' that embraced all of the participating entities, including the human viewer." (Ibid.)

In the third chapter we observed artworks with different system configurations, resulting in different types of interactions and outcomes. In some projects *Movement* is used as input into the *Sound* and *Visual* domains simultaneously (like in *Anatta* or *Gameplay*), in others *Movement* is used to generate *Visuals* and *Visuals* are sequentially used to generate *Sound* (*Manual Input Sessions*)*,* in others *Movement* and *Sound* converge to transform the *Visual* domain (like in *Messa di Voce*). Different variations are possible, and the way they are configured and how data flows through the domains can be used to describe and categorize a system, not through its level of interaction, a strategy that has already been widely covered in the literature, but rather through the data flows and transformations across these domains.

Another challenge is the definition of the artwork system itself, what is the proper definition of the systems to be included in the classification. Should it be called *Interactive*? *Digital*? *Electronic*? Which systems should be included or excluded? Is a system really interactive, or is it only reactive? The word *interactive* is often used very loosely or even inaccurately, "the question of whether one piece is 'more interactive' than another is one difficult to address without more accurate terms of reference" (Graham 1997, 38). Discussions on this issue are frequent in the field and many different approaches distinguishing

different levels and types of interactivity have been developed[1] over the years. Therefore, clearly defining the borders of our approach is extremely important in order to communicate with accuracy and coherence our objects of study.

Steve Dixon, on his research on *Digital Performance: History of New Media in Theater, Dance, Performance Art, and Installation* (2007), used the term *Digital Performance* in order to include a wide range of works "where computer technologies play a role rather that a subsidiary one in content, technologies, aesthetics, or delivery form" (3). The broad range of the definition "digital" allowed Dixon to include a wide variety of very different types of work from live stage performance with video projections and robotic or virtual reality performers, to interactive or telematic installations.

Kwastek on her book *Aesthetics of Interaction in Digital Art,* also used a wide definition of *interactive art* to state the objects of her study. The term *interactive art* is used on every case where processes of interaction are discussed, even if the system is not digitally mediated (2013, 9). The focus is on processes of interaction and on their aesthetics, and following the definition given by Soke Dinkla of *interactive art* that "serves as a category-specific designation for computer-supports works in which an interaction takes place between digital computer systems and users" (1970, qtd. in Kwastek 2013, 4), only projects where activation by users is required are included on her study. Kwastek excludes all the other systems that do not validate this premise, like self-sustained generative systems as an example (271), even if they are real-time interactive systems producing the artwork.

Whitelaw (1998) references the artworks presented at the *Cybernetic Serendipity* exhibition in 1968[2] and divides them in two categories: the first *generative*, exploring aesthetics of permutation, like drawing and painting machines, or pattern generators; and the second *post-objects* that are dynamic, processual, interactive or kinetic, covering artworks that contain "processes of interaction and response, translation across sensory-kinetic modes (sound into light, light into motion)" (Ibid.). However, despite the division in two categories Whitelaw defines all artworks as *Cybernetic Systems.*

The notion of *post-object* comes from Jack Burnham's articles *System Esthetics* (1968) and *Real Time Systems* (1969) where he addresses the cybernetic organism as an artwork (Dixon 2007, 103), and proposes an art system that contains *real-time information processing* and *interactive dynamics* resulting in pieces that are *post-object*s. The definition became popular among artists and writers of the time, like Paul Brown who stated: "Previously ... I had seen artworks as objects. Now they became processes" (quoted in Dixon 2007, 103).

All the previous definitions overlap the objects of study in this research. The case studies presented cover a wide variety of systems from autonomous interactive machines that do not need human input (like *Cloud Piano),* interactive installations waiting for human input (*Laser Forest*), audiovisual performances (*Atom* or *Soft Revolvers*), to interactive dance performances by human dancers (*Anatta* or *Apparition*) or by robotic ones (*Quadrotor Show).* They are *Digital, Interactive* and *Cybernetic,* and despite many differences in the processes, type of system, and presentation form of each one, all share the same goal of exploring interactive and dynamic process as creative expression.

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1 see chapter *2.6 "Audiovisual Interactive Systems"*

2 Cybernetic Serendipity: cybernetic art exhibition held in London in 1968, curated by Jasia Reichardt

The definition used on this thesis of interactive system is broader than Kwastek's (2013), as it includes cases where the human input is not a premise (like *Cloud Piano),* or where the dynamics of the piece have been pre-sequenced in advance (like on *Axial* or *Spectra-3),* similar to the category *score-driven,* given by Rowe (1992), on his classification of interactive music systems*.* The target projects of this research are then *post-objects* with *dynamic*, *interactive*, *kinetic*, *computerized* or *electronic* systems made for dance performances, performing interfaces, installations, explorative spaces, among others, where the domains *Sound*, *Movement* and *Visual* are present, and processes of transformation and translation occur between them in real time. The fact that these artworks have so many diverse characteristics raises the question of how can we describe coherently all these projects.

Categorizing interactive artworks presents many challenges and a variety of discords, as classification systems are often "subject to criticism, as they neglect the specific characteristics of individual works (…) in favor to generalization" (Kwastek 2010, 504). In the case of the field of interactive art, one of the biggest obstacles is the fact that this field is very multidisciplinary, composed by practitioners from many different areas where "the ubiquity of tools and the similarity of working methods, media and processes across artists and designers with diverse backgrounds, leads to a blurring of boundaries between practitioners and many of the fields where they are active" (Carvalhais 2010, 27). Creators with different backgrounds and approaches, from a wide range of fields from stage performance and visual arts to computer science or engineering, produce multidisciplinary work where each interactive system can achieve many different forms and outputs, use different technologies, and types and levels of interaction.

The strategy followed on this research of analyzing interactive systems focused on the relations and transformations across the *Sound*, *Visual* and *Movement* domains arises as a solution to frame all the different systems in a common language, relating them between what they have in common, and bringing together projects that are often separated by technical details, relation with the audience/participation type and levels of interactivity.

4.3 EXISTING CLASSIFICATIONS OF INTERACTIVE SYSTEMS

Along the history of *Interactive Art* field we can find several proposals for classifications that describe artworks based on their interactive properties. They were conceived to help tho analyze and contextualize each work by identifying parameters of comparison between them.

In this section, we present nine different classifications, chosen due their key roles in the literature, and the fact that they cover or overlap the topics, approaches and goals of this research, being an important contribute to the development of the *S+V+M* classification. The case studies selected in the previous chapter are then categorized under the features of each classification.

4.3.1 *Static*, *Dynamic* and *Varying* Systems

An early classification was made by Stroud Cornock and Ernest Edmonds on their article *The Creative Process Where the Artist is Amplified or Superseded by the Computer* (1973). Cornock and Edmonds stress the participatory role of the audience in this type of art, and make the relation with the artwork the crux of their classification. They present four categories:

1) *Static System*: related to the traditional artwork. The audience observes the piece and nothing happens, it stays unchanged. The relation is unidirectional from the artwork to the spectator;

2) *Dynamic Passive System*: for dynamic artworks that changes autonomously over time, like in a kinetic sculpture. The audience observes the artwork and its processes but does not interact;

3) *Dynamic Interactive System:* The dynamic artwork now includes the audience. A feedback loop is created between piece and participant. Their actions influence the dynamics of the piece;

4) *Varying System:* Where the participant changes the process of the piece. Not only they interact with a set of predefined parameters (like in the *dynamic interactive system*) but changes them in a way not anticipated in the beginning.

4.3.2 *Reflected*, and *Internal Intelligence*

Kurt F. Lauckner (1976) proposes grouping interactive sculptures based on their level of "intelligence", on their ability to receive inputs and "think" of the output. If a system receives inputs from the exterior (like movement, sound, temperature) and then directly *reflects* them back (in the form of sound, light or movement) without any kind of decision or computation, he classifies it as *Reflected Intelligence*. He classifies as *Internally Intelligent* those that, after receiving the inputs from the outside world, make *intelligent decisions* or *think* of the feedback (Ibid.).

Below we can observe how the selected case studies would be classified under Cornock and Edmonds's classification of *Static*, *Dynamic* or *Varying* Systems, and also and with Lauckner's *Reflected*, and *Internal Intelligence* systems.

Table2: Case studies categorized according to Cornock and Edmonds's (1973) and Lauckner's (1976) classifications.

ARTWORK	CORNOCK AND EDMONDS	LAUCKNER (1976)
Epizoo **(1994)**	Dynamic Interactive	Reflected
The Trace **(1995)**	Dynamic Interactive	Internal
Symphony #2 for Dot Matrix Printers **(1999)**	Dynamic Passive	Reflected
Messa Di Voce **(2003)**	Varying	Internal
Manual Input Sessions **(2004)**	Varying	Internal
Appariton **(2004)**	Varying	Internal
Gameplay **(2005)**	Varying	Internal
Will.0.W1sp **(2005)**	Varying	Internal
Atom **(2007)**	Dynamic Interactive	Internal
Hypo Chrysos **(2011)**	Varying	Internal
Quadrotor Show **(2012)**	Dynamic Passive	Internal
(Glitch) Music for a Computer Classroom **(2013)**	Varying	Internal
Laser Forest **(2013)**	Varying	Reflected/Internal
Anatta **(2014)**	Varying	Internal
Axial **(2014)**	Dynamic Interactive	Reflected/Internal
Biomeditation **(2014)**	Varying	Internal
Cloud Piano **(2014)**	Dynamic Passive	Reflected/Internal
Soft Revolvers **(2014)**	Varying	Internal
Luxate **(2015)**	Varying	Internal
Wave Is My Nature **(2015)**	Varying	Internal
Deep Web **(2016)**	Dynamic Passive	Reflected
Spectra 3 **(2016)**	Dynamic Passive	Reflected

4.3.3 *Interactions in Interactive Installation Art*

Trifona, Jaccheri and Bergaust (2008) established a categorization system to classify interactivity on artistic installations. Their system was based on Edmonds, Turner and Candy's (2004) classification (that was itself an update of the Cornock and Edmonds's (1973)); also based on Hannington and Reed's classification (2002, quoted by Trifona, Jaccheri and Bergaust 2008) that used the terms *passive*, *interactive* and *adaptive* to classify the interaction on multimedia applications; and Sommerer and Mignonneau's (1999, quoted by Trifona, Jaccheri and Bergaust 2008) which is focused on interactive artworks on CD-ROMs and uses the terms *pre-designed* and *evolutionary* to distinguish the possibilities that the users have when exploring interactive paths.

The authors identified important viewpoints on the refereed classifications but stressed that they were in way incomplete, unable to fulfil their perspectives and interests for interactive art installations. Therefore, based on the refereed classifications they added three dimensions which categorize three different features of the interaction:

1) *Interaction rules:* the rules of the interaction process, which can be *static* or *dynamic;*

2) *Triggering parameters:* Which can be *Human Action* or *Environment.* It distinguishes when the interaction depends on actions run by the audience or a performer, e.g. using sensors, cameras, physical interfaces, or any other type of data input; or when the interaction depends on the environment like when it uses as input data from the weather for example;

3) *Content Origin*: It identifies the origin of the audiovisual content presented in the interaction, which can be pre-defined by the artist, dynamically *generated by software* or might come from *user input.*

Table 3: Case studies categorized according to Trifonova, Jaccheri and Bergaust's (2008) classification.

ARTWORK	INTERACTION RULES	TRIGGERING PARAMETERS	CONTENT ORIGIN
Epizoo **(1994)**	Dynamic	Human action	Predefined by artist/user input
The Trace **(1995)**	Dynamic	Human action	Predefined by artist/generated by software
Symphony #2 for Dot Matrix Printers **(1999)**	Static	Human action	Predefined by artist/generated by software
Messa Di Voce **(2003)**	Dynamic	Human action	Predefined by artist/provided by user/ generated software
Manual Input Sessions **(2004)**	Dynamic	Human action	Predefined by artist/provided by user/ generated software
Appariton **(2004)**	Dynamic	Human action	Predefined by artist/provided by user/ generated software
Gameplay **(2005)**	Dynamic	Human action	Predefined by artist/provided by user/ generated software
Will.0.W1sp **(2005)**	Dynamic	Human action	Predefined by artist/provided by user/ generated software
Atom **(2007)**	Dynamic	Human action	Predefined by artist/generated software
Hypo Chrysos **(2011)**	Dynamic	Human action	Predefined by artist/user input/generated by software
Quadrotor Show **(2012)**	Static	Environment	Predefined by artist
(Glitch) Music for a Computer Classroom **(2013)**	Dynamic	Human action	Predefined by artist/generated software
Laser Forest **(2013)**	Dynamic	Human action	Predefined by artist/generated software
Anatta **(2014)**	Dynamic	Human action	Predefined by artist/provided by user/ generated software
Axial **(2014)**	Static	Human action	Predefined by artist/user input/generated by software

***Biomeditation* (2014)**	Dynamic	Human action	Predefined by artist/provided by user/ generated software
***Cloud Piano* (2014)**	Static	Environment	Predefined by artist/generated software
***Soft Revolvers* (2014)**	Dynamic	Human action	Predefined by artist/generated software
***Luxate* (2015)**	Dynamic	Human action	Predefined by artist/user input/generated by software
***Wave Is My Nature* (2015)**	Dynamic	Human action	Predefined by artist/user input/generated by software
***Deep Web* (2016)**	Static	Human action	Predefined by artist/generated by software
Spectra 3 (2016)	Static	Human action	Predefined by artist/generated by software

4.3.4 *Classification of Interactive Digital Works*

Enrico Nardelli (2010) revisits Trifonova, Jaccheri and Bergaust's (2008) research and proposes a new and a broader classification. According to him, the classifications analyzed and proposed on Trifonova, Jaccheri and Bergaust's research are focused on very narrow specific interactive systems, as *interactive installation art* in this case, or interaction with *multimedia applications* in the case of Hannington and Reed's. Nardelli also emphasis the fact that in Edmonds, Turner and Candy (2004) the focus is only on the relationships between the artist, the audience, the artwork and the environment, and that is does not cover the input and process on the system. He stressed the need of an approach focused on the *input-process-output* viewpoint (Nardelli 2010, 2).

Nardelli's classification proposes three different dimensions:

1) *Content Provide*r: who produces the audiovisual material, which can be the *artist*, the *audience* or the *environment*;

2) *Processing Dynamics*: what kind of variations the interactive process presents. It can be *static*, when there are no changes along the time. It can be *Predefined Change*, for the cases where the variations follow a path defined by the artist. *Casual change*, for the cases where the variations are affected by random parameters; or *Evolutionary Change,* for the cases where the variations evolve into unpredictable paths and change to new forms;

3) *Processing Contributors*: Defines where are the inputs into the system coming from. It can be from the *audience,* from the *environment*, or *self* (which means that the artist programed the inputs in the core of the system);

Table 4: Case studies categorized according to Nardelli's (2010) classification.

ARTWORK	CONTENT PROVIDER	PROCESSING DYNAMICS	PROCESSING
Epizoo (1994)	Artist	Predefined Change	Audience
The Trace (1995)	Artist	Evolutionary Change	Audience
Symphony #2 for Dot Matrix Printers (1999)	Artist	Predefined Change	Self
Messa Di Voce (2003)	Artist	Evolutionary Change	Audience
Manual Input Sessions (2004)	Artist, Audience	Evolutionary Change	Audience
Appariton (2004)	Artist	Evolutionary Change	Audience
Gameplay (2005)	Artist	Evolutionary Change	Audience
Will.0.W1Sp (2005)	Artist, Audience	Evolutionary Change	Audience
Atom (2007)	Artist	Casual Change	Self
Hypo Chrysos (2011)	Artist	Casual Change	Audience
Quadrotor Show (2012)	Artist	Predefined Change	Self
(Glitch) Music for a Computer Classroom (2013)	Artist	Evolutionary Change	Audience
Laser Forest (2013)	Artist	Evolutionary Change	Audience
Anatta (2014)	Artist	Evolutionary Change	Audience
Axial (2014)	Artist	Predefined Change	Self, Audience
Biomeditation (2014)	Artist	Evolutionary Change	Audience
Cloud Piano (2014)	Artist, Environment	Casual Change	Environment
Soft Revolvers (2014)	Artist	Evolutionary Change	Audience
Luxate (2015)	Artist	Casual Change	Audience
Wave is My Nature (2015)	Artist	Casual Change	Audience
Deep Web (2016)	Artist	Predefined Change	Self
Spectra 3 (2016)	Artist	Predefined Change	Self

4.3.5 *A Framework for Generative Art*

In *A Framework for Understanding Generative Art* (2012), Dorin et al. stress the need of a taxonomy to classify and relate the processes used in generative art, and present a framework to analyze and compare generative systems. The authors highlight the fact that many of these artworks have very different characteristic, are presented in different media, and experienced in different ways, however many of the generative process are similar. The goal is to be able to have a "practice's classification and critical understanding" of these systems enabling "artists and designers to deconstruct existing generative systems, as well as devise generative systems with new attributes" (3).

The framework is divided in four categories, describing the main components that take part in each generative art system:

1) *Entities*: Elements that take part on the generative process. They can be points, lines, sound, body shapes, faces, graphic shapes, 3D meshes, etc.;

2) *Processes*: The mechanisms of the generative system, which can be physical, mechanical, computational, or resulting of human actions. Generative processes can

include translating pixel colors into sound, transforming silhouettes of bodies captured by computer vision into digital visual shapes or using position data from artificial satellites around the planet earth to create a visualization;

3) *Environmental Interaction*: The existence of interaction with elements from the environment around the artwork. Which can be as an example real-time meteorological data, or the characteristics of the room where the artwork is installed;

4) *Sensory Outcomes*: The outputs of the system. Which can be artifacts in static or time-based forms (visual, sonic, sculptural, etc.) or processes.

Table 5: Case studies categorized according to Dorin et al. (2012) classification.

ARTWORK	ENTITIES	PROCESS	ENVIRONMENTAL INTERACTION	SENSORY OUTCOMES
Epizoo (1994)	Pneumatic exoskeleton, Videoprojection, Light, Sound	pneumatic exoskeleton controls performer body, also triggers sound, animations and lights.	None	Sonic, Visual, Motion
The Trace (1995)	Videoprojection, Light, Sound	Participants movements are tracked and used as input into sound, video-projection and lights.	None	Sonic, Visual
Symphony #2 for Dot Matrix Printers (1999)	Computers, Dot Matrix Printers, Microphones, Videocameras	Printers receive instructions over network. Microphones and videocameras capture the movements of the Printers' mechanics	None	Sonic, Visual
Messa Di Voce (2003)	Graphic shapes	Performers' body position and voices used to interact with sound and visuals	None	Sonic, Visual
Manual Input Sessions (2004)	Graphic shapes, Sound	silhouettes from user hands generate virtual shapes, virtual shapes create sounds	None	Sonic, Visual
Appariton (2004)	Graphic shapes, Sound	Dancers' body is captured by Computer Vision and used to interact with graphics	None	Sonic, Visual
Gameplay (2005)	Graphic shapes, Sound	Dancers' body is captured by Computer Vision and used to interact with graphics and Sound	None	Sonic, Visual
Will.0.W1sp (2005)	Particles, Sound	position and movement of visitors used to manipulate real time particle animations an sound generation	None	Sonic, Visual
Atom (2007)	Sound, LEDS Lights	Lights, ballon movement and sound are pre-sequenced or triggered by the human performer	None	Sonic, Visual, Motion
Hypo Chrysos (2011)	Human body, Sound, Graphic shapes	Biophysical sensors capture the sound of muscles, hearth and blood. Used as input to manipulate sound and visuals	None	Sonic, Visual

***Quadrotor Show* (2012)**	Light, Drones, Sound	Lights, Drone's paths and sound are pre-sequenced	None	Sonic, Visual
***(Glitch) Music for a Computer Classroom* (2013)**	Graphic shapes, Sound	Hands positions and gestures are mapped to trigger and modulate sound and visuals on the screens	None	Sonic, Visual
***Laser Forest* (2013)**	Lasers, Sound	Oscillation of the branches used to modulate sound created visuals patters on the ceiling	Lasers draw shapes on the ceiling	Sonic, Visual, Motion
***Anatta* (2014)**	Graphic Shapes, Sound	Dancers' body is captured by Computer Vision and used to interact with graphics and Sound	None	Sonic, Visual
***Axial* (2014)**	Light, Sound	Lights and sound are pre-sequenced. A gesture device allows the audience to interact with the system.	None	Sonic, Visual, Motion
***Biomeditation* (2014)**	Body mesh, pointclouds	Brain waves data modulate sound effects, body of the performed is scanned and displayed as mesh in virtual space. Sound analyze data modulates and deforms the mesh	None	Sonic, Visual
***Cloud Piano* (2014)**	Clouds' shape	black/white pixels of the pictures of the sky are used to map over the piano keys.	clouds in the sky	Sonic, Motion
***Soft Revolvers* (2014)**	Sound, LED ligths	Rotation data used to control real-time sound generation	None	Sonic, Visual, Motion
***Luxate* (2015)**	Projected Light, Sound, Human body	Dancers' body is captured by computer vision to manipulate visual shapes, and sound parameters	None	Sonic, Visual
***Wave is My Nature* (2015)**	Kinetic Structure, LEDs	Servo motors move stretched cables with light on the tops around the space. It reacts to presence of audience in the space. Sound generated in real-time according to the kinetic movement.	None	Sonic, Visual, Motion
***Deep Web* (2016)**	Kinetic structure, Lasers	Kinetic structure's movement and lasers are pre-sequenced in synchrony with the sound	None	Sonic, Visual, Motion
***Spectra 3* (2016)**	Kinetic structure, Sound	Kinetic structure's movement are pre-sequenced in synchrony with the sound	None	Sonic, Visual, Motion

4.3.6 *Typology for Procedural Aesthetic Artifacts*

Carvalhais, on his dissertation *Towards a Model for Artificial Aesthetics* (2010), proposes an analytic model to characterize computational aesthetic artifacts. It takes as a starting point Espen Aarseth's model for the analysis of cybertexts (1997, quoted in Carvalhais 2010, 345), which uses a set of seven variables (*Dynamics*, *Determinability*, *Transiency, Perspective*, *Access*, *Linking* and *User Function).*

Carvalhais's model adjusts the parameters Aarseth's variables to fit the analysis of computational artwork requirements, eliminates the *Perspective* variable, and adds three new ones (*Modes*, *Autonomy* and *Class*). The proposed model uses the following variables:

1) *Dynamics*: Describes the dynamics of the elements, or units that compose the artwork. It can be *Static*, if the systems have a fixed number of elements and combinations. The term *Surface Unit Dynamics (SUD)*, is used for cases where the possible outcomes are variable, but the elements used in the generative and composition processes are already part of the system. *Deep Unit Dynamics (DUD)* for the cases where the users can intervene in the elements that are used in the generate the compositions;

2) *Determinability*: The system can be categorized as *Determinable* if the results are similar every time the system is executed, or *Indeterminable* if any parameters trigger unpredictable results;

3) *Transiency*: Related to the temporal existence of the artwork. The system can be *Transient* if the mere passing of time creates changes in the outcomes, or *Intransient* if it needs external inputs or user actions;

4) *Access:* Describes if the users are able to access and interact with all elements of the system at all times, when they have *Random* access. If not, users have their access *Controlled* by the system;

5) *Linking:* Identifies if there are connections or rules between the different scenes of the interaction, and users follow them. Linking can be *none*, *explicit* or *conditional*;

6) *User Function:* Describes the role of the user on the interactive system. Which can be *Explorative*, when the user navigates in the systems*. Configurative* when the user is able to change the configurations of the system. In addition there is the omnipresent *Interpretative* function, where the user is not intervening but only perceiving the artwork outcome;

7) *Modes:* Number of sensory modalities, ranging from 1 to 5;

8) *Autonomy*: Distinguishes between systems that hold all the data to produce the outcomes, which are *Autonomous,* or other fed by sources of data, which are *Data-Driven*;

9) *Class:* Classification between 1 and 4 according to the class of computation developed by the system (following Stephen Wolfram's classification, quoted in Carvalhais 2010, 144). Systems with static intransient outputs are classified as *Class 1*, static transient outputs as *Class 2*, and those with complex behaviors classified as *Class 3*, if they provide random and unpredictable outputs, or *Class 4* for complex behaviors that present a structured and partially predictable output.

Table 6: Case studies categorized according to Carvalhais's *Typology for Procedural Aesthetic Artifacts* (2010)

ARTWORK	DYN	DET	TRANS	ACC	LINK	U.F.	MODE	AUT	CLASS
Epizoo (1994)	SUD	Ind.	Int.	Rand.	Exp.	Explor.	3	D-D	4
The Trace (1995)	DUD	Ind.	Int.	Rand.	Exp	Config.	3	D-D	4
Symphony #2 for Dot Matrix Printers (1999)	Static	Det.	Trans.	Cont.	None	Int.	2	Aut.	2
Messa Di Voce (2003)	DUD	Ind.	Int.	Rand.	Exp.	Config.	3	D-D	4
Manual Input Sessions (2004)	DUD	Ind.	Int.	Rand.	Exp.	Config.	3	D-D	4
Appariton (2004)	DUD	Ind.	Int.	Rand.	Exp.	Explor.	3	D-D	4
Gameplay (2005)	DUD	Ind.	Int.	Rand.	Exp.	Explor.	3	D-D	4
Will.0.W1sp (2005)	DUD	Ind.	Int.	Rand.	Exp.	Config.	3	D-D	4
Atom (2007)	SUD	Ind.	Int.	Rand.	Cond.	Explor.	2	D-D	4
Hypo Chrysos (2011)	DUD	Ind.	Int.	Rand.	Exp.	Config.	3	D-D	4
Quadrotor Show (2012)	Static	Det.	Trans.	Cont.	Cond.	Inter.	2	Aut.	2
(Glitch) Music for a Computer Classroom (2013)	DUD	Ind.	Int.	Rand.	Exp.	Config.	3	D-D	4
Laser Forest (2013)	SUD	Ind.	Int.	Rand.	Exp.	Explor.	3	D-D	4
Anatta (2014)	DUD	Ind.	Int.	Rand.	Exp.	Config.	3	D-D	4
Axial (2014)	Static	Ind.	Trans.	Cont.	None	Inter.	2	Aut.	2
Biomeditation (2014)	DUD	Ind.	Int.	Rand.	Exp.	Explor.	3	D-D	4
Cloud Piano (2014)	SUD	Ind.	Transi	Rand.	None	Inter.	1	D-D	4
Soft Revolvers (2014)	SUD	Ind.	Int.	Rand.	Explicit	Config.	3	D-D	4
Luxate (2015)	DUD	Ind.	Int.	Rand.	Explicit	Explor.	3	D-D	4
Wave Is My Nature (2015)	DUD	Ind.	Int.	Rand.	Explicit	Explor.	2	D-D	4
Deep Web (2016)	Static	Det.	Trans.	Cont.	None	Int.	2	Aut.	2
Spectra 3 (2016)	Static	Det.	Trans.	Cont.	None	Int.	2	Aut.	2

4.3.7 *Capturing Unstable Media*

V2_[3], an interdisciplinary center for art and media technology, developed a model to capture and document interactive media art (or "unstable media" as they call it), for their own archive (Fauconnier and Frommé 2003). This descriptive model uses "an object-relation instead of a record-based approach" (Ibid), and arises from their need to archive and document projects that use different media, and generate different outputs.

The model is divided in the following parameters, describing the interaction and features of the artwork:

1) *Time:* Can be *Scheduled* for the cases where it needs to happen at a specific time, like a performance. Or *Not Scheduled* for cases where the artwork is continuously active and the time is not important, like an installation or an online project;

2) *Location*: Indicates if the interaction happens physically in a *Specific Location*, for installations or performances as an example. Or *Undefined Location* for the cases where it can be experience remotely;

3) *User Number:* The interaction can be designed for a *Single User*, for a *Group of Users,* or for an *Audience. The Minimum* and *Maximum* number of users can also be specified;

4) Interaction Level: Which can be *Observational, Navigational, Participatory, Co-authoring, Intercommunication*;

5) *Sensory Mode:* It indicates which senses are used during the interaction. It can be *Visual, Auditive, Olfactory, Tactile* or *Gustative*.

Table 7: Case studies categorized according to V2_'s
Capturing Unstable Media's (2003) classification.

ARTWORK	TIME	INT. LOC.	USER	MIN/MAX	INT. LEVEL	SENSORY MODE
Epizoo **(1994)**	Scheduled	Specific Loc.	Single User	1, Does Not Apply	Control	Visual, Auditive, Tactile
The Trace **(1995)**	Scheduled	Specific Loc.	Group User	2,2	Participate	Visual, Auditive
Symphony #2 for Dot Matrix Printers **(1999)**	Scheduled	Specific Loc.	Audience	Does Not Apply	Observational	Visual, Auditive
Messa Di Voce **(2003)**	Scheduled	Specific Loc.	Audience	Does Not Apply	Participate	Visual, Auditive
Manual Input Sessions **(2004)**	Scheduled	Specific Loc.	Single User	1,1	Participate	Visual, Auditive
Appariton **(2004)**	Scheduled	Specific Loc.	Group Use	Does Not Apply	Participate	Visual, Auditive
Gameplay **(2005)**	Scheduled	Specific Loc.	Single User	1,1	Participate	Visual, Auditive
Will.0.W1Sp **(2005)**	Scheduled	Specific Loc.	Audience	Does Not Apply	Participate	Visual, Auditive

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3 V2_ Institute for the Unstable Media, Rotterdam, Holland. <http://v2.nl/>. Accessed 2016.03.06

***Atom* (2007)**	Scheduled	Specific Loc.	Single User	Does Not Apply	Control	Visual, Auditive
***Hypo Chrysos* (2011)**	Scheduled	Specific Loc.	Group User	1,1	Participate	Visual, Auditive
***Quadrotor Show* (2012)**	Scheduled	Specific Loc.	Audience	Does Not Apply	Observe	Visual, Auditive
***(Glitch) Music for a Computer Classroom* (2013)**	Scheduled	Specific Loc.	Single User	1,1	Control	Visual, Auditive
***Laser Forest* (2013)**	Not Scheduled	Specific Loc.	Audience	1, Does Not Apply	Activate	Visual, Auditive
***Anatta* (2014)**	Scheduled	Specific Loc.	Audience	1,1	Participate	Visual, Auditive
***Axial* (2014)**	Not Scheduled	Specific Loc.	Audience	Does Not Apply	Observational	Visual, Auditive
***Biomeditation* (2014)**	Scheduled	Specific Loc.	Single User	1,1	Participate	Visual, Auditive
***Cloud Piano* (2014)**	Not Scheduled	Specific Loc.	Audience	Does Not Apply	Observe	Auditive
***Soft Revolvers* (2014)**	Scheduled	Specific Loc.	Single User	1,1	Control	Visual, Auditive
***Luxate* (2015)**	Scheduled	Specific Loc.	Single User	1,1	Participate	Visual, Auditive
***Wave Is My Nature* (2015)**	Not Scheduled	Specific Loc.	Group User	1,1	Participate	Visual, Auditive
***Deep Web* (2016)**	Not Scheduled	Specific Loc.	Audience	Does Not Apply	Observational	Visual, Auditive
***Spectra 3* (2016)**	Not Scheduled	Specific Loc.	Audience	Does Not Apply	Observational	Visual, Auditive

4.3.8 A Taxonomy of Interactive Art

Kwastek et al. (2009) presents a report on the taxonomy developed by the *Ars Electronica Festival* to classify the projects submitted to its annual prize for electronic arts.[4] The taxonomy is used in the entry forms, to describe and divide them through the proper festival categories. Some of the form fields are open to new terms, allowing this way the artists to submit new keywords and organically evolve the taxonomy over the time.

The taxonomy is divided in the following parameters:

1) *Form of Work*: installation, performance, software, etc.;

2) *Range of Artwork*: Indicates where the artwork is presented (stand-alone application, public space, site specific, etc.);

3) *Interaction Partners*: Defines who is involved in the interaction (Human-Computer, Computer-Environment, Computer-External Data);

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4 Prix Ars Electronica, Linz. <http://www.aec.at/prix/en/>. Accessed 2016.07.20

4) *Type of Interaction:* Describes the interaction and it is divided into two sub-topics.

4.1) *The visitor/performer does*, how the audience or the performer interacts with the system (observe, explore, activate, select, participate, leave traces, co-author, exchange).

4.2) *The work/project does*, what function does the system realize (monitor, serve as an instrument, tell, narrate, document, enhance perception, offer a game, enable communication, visualize, sonify, transform, store, immerse, process, mediate;

5) *Media:* Which types of media and tools are used as input/output in the system (video, computer graphics, sound, light, GPS, sensors, RFID, motors, etc.);

6) *Processing Technology:* Describes the processes that the interactive system performs (Motion capture, voice recognition, text recognition, chroma-keying, eye-tracking, image capture, biometric identification, bio-feedback, custom, other, none);

7) *Catchword:* general terms and trends that describe the artwork technically (locative media, augmented reality, ubiquitous/pervasive computing, virtual reality, telepresence, artificial intelligence, low-tech, media archaeology, interactive cinema, ubiquitous/pervasive gaming, wearable computing, cybernetics);

8) *Topic:* Context and theme of the artwork (artificial life, artificial intelligence, biographies, economic systems, environment, etc.).

Table 8: Case studies categorized according to
Taxonomy of Interactive Art (Kwastek et al. 2009). Part 1.

ARTWORK	FORM OF WORK	RANGE	INT. PARTNERS	MEDIA (In/Out)
Epizoo **(1994)**	Performance	Pubic Space	(H)uman >< (C)omputer >< H (Audience Interact.)	Mouse, Interface, Exoskeleton, Body, Video, Lights, Sound
The Trace **(1995)**	Installation	Public Space, Separate Sites	H >< C >< H (Audience Interact.)	Projection, Lights, Sound
Symphony #2 for Dot Matrix Printers **(1999)**	Performance	Public Space	C >< C	Printers, Videocameras, Microphones, Sound, Projection
Messa Di Voce **(2003)**	Performance	Public Space	H >< C (Artist Interact.)	Projection, Computer Graphics, Speakers
Manual Input Sessions **(2004)**	Performance, Installation	Public Space	H >< C (Artist Interact.)	Projection, Computer Graphics, Speakers
Appariton **(2004)**	Performance	Public Space	H >< C (Artist Interact.)	Projection, Computer Graphics, Speakers
Gameplay **(2005)**	Performance	Public Space	H >< C (Artist Interact.)	Projection, Computer Graphics, Speakers

***Will.0.W1Sp* (2005)**	Installation	Public Space	H >< C (Audience Interact.)	Projection, Computer Graphics, Speakers
***Atom* (2007)**	Performance	Public Space	H >< C (Artist Interact.)	Speakers, Light, Motors
***Hypo Chrysos* (2011)**	Performance	Public Space	H >< C (Artist Interact.)	Bio Sensors, Speakers, Projection
***Quadrotor Show* (2012)**	Performance	Public Space	C >< C	Speakers, Light, Motors
***(Glitch) Music for a Computer Classroom* (2013)**	Installation	Public Space	H >< C (Artist Interact.)	Monitor/Screen, Computer Graphics, Speakers
***Laser Forest* (2013)**	Installation	Public Space	H >< C >< Analog Devices (Audience Interact.)	Speakers, Light, Sensors, Tangible Interfaces
***Anatta* (2014)**	Performance	Public Space	H >< C (Artist Interact.)	Projection, Computer Graphics, Speakers
***Axial* (2014)**	Installation	Public Space	C >< C	Robotic Lights, Smoke, Speakers
***Biomeditation* (2014)**	Performance	Public Space	H >< C (Artist Interact.)	Projection, Computer Graphics, Speakers, Sensors
***Cloud Piano* (2014)**	Installation, Object	Stand-Alone	C >< Ext Digital Data	Video Camera, Sound Acoustic, Motors
***Soft Revolvers* (2014)**	Performance	Public Space	H >< C >< Analog Devices (Artist Interact.)	Speakers, Light, Sensors, Tangible Interfaces
***Luxate* (2015)**	Performance	Public Space	H >< C (Artist Interact.)	Projection, Haze, Camera, Speakers
***Wave Is My Nature* (2015)**	Installation	Public Space	H >< C (Audience Interact.)	Servo Motors, Led, Ultrasound Sensors, Speakers
***Deep Web* (2016)**	Installation	Public Space	C >< C	Kinetic Mechanism, Speakers, Lasers
***Spectra 3* (2016)**	Kinetic Installation, Object	Public Space	C >< C	Kinetic Mechanisms, Motor, Speakers

Table 9: Case studies categorized according to *Taxonomy of Interactive Art* (Kwastek et al. 2009). Part 2.

ARTWORK	TYPE OF INT. (USER DOES)	TYPE OF INT. (COMPUTER DOES)	PROCESSING TECHNOLOGY	CATCHWORD
Epizoo **(1994)**	Controls	Serve As An Instrument/Tool	Bio-Feedback	Embodiment, Wearable Computing
The Trace **(1995)**	Participates	Mediate, Visualize, Sonificate, Enable Communication	Motion Capture	Telepresence
Symphony #2 for Dot Matrix Printers (1999)	Observes	Process, Visualize, Sonificate	Network Communication	Low-Tech, Media Archaeology
Messa Di Voce **(2003)**	Participates	Serve As An Instrument/Tool, Visualize, Sonificate	Motion Capture, Sound Analysis	Embodiment
Manual Input Sessions **(2004)**	Participates	Serve As An Instrument/Tool, Visualize, Sonificate	Motion Capture	Interface Design
Appariton **(2004)**	Participates	Serve As An Instrument/Tool, Visualize	Motion Capture	Embodiment
Gameplay **(2005)**	Participates	Serve As An Instrument/Tool, Visualize, Sonificate	Motion Capture	Embodiment
Will.0.W1Sp **(2005)**	Participates	Serve As An Instrument/Tool, Visualize, Sonificate	Motion Capture	Embodiment
Atom **(2007)**	Controls	Serve As An Instrument/Tool	Force Feedback	Robotics
Hypo Chrysos **(2011)**	Controls	Serve As An Instrument/Tool, Visualize, Sonificate	Bio-Feedback	Embodiment
Quadrotor Show **(2012)**	Observes	Process, Visualize, Sonificate	Motion Capture	Robotics
(Glitch) Music for a Computer Classroom **(2013)**	Controls	Serve As An Instrument/Tool, Visualize, Sonificate	Motion Capture	Interface Design
Laser Forest **(2013)**	Activates	Serve As An Instrument/Tool,	Force Feedback	Low-Tech
Anatta **(2014)**	Participates	Serve As An Instrument/Tool, Visualize, Sonificate	Motion Capture	Embodiment
Axial **(2014)**	Observes	Process, Visualize, Sonificate	Custom Kinetic Mechanism	Robotics
Biomeditation **(2014)**	Participates	Serve As An Instrument/Tool, Visualize, Sonificate	Motion Capture, Bio-Feedback, Sound Analysis	Embodiment
Cloud Piano **(2014)**	Observes	Process, Visualize, Sonificate	Image Capture	Cybernetics
Soft Revolvers **(2014)**	Controls	Serve As An Instrument/Tool, Visualize, Sonificate	Motion Sensor, Sound Analysis	Low-Tech

Luxate (2015)	Participates	Serve As An Instrument/Tool, Visualize, Sonificate	Motion Capture	Embodiment
Wave Is My Nature (2015)	Participates	Serve As An Instrument/Tool, Visualize, Sonificate	Motion Sensor And Custom Kinetic's Mechanism	Ubiquitous/ Pervasive Computing
Deep Web (2016)	Observes	Process, Visualize, Sonificate	Custom Kinetic's Mechanism And Laser Controller	Ubiquitous/ Pervasive Computing
Spectra 3 (2016)	Observes	Process, Visualize, Sonificate	Custom Kinetic Mechanism	Robotics

4.3.9 *Interactive Music Systems*

Robert Rowe (1992, 6) builds a classification to group and analyze systems for inter-active music creation. His method is a "rough classification" that intends to "not simply to attach labels to programs but to recognize similarities between them and to be able to identify the relations between new systems and their predecessors" (Ibid.). Despite Rowe's classification is intented for interactive music it can also be applied for the interactive systems addressed in this dissertation.

Rowe's classification is divided in the following three dimensions:

1) *Score or Performance Driven*: On the one hand if the musical events are prede-termined in advance and organized and stored under traditional music methods (as beat, meter, tempo), and waiting for an input to trigger, they are classified as *Score Driven*. On the other hand, if the system does not use any predetermined score, it is classified as *Per-formance Driven*;

2) *Methods*: Processing methods can be *Transformative* when existing musical mate-rial is taken (live feed or stored) and transformation algorithms are applied producing variants. They can be *Generative* for when elementary or fragmentary material, that can be taken from different data sources (not necessarily from music), is used as input and subject to different sets of rules to produce musical outputs. And *Sequenced* when pre-re-corded music is triggered after a real-time input.

3) *Instrument or Player Paradigm*: The system is classified as *Instrument Paradigm* when it works as an extended musical instrument to be played by a human (like a system that captures gestures from a performer to use as an input to sound generation). It is classified as *Player Paradigm* when the system acts as an artificial player, a partner of the human player.

Table 10: Case studies categorized according to *Interactive Music Systems* (Rowe 1992)

ARTWORK	SCORE/PERFORMANCE	METHODS	PARADIGM
Epizoo (1994)	Performance-Driven	Sequenced	Instrument
The Trace (1995)	Performance-Driven	Generative	Instrument
Symphony #2 for Dot Matrix Printers (1999)	Score-Driven	Sequenced	Player
Messa Di Voce (2003)	Performance-Driven	Generative	Instrument
Manual Input Sessions (2004)	Performance-Driven	Generative	Instrument
Appariton (2004)	Performance-Driven	Generative	Instrument
Gameplay (2005)	Performance-Driven	Generative	Instrument
Will.0.W1Sp (2005)	Performance-Driven	Generative	Instrument
Atom (2007)	Performance-Driven	Transformative	Instrument
Hypo Chrysos (2011)	Performance-Driven	Generative	Instrument
Quadrotor Show (2012)	Score-Driven	Sequenced	Instrument
(Glitch) Music for a Computer Classroom (2013)	Performance-Driven	Generative	Instrument
Laser Forest (2013)	Performance-Driven	Transformative	Instrument
Anatta (2014)	Performance-Driven	Generative	Instrument
Axial (2014)	Score-Driven	Sequenced	Player
Biomeditation (2014)	Performance-Driven	Generative	Instrument
Cloud Piano (2014)	Performance-Driven	Transformative	Player
Soft Revolvers (2014)	Performance-Driven	Generative	Instrument
Luxate (2015)	Performance-Driven	Generative	Instrument
Wave Is My Nature (2015)	Performance-Driven	Generative	Instrument
Deep Web (2016)	Score-Driven	Sequenced	Player
Spectra 3 (2016)	Score-Driven	Sequenced	Player

4.3.10 ANALYSIS OF THE PREVIOUS CLASSIFICATIONS OF INTERACTIVE SYSTEMS

Nine frameworks to classify interactive systems were described and tested with the selected case studies. Each presents different approaches and methods, however all share similar goals on providing creators and scholars with a structure to help to analyze and contextualize interactive artworks by identifying parameters of comparison. They also present different focus, diverging from defining the levels of interaction, on input and outputs, interactive elements, or system and process description. However, despite the different viewpoints, all present strong points of convergence with the goals of this research and where important for the development of the *S+V+M* framework presented on the next section.

The classifications provided by Cornock and Edmonds (1973) and Lauckner (1976) are focused on the level of interactivity of the system, on the system's response to the user or audience. They distinguish if a system just reacts to inputs or if it has any ability to interpret the inputs and provide different and dynamic outputs. Despite presenting basic and

limited parameters, both were extremely important in building the foundations and base-lines for future classifications and research related to interactive systems.

Trifonova, Jaccheri and Bergaust's (2008) classification was built over the same idea of classifying the level of interactivity of each system, however the authors added two more dimensions that contributed to a more complete approach on analyzing interactive art installations. These two new dimensions were related to the origin of the content and the triggers for the interaction.

Nardelli (2010) revisits Trifonova, Jaccheri and Bergaust's research and contributes with the focus on the *input-process-output* viewpoint. This approach is an important topic for the research presented on this dissertation and shares similar interests as in Nardelli's work. Even though Nardelli's attention is on the origin of the input (*audience*, *environment* or *self*), and not on the *Sound*, *Visual* and *Movement* domain, it highlights the focus on input and outputs of data in the system and not on the software or hardware for the categorization of an interactive system.

Dorin et al. (2012) focus on the processes and entities that take part on generative systems, highlighting the fact if many of the artworks have very different characteristics, and are presented in different mediums, nevertheless many of the generative systems and processes developed by them are similar. This is also one of the main concerns on the classification presented on this dissertation, as the goal is to be able to analyze and compare under the same scope audiovisual stage performances with interactive spaces or kinetic installations. Just like the authors stated: "the medium and experience of these works appear to be quite different. Yet, when we look carefully we find that the underlying generative processes are remarkably similar." (2012, 3).

Another feature that relates with the focus of this research is the *Sensory Outcomes.* It uses as classification the outputs from the system which can be *visual*, *sonic*, *sculptural*, *literary*, etc. Even if it predicts a broader viewpoint on the outcomes, in fact a description of the final state of the artwork, this approach on considering the outcomes perceived by the audience is a point of convergence with the work developed on this dissertation.

Carvalhais's model (2010) has similarities with the previous framework as it categorizes and describes the processes of computational artworks. Besides the variable *Modes* which is related to the sensory outcomes, that just like Dorin's et al. (2012) framework is a point of convergence with our work, we should also highlight the feature *Autonomy*. This feature sets apart *Autonomous* from *Data-Driven* systems, distinguishing systems that contain all the data to produce their outputs from systems fed by external sources of data. This is also an important feature on the framework proposed in this dissertation as it allows to define under the same scope of interactive systems artworks projects like *Spectra-3* (Field 2016), or *Deep Web* (Henke and Bauder 2016), where all the events are predefined in a score or are generated by the system autonomously, and projects like *Cloud Piano* (Bowen 2014) or *Soft Revolvers* (Bleau 2014) where a real-time input of data from outside of the system is needed to make it work.

Rowe's classification on interactive music system (1992) provides three dimensions that define the features of each system. The systems are sorted by *Score* or *Performance Drive*, type of *Processing Methods (Transformative*, *Generative* or *Sequenced)*, and *Instrument* or *Player Paradigm.* This classification had a significant contribution to the present research specially due to its first dimension (*Score/Performance Driven*) that helped to

embrace under the roof of interactive systems artworks where the events are pre-defined and scored, like *Axial*(PlayMID 2014) *Quadrotor Show* (Marshmallow Laser Feast 2012) or *Spectra-3* (Field 2016). In addition, another topic on Rowe's approach that resonates strongly with this work is his motivations, where he states that he intends "not simply to attach labels to programs but to recognize similarities between them and to be able to identify the relations between new systems and their predecessors" (1992, 6).

Finally, Fauconnier and Frommé (2003) and Kwastek et al. (2009) present descriptive classifications made to document, archive, register and catalogue media artworks. Both are highly descriptive and extensively cover the technical and functional elements of each artwork as *Time*, *Location*, *Number of Users* or *Interaction Level (for Capturing Unstable Media*), and parameters such as Form of Work, a description of *What the User Does* and *What the Computer Does* or *Processing Technology* (for *A Taxonomy of Interactive Art*).

Despite having different approaches to the goals of the framework presented in this dissertation, both cases present some features that must be highlighted as they have points of convergence with our work. In the case of *A Taxonomy of Interactive Art* the features

Media In/Out and *Interactive Partners* relate to the flux, direction and inputs and outputs of data inside de system, an issue that is central focus on this research. In the case of Fauconnier and Frommé (2003) classification we should emphasize their notes for future research on describing the input and output of the interaction in the systems as well as the direction of the communication (20).

4.4 *S+V+M*, A FRAMEWORK FOR THE CLASSIFICATION OF INTERACTIVE SYSTEMS

S+V+M (*Sound*, *Visuals*, *Movement*) is a framework to classify interactive artworks based on the flow of data through their systems. Like Rowe (1992, 6), on his classification of interactive music systems, the ultimate goal is not to simply attach labels but to recognize similarities and establish common parameters in artworks with different characteristics, so they can be evaluated and discussed under a unified perspective. In such a way that one can connect and compare under the same scope audiovisual stage performances, interactive spaces or kinetic installations.

S+V+M framework's goals are also lined up with Kwastek's motivations, on defining interactive art's aesthetics, stressing that the goal was not to present "a purely theoretical model", but to "elaborate criteria - based on the concrete observation of exemplary artistic project - that facilitate the description and the analysis of interactive art" (2013, 62).

This classification does not intend to describe types or levels of interaction, data mappings, generative processes or other specific details of the systems, which have already have been widely covered in several classifications and frameworks. Instead, it aims to provide a higher level of abstraction by looking at the input and outputs, transformations and data-flow occurring across the Sound, Visual and Movement domains inside the interactive system. The goal is to outline the interactive systems in a simple and descriptive way, taking into account the translations "across sensory-kinetic modes (sound into light, light into motion)" (Whitelaw 1998) as a unifying factor. This strategy was also pinned down by the art and technology center V2_[5] in their model for capturing, documenting and archiving interactive art, or "unstable media" as they call it (Fauconnier and Frommé 2003). As future research they stressed some possible directions for their model like describing the input and output of the interaction in the systems as well as the direction of the communication (20).

This approach allows us to compare, e.g. the installation *Cloud Piano* (Bower 2014) with the audiovisual performances *Soft Revolvers* (Bleau 2014) and *Manual Input Sessions* (Levin and Lieberman 2004). *Cloud Piano* uses images from clouds to make a mechanism move and play the piano, *Manual Input Sessions* hand gestures create visual shapes that are then translated into sound, and on *Soft Revolvers* the rotational data of a series of tops is used to generate sound. As we can see these examples have very different typologies, ranging from an autonomous robotic piano player to a gesture based audiovisual instrument, and an audiovisual interface, however we can still group them. The three share a similar data-flow structure, with data from one domain translating into another domain, and this one into the other one. However, despite the same structure the actual sequence of the transformations is different: on *Cloud Piano* it goes from the *Visual* domain to *Movement*, and from *Movement* to *Sound*; on *Soft Revolvers* it goes from *Movement* to *Sound*, and from *Sound* to *Visual*; and on *Manual Input Sessions* it goes from *Movement* to *Visual* and from *Visual* to *Sound*.

The method used to classify interactive systems consists on textually describing the processes of transformation happening across the domains, i.e., between which domains

5 V2_ Institute for the Unstable Media, Rotterdam, Holland. <http://v2.nl/>. Accessed 2016.03.06

the transformations are happening and which are inputs or outputs: *Visuals to Movement*, *Visuals to Movement and Sound*, *Sound to Visuals*, etc.

With the purpose of making the classification concise and easy to read, descriptions are then transcoded to a symbolic system where each domain is represented by its initial (S for Sound, V for Visual, M for Movement). The direction of data between the domains is represented by the "greater-than" sign (>), and a comma is used to separate each independent transformation. As an example, as we just saw on *Soft Revolvers* we have *Movement* to *Sound* and *Sound* to *Visual*, so we should represent it as: *M > S > V.*

This framework does not intend to be a closed system, but a flexible one, open to new designations that help to describe the artwork. Like on *Spectra-3* where the input does not have origin on one specific domain, but rather on a data stream that does not belong to *Movement*, *Visual* or *Sound* domains. It comes from an external and pre-defined source, the interactive events have been defined on a timeline as scored data, which is the source to simultaneously trigger all three domains. In this case we designate an extra element on the framework, the *Data*, to be assigned for external sources to Sound, Visual and Movement domains. So on *Spectra-3* we have *Data to Sound, Visual and Movement*, which is then represented by: *D > SVM*. As we saw, on *Spectra-3,* the domain *Data* is used to symbolize a case where all inputs have been scored on a timeline. But it can also be used for different sources, like cases where the inputs for the interaction system comes from data collected on the internet (like weather of financial data), or to designate a specific interface that triggers data into the *Sound*, *Visual*, *Movement* domains, like on *Epizoo* where an external interface is used by the audience to trigger live inputs to the live performance.

It is also possible that elements from the same domain interact with each other, like on *Quadrotor Show*, where the movement of the drones in the air is tracked by infrared cameras and its data used as input into the moving head lights makings them follow the drones. In this case we have the following classification *Data to Sound, Visual and Movement*; *Movement to Movement*, which is represented by: *D > SVM, M>M*. In cases where one domain is independent and does not have any interactions with others we should represented it inside brackets, meaning it is isolated. As in *Apparition*: M > V, [S].

In the table bellow we can find a list of the selected case studies and their correspondent *S+V+M*'s classification.

Table 11: Case studies categorized according to *S+V+M*

NAME	CLASSIFICATION
Epizoo (1994)	D > SVM
The Trace (1995)	M > SV
Symphony #2 for Dot Matrix Printers (1999)	D > M, M > SV
Messa Di Voce (2003)	MS > V
Manual Input Sessions (2004)	M > V > S
Appariton (2004)	M > V, [S]
Gameplay (2005)	M > SV
Will.0.W1sp (2005)	M > SV
Atom (2007)	S > VM
Hypo Chrysos (2011)	M > SV

Quadrotor Show (2012)	D > SVM, M > M
(Glitch) Music for a Computer Classroom (2013)	M > SV
Laser Forest (2013)	M > SV
Anatta (2014)	M > SV, S > V
Axial (2014)	D > SVM, M > SVM
Biomeditation (2014)	M > SV, S > V
Cloud Piano (2014)	V > M > S
Soft Revolvers (2014)	M > S > V
Luxate (2015)	M > SV
Wave Is My Nature (2015)	M > SVM
Deep Web (2016)	D > SVM
Spectra 3 (2016)	D > SVM
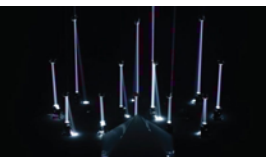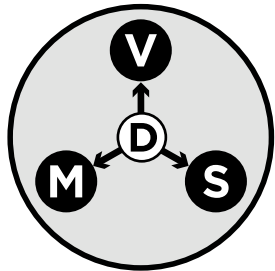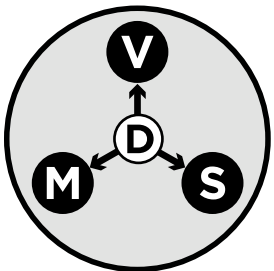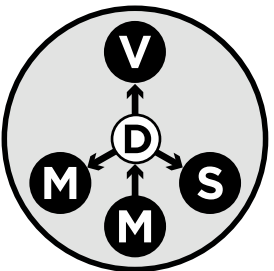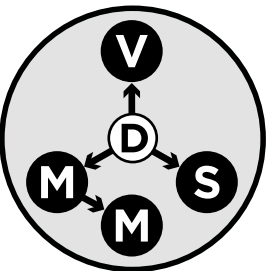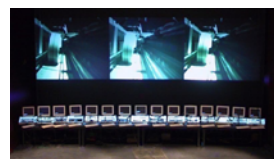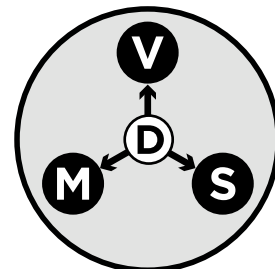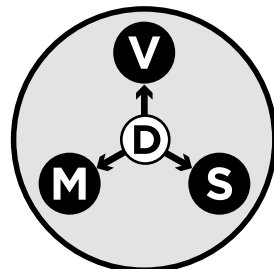
A graphical representation of the classification has been developed to visualize each interactive system. Visually it suggests a representation of an electronic circuit, demonstrating its inputs and outputs. It aims to add a new layer of interpretation on the *S+V+M* framework, as it abstracts the particular specificities of each project and reveals visually patterns of data-flow. It consists of a light grey circle, the interactive system, with a diagram inside. The diagram shows *Sound*, *Visual* and *Movement*'s domains, represented by circles with a letter inside (corresponding to the initial letter of the domain's name). An arrow is then used to connect the domains and reveal the flow of data between them. The visual representation of the system helps us to establish relations between different systems, to group them by similar data-flow, to identity common strategies for audiovisual interactions or to highlight interesting or unusual approaches.

Bellow we have the diagrams for *Deep Web, Spectra-3*, *Axial*, *Quadrotor Show,* and *Symphony #2 for Dot Matrix Printers*, where all share a similar system: a score-base system where all events have been choreographed on a timeline. On the diagrams we see the *D* symbol (representing the data that have been previous scored a timeline) from which three arrows point to three different circles, representing the *Sound*, *Visual* and *Movement* domains. However, *Axial* and *Quadrotor Show* have some distinct details on the system. On *Quadrotor Show,* the drones' movements are previously scored on a timeline but the movement of the moving-heads does not have any pre-sequenced moving patterns, they track the drones' positions and point the lights towards them. So, when categorizing the relations between the domains we can describe it as from *Movement to Movement* (drones' movements tracked by moving-head lights). For this reason, an extra *M* circle was added receiving an input from the other *M* circle.

On *Axial*, we also have an external element that adds variety to the pre-defined events, a gesture interface allows the audience to interact with the system and generate new outputs. In this case an extra *M* circle was added representing the Movement generated by the audience gestures that send inputs to the system that controls all the events, changing this way the predefined choreography.
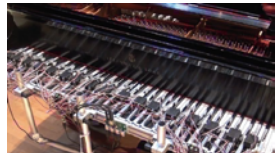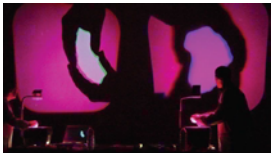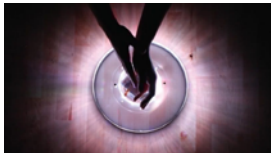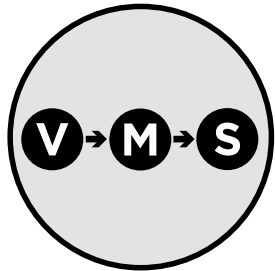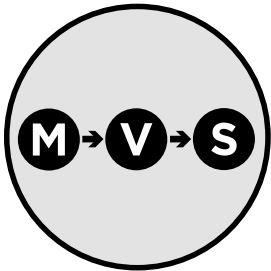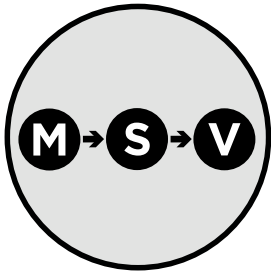
Epizoo has similar data-flow and *S+V+M* classification, but the input source does not come from a pre-sequenced score, but it is being triggered live by the audience on an external interface.

Table12: *Diagrams for Deep Web* (Henke and Bauder 2016), *Spectra-3* (Field 2016), *Axial* (PlayMID 2014), *Quadrotor Show* (Marshmallow Laser Feast 2012), *Epizoo* (Antúnez Roca 1994) and *Symphony #2 for Dot Matrix Printers* (McIntosh and Madan 1999).

Deep Web	Spectra-3	Axial	Quadrotor Show

Epizoo	Symphony #2 for Dot Matrix Printers

The following diagrams represent systems where the data-flow structure is sequential, from one domain to another, and from this one to the next one. All of them share the fact that they are audiovisual instruments, one autonomous (*Cloud Piano*), and the other two used by human performers (*Manual Input Sessions* and *Soft Revolvers*), however in each one of them, the domains are placed in a different order in the flow sequence.

Table13: Diagrams for *Cloud Piano* (Bowen 2014),
Manual Input Sessions (Levin and Lieberman 2004) and *Soft Revolvers* (Bleau 2014).
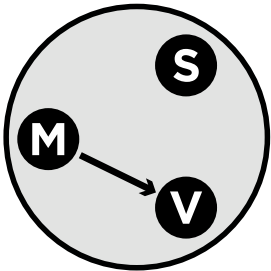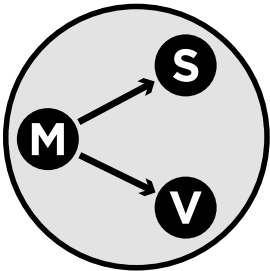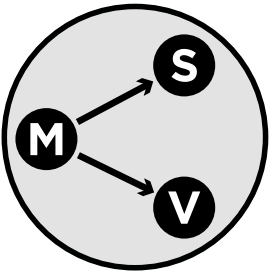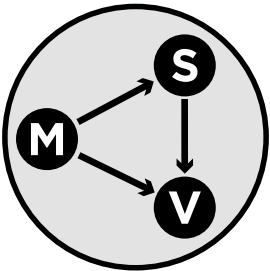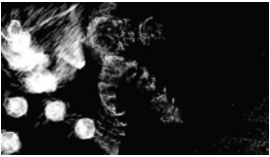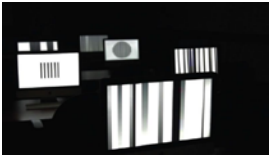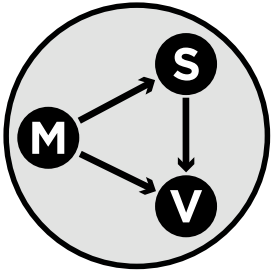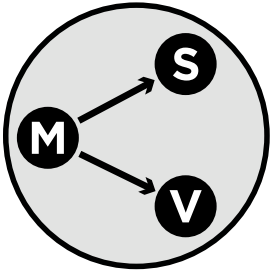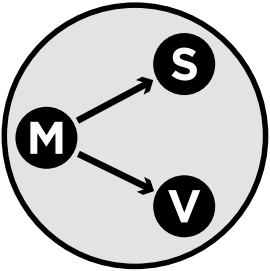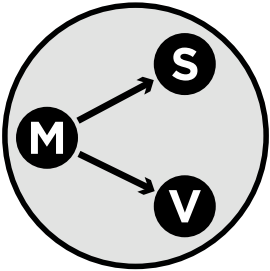
Cloud Piano	Manual Input Sessions	Soft Revolvers

Below we have a collection of cases where *Movement* is used as input for the *Visual* and *Sound* domains. All of them are represented by arrows coming from *Movement* to *Sound* and *Visual*. This typology is the most common on stage performances, since the body is the central element of the performance, and is also used in many interactive installations.

In *Gameplay*, *Luxate*, *Anatta*, *The Trace*, *Biomeditation* and *(Glitch) Music for a Computer Classroom* we have similar setups where the body of the performance is tracked by a camera and its motion data used to generate or manipulate sound and visuals. Besides these, in *Anatta* and *Biomeditation* sound is also used to control visual parameters, so an extra arrow was added. *Apparition* has a similar setup, where the movement of the performer's body is tracked, but in this case it is only used on the *Visual* domain, *Sound* is independent and stand-alone, so its circle was let without any connection. The performance *Hypo Chrysos* has a similar scheme, with *Movement* generating sound and visual, but a completely different approach. Instead of capturing the body's movements with a camera, biophysical sensors are used to capture the inner sounds of the body and use its signal as source for sound and visual generation.

Laser Forest, *Wave is My Nature* and *Will.0.W1sp* are interactive installations that besides different approaches on capturing movement, still have the same diagrammatic representations. On *Laser Forest* the movement's data comes from the vibration of the rods created by visitors interaction, on *Will.0.W1sp* comes from body tracking data (both collected and also from live visitors tracking) and on *Wave is My Nature* from infrared sensors capturing presence on the space.

Table14: Diagrams for *Apparition*(Obermaier 2004), *Gameplay* (Schmitt, Matos and Holst 2005), *Luxate* (Beira 2015), *Anatta* (Delev and Gruberska 2014), *Biomeditation* (Beira and de Quay 2014), *Hypo Chrysos* (Donnarumma 2011), *Will.0.W1sp* (Woolford and Guedes 2005), *(Glitch) Music for a Computer Classroom* (Maheu 2013), *Laser Forest* (Marshmallow Laser Feast 2013), *Wave is My Nature* (Vtol 2015) and *The Trace* (Lozano-Hemmer 1995).

Apparition	Gameplay	Luxate	Anatta

Biomeditation	Hypo Chrysos	Will.0.W1sp	(Glitch) Music For A Computer Classroom

Laser Forest	Wave Is My Nature	Trace
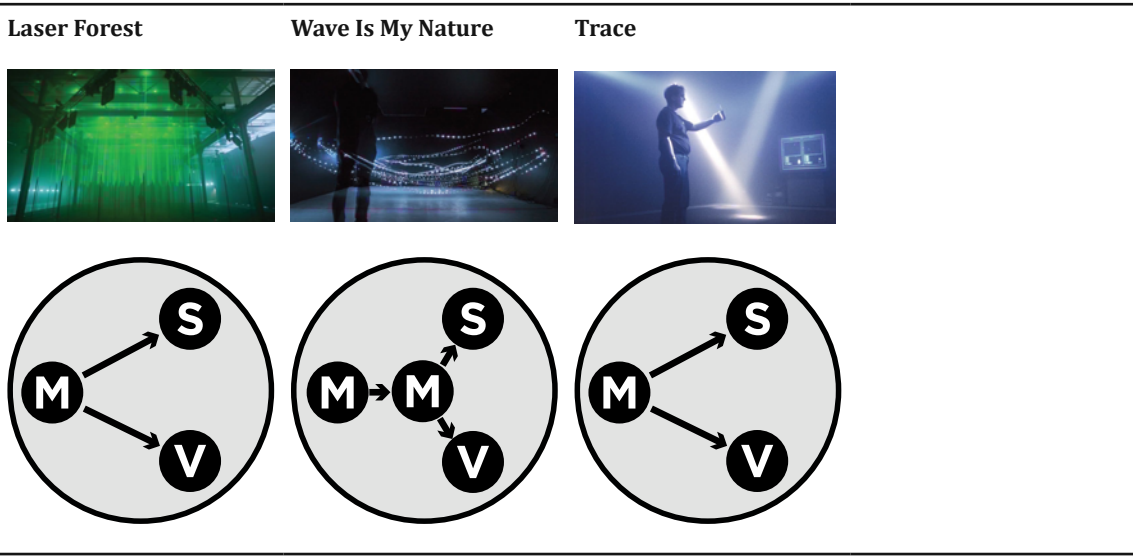
Finally, two more performances that do not share similar configurations with the rest of the case studies: *Atom,* where the *Sound* domain is the source to *Movement* and *Visual* interactions and *Messa di Voce* where *Sound* and *Movement* are the sources, and the data-flow converge to into the *Visua*l domain.

Fig15: Diagrams for *Messa di Voce* (Levin and Lieberman 2003) and *Atom* (Henke and Bauder 2007).

Messa Di Voce	Atom
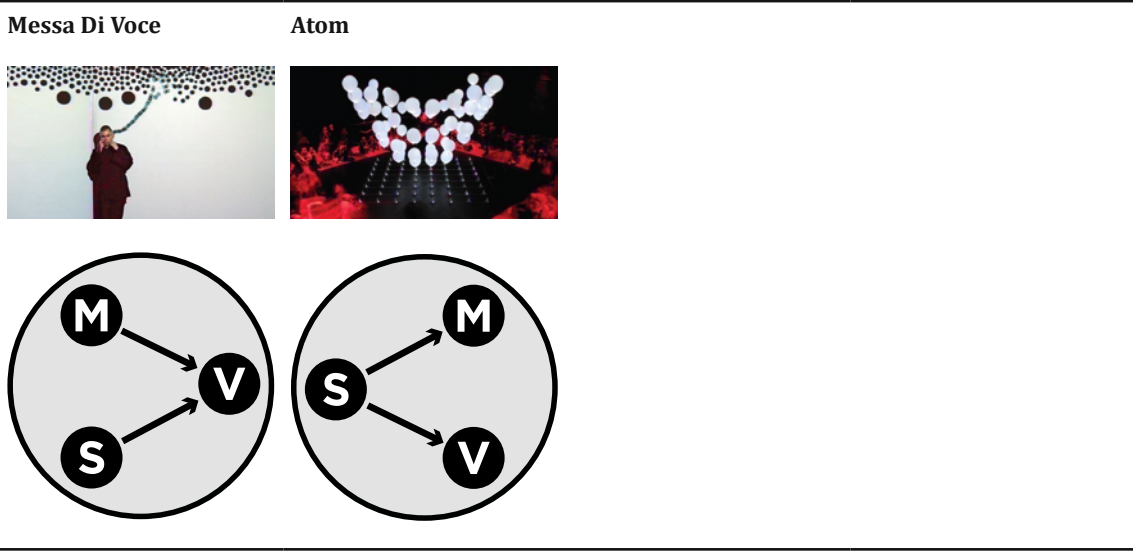
4.5 CONCLUSION

In this chapter it was presented the *S+V+M* framework, that intents to classify interactive artworks based on the flow of data through the interactive system, specifically across the *Sound*, *Visual* and *Movement* domains.

First, it was described this research's approach on interactive systems, and on *Sound*, *Visual*, and *Movement* domains. Then a review from different classifications from the literature on interactive arts was addressed. The features of each classification were described, and highlighted their particular details and contributions for this research. Finally the *S+V+M* framework was presented, explaining its approaches, parameters and goals, and applying them to case studies.

From the twenty-two case studies classified under the *S+V+M* framework, there are some observable data-flow patterns that emerge when observing the classifications.

One pattern that is easily detected on the diagrams is related to the structure of the systems themselves and the way their data is mapped between domains. We can find three different flow structures:

1) The data-flow starts in one domain and diverges to the others, like on *The Trace* (1995)*,* where it goes from *Movement* to *Visual* and *Sound*;

2) Data from different domains converge into one, like on *Messa di Voce* (2003), where it goes from *Movement* and *Sound* to the *Visual* domain;

3) The data-flow structure is sequential, it goes from one domain to another, and from this one to the next one, like on *Manual Input Sessions* (2004).

From these different structure schemes we can instantly make a connection with three different mapping strategies distinguished by Rovan et al. (1997) on their article categorizing gesture mappings strategies for music performance. The strategies *One-to-one*, *One-to-Many* and *Many-to-One*, (despite being developed only for gesture mappings for music performance)*,* are comparable to data-flow structures between the Sound, Visual, and Movement's domains.

Another identifiable pattern is related to which domains are primary inputs or outputs. On the twenty-two cases presented the *Movement* domain is the input for the most part. More specifically *Movement* has the role of input in fourteen cases, followed by the external data sources that is present on six cases. *Sound* domain is the input source only on two cases and *Visual* domain on one case.

Movement being the input for most cases, leads to the most common flow structure: *Movement* to *Sound* and *Visual*. This happens mostly on the interactive dance cases, where the body of the performers is tracked by cameras or sensors and its data used as input for the *Sound* and *Visual* domains. The predominance of *Movement* as input in the case studies is obvious related to the fact that interactive dance performances are one of the focus of the work developed on this research.

As discussed before, *S+V+M* does not intend to focus on technical specifications of interactive systems, but to characterize these systems in a simple and descriptive way. It is focused on the input/outputs, transformations and data-flow occurring across the *Sound*, *Visual* and *Movement* domains to provide a high level of abstraction to frame different types of systems in a common language. Relating them between what they have in

common, and bringing together projects that are often separated by technical details, relation with the audience/participation type and levels of interactivity and outputs.

 S+V+M intends to be not just a tool for scholars, artists or technical experts, but also for the audiences, who, due to the high-level approach of *S+V+M*, can also be able to analyze and make relations between different interactive artworks based on. Just like Kwastek's motivations on her model for interactive art's aesthetics, where the goal was not to present "a purely theoretical model", but "elaborate criteria - based on the concrete observation of exemplary artistic project - that facilitate the description and the analysis of interactive art." (2013, 62).

5. PRACTICE-BASED RESEARCH ARTWORKS

5.1 OVERVIEW

This chapter covers the projects developed in this dissertation as practice-based research. For each one a project-sheet was created, explaining its interactive system and operation modes. A system scheme for each project is also presented, explaining its data flux, interactions modes, the software used and the project setup. Finally, links to access additional documenting materials, as videos, pictures, and code are provided.

The projects are then used as case studies to be classified under the *S+V+M* framework, and their similarities, common parameters, and flows of data are highlighted. Besides the case studies, a series of experimental projects are also presented and documented, that although not being used as case studies, had a significant importance on the development of the research process. Lastly, on section 5.6, two draft projects are proposed as future explorations on *S+V+M* interactions.

5.2 RESEARCH CONTEXT

This research is strongly aligned with Haseman's *Manifesto for Performative Research* (2006). He states that "many practice-led researchers do not commence a research project with a sense of 'a problem'. Indeed, they may be led by what is best described as 'an enthusiasm of practice': something which is exciting, something which may be unruly, or indeed something which may be just becoming possible as new technology or networks allow (but of which they cannot be certain)" (4). This "enthusiasm of practice" perfectly illustrates the paths taken on this research, and the projects that were developed, as many of them were created with the specific goal of exploring new interactions, new relations between domains, and different data sources. As Haseman states "Practice-led researchers construct experiential starting points from which practice follows. They tend to 'dive in', to commence practicing to see what emerges." (Ibid.)

The projects in the following sections are presented in chronologic order, which is important to understand the sequence and unfolding of this research. *Dancing with Swarming Particles* (2011), and *Prefalll135* (2012) were created before the beginning of the doctoral program and had a particular importance in outlining the path, and triggering the core ideas behind this dissertation research.

Boris Chimp 504 has a special significance, as it is an ongoing and continuously work-in-progress, started in 2010, and that followed the entire research work for the past years, working as a free platform for audiovisuals and interactions explorations. It started as an audiovisual live performance, and later evolved to another forms as interactive installations, as the installation series *Non Human Device*. *Boris Chimp 504* and the series of pieces titled *Non Human Device* (with the exception of *#02*), where not included as case studies for the framework as they do not contain interactions on all the three domains, but explore only relations between *Sound* and *Visuals*. They nevertheless had an important role in the development of the research, and for that reason they are reported as part of the practice-based research.

The rest of the projects were developed throughout the years according to exhibition or performance opportunities, workshops, residencies, and research challenges. The interactive dance performances *Breakdown* (2014), *Ad Mortuos* (2015) and *With Oui* (2015) emerged from opportunities for collaboration with the Theatre and Dance Department of the University of Texas in Austin, during a visiting-researcher stay. In all of them different approaches for interactions were explored, from the use of cameras, to body sensors or interaction with devices on stage.

Some projects were created with the specific goal of exploring a particular aspect of the relations between the *Sound*, *Visual* and *Movement* domains. Like *The Interprete*r (2014), a spin-off from *The Breakdown*, that explores recorded motion-data, as source for an audiovisual instrument, or *Floating Satellites* (2014), created under the premise of taking feeds from transport tracking data, and use them to trigger sound and visuals. Before this project, all the motion data used obtained from dancers' bodies. So the main goal of this project was to give a new approach to the *Movement* domain, and evince that all physical movement can be considered as part of the movement domain under this research. After some experiences with databases and live feeds of different transportation data (as airplanes, ships or public transportations) the decision was on position data from satellites in orbit around the planet Earth. Other good examples of projects that were triggered by a will of exploring a specific aspect on the relations between *Sound*, *Visuals* and *Movement,* are found on *Infinite Delta* (2016) and *Drippigment* (2016). On all previous works, the *Movement* domain was always used as input on the system, and never as output. *Infinite Delta* and later *Drippigment* were developed with the aim of creating an interactive kinetic mechanism that could generate movement according to different interactions and data inputs, in a way that the domain *Movement* could be an output.

5.2.1 *BORIS CHIMP 504* (2010-...)

Boris Chimp 504 started in 2010 as an audiovisual live performance. The project's name was taken from a speculative fiction article written by Dwayne Allen Day in 1969[1]. The article is about a chimp cosmonaut who was sent on a mission to the moon and never returned, his last communication being sent from the moon's surface on July 7th 1969. The audiovisual live performances take this fringe event as a starting point for its narrative and sound and visual aesthetics.

The live performances are created from improvised sessions where music and visuals follow a common path, but where nothing is predetermined. It is a real time interactive/reactive system between the audio and the image, between the human and the machine. It has been presented in a range of events and venues, as Micro-Mutek and Sonar in Barcelona, Passos Manuel in Porto, VAVA's events in Berlin and Milan, Som Riscado Festival in Loulé, Noites Brancas in Braga, or BAM Festival in Liège. [2]

Fig. 69: Picture from a *Boris Chimp 504*'s AV live performance at Noites Brancas in Braga, 2015. The gear table is always positioned in a way that both performers can see the visual output during the performance.

The visuals are developed in Quartz Composer[3], rendered in real-time and react to the sound. The visual work process starts on the development of small and independent visual patches where a series of parameters are selected to be controlled live (e.g. rotation, dimensions, or color values). The patches are then grouped and mounted on VDMX, a software for live performance that is able to trigger and manipulate Quartz Composer patches in real time. The parameters that were selected on every visual patch are now visible on a menu inside VDMX, and each can be mapped, automated or synced to any signal, as sound frequencies, MIDI and OSC messages, or LFO signals.

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1 "Details of the Soviet Primate Lunar Landing Program", Dwayne Allen Day, 1969. < http://www.astronautix.com/b/borischimp504.html >. Accessed 2015.12.10.

2 Full list of appearances at Boris Chimp 504 website <http://borischimp504.com/>. Accessed 2017.10.10

3 Node-based visual programming language provided as part of the Xcode development environment in macOS
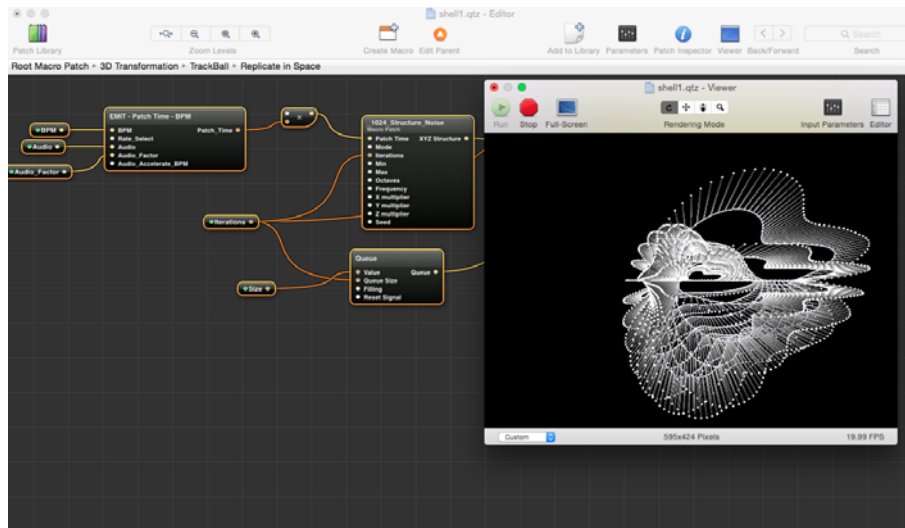
Fig. 70: Print-screen from Quartz Composer where the reactive visual shapes are created through visual programming and nodes logic. Specific shape's parameters are chosen to be controlled in real time during the performance
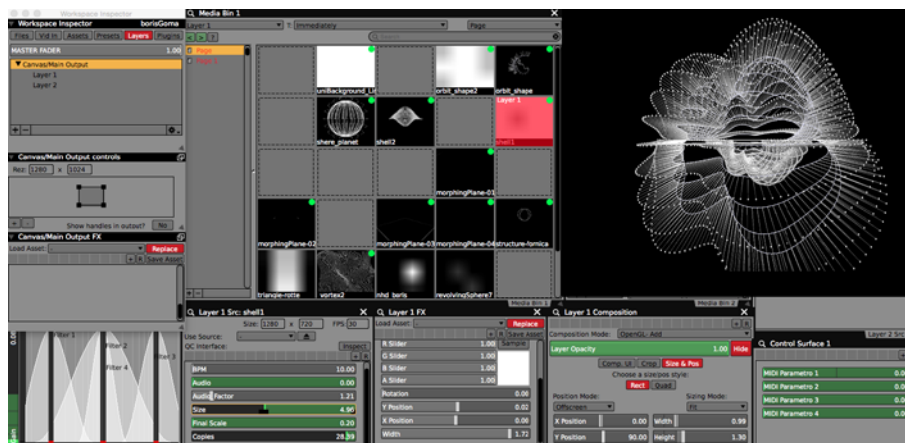
Fig. 71: Print-screen from VDMX where the visual patches are combined and manipulated live. On each visual patch the parameters that were previously chosen to control its shape are visible here and can be mapped many types of real-time data as audio frequencies, MIDI devices, OSC messages or LFO signals.

A narrative for each performance is then lined up experimenting which visuals react better to each sound and vice versa. Despite the predefined narrative path, during the performance, sound and visuals evolve in an organic and explorative way, with the goal being to start in a specific audio and visual content, going through some checkpoints and finishing in another place, but what happens in middle is unpredictable and undetermined.

Although technically the visuals are dependent from the sound, what happens on stage is that the reactive visuals influence in many ways the sound being produced. Miguel Neto is on stage watching the visuals and the effects that sounds produce on them. This allows him to explore and manipulate the sounds according to the visual output. In a way this is very aligned with Ryoji Ikeda and Alva Noto's description on *Cyclo.Id* book: "… we abandoned the idea that image acts only as a functional accompanist to sound and instead subordinated the audio element for our desire for the image." (2011).

While manipulating the sound, when Neto discovers a visual reaction that he finds interesting, he tries to identify the direct connection from the sound with that specific

visual output and he explores it, thus inverting the system and subordinating the sound to the desired visual output. The informal, explorative nature of *Boris Chimp 504* leads the project to evolve from being only an audiovisual live performance to evolve to different media and outputs as interactive installations (described in the following sections). In sum the project works as an experimental audiovisual laboratory for interactive audiovisual creation.

Credits: Rodrigo Carvalho (Concept, Visuals); Miguel Neto (Concept, Music). Documentation and videos from the live performances can be found at Boris Chimp 504's website: <http://borischimp504.com/>.

5.2.2 *NON HUMAN DEVICE*

Non Human Device, a series of interactive installations where experimental audiovisual devices are explored, is a spinoff from *Boris Chimp 504*. The installations share the same narrative and science fiction aesthetics, and every version is based on an alien object found by *Boris Chimp 504* during its missions through deep space.

According to the official speculative fiction narrative:

> *During an exploration to Kepler-22b, an exoplanet from the Kepler-16 binary star system, Boris Chimp 504 found a metallic object on its surface. Though the origin of this object is totally unknown, it's probably a piece of technology from an extra-terrestrial civilization. Boris has sent this object in a hyperspace capsule to the Vladivostok Space Center, on Earth.*
> *It is believed that it's a part of a machine, a mechanism or a device of some kind. Recent investigations on the object lead to believe that it is an interface to control the position and orientation in space and time of something bigger, a spaceship maybe.*
> *The device (...) generates an electromagnetic field that interferes with audiovisual signals and causes space-time distortions.*
> (Carvalho and Neto 2013)

To support the fictional narrative a set of pictures were created illustrating Boris's mission on Kepler-22b's surface. These pictures intentionally imitate the style of pictures sent by real space missions, like those from the Curiosity rover on planet Mars.[4] Pictures were then sequentially shared on Boris's social media account on the weeks prior to the installation opening, documenting and informing the audiences about Boris's mission and findings.

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4 Curiosity is explorer robotic car that arrived on Mars' surface on August 2012 as part of NASA's Mars Exploration Program. <https://www.nasa.gov/mission_pages/msl/index.html> Accessed 2015.12.10

Fig. 72: Picture from Kepler-22b's surface.
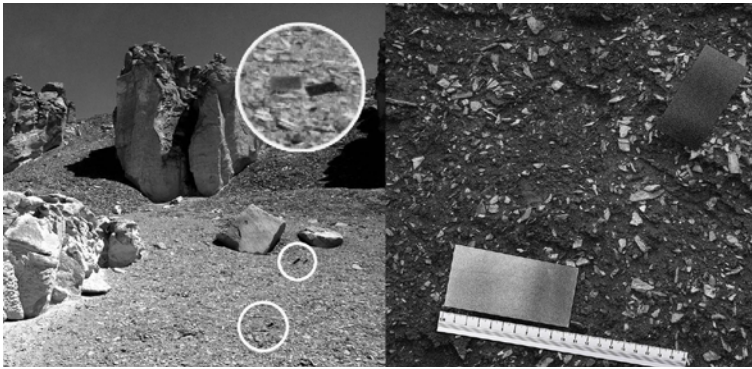
Fig. 73: Documentation from Boris's findings on the planet surface. An unknown metal object that was then sent to Vladivostok Space Center on planet Earth for further analysis.
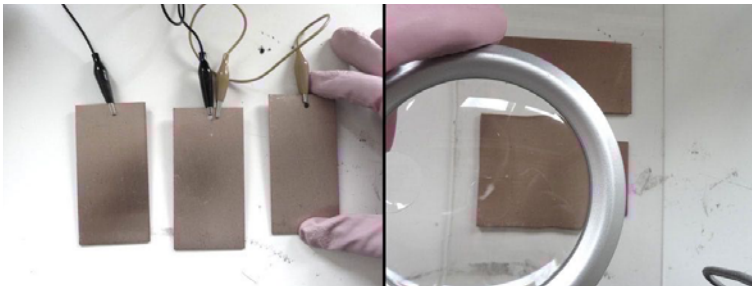
Fig. 74: Metallic objects being analyzed by scientists at Vladivostok Space Center.

These installations are used as a laboratory for possible future stage instruments for the live performance. It is also an opportunity to present audiovisual content in a different format and to communicate with the audience on a different level. Three installations have already been developed, and in every version a new interface is presented, with whom the audience is invited to interact and explore with sound and visuals in real time. More information can be found on the project page[5], and on the article *Boris 504's Non-Human Device Challenges Viewers to Take a Trip into Space with a Soviet Chimpanzee* by Sean Higgins[6].

5 <http://www.borischimp504.com/nonhumandevice/> Accessed 2015.12.10

6 "The Creators Project". Jan 2014. <http://thecreatorsproject.vice.com/blog/boris-504s-non-human-device-challenges-viewers-to-take-a-trip-into-space-with-a-soviet-chimpanzee> Accessed 2015.12.10

5.2.2.1 *NON HUMAN DEVICE #01*

The first version of *Non Human Device* was presented at the Convent San Agustin, Barcelona on February 2013 as part of Micro-Mutek Festival, and later at Montemor-o-Novo (Cidade PreOcupada 2013), at Edificio AXA, Porto (DeBandada 2014) and Abrantes (180 Creative Camp 2015). The installation was based on the first objects found by Boris Chimp 504 on Kepler-22b surface, which were four similar metal pieces, each one with 10x5cm.

The metallic pieces are used as a capacitive sensor, a technique which uses human body capacitance as input. When a visitor touches one of the metallic pieces, their electrical capacitance is detected and an analogue signal is sent to the system. Each of the four metallic pieces controls a different parameter on the sound and visuals controllers.

The metallic pieces are mounted over a box, housing an Arduino micro-controller is hidden and used to read the capacitive sensor values. A dedicated computer running a Max application is constantly reading and parsing the values received by the Arduino and mapping its values to MIDI messages that are then sent to Quart Composer to manipulate the visuals and to Ableton live to interact with the sound.
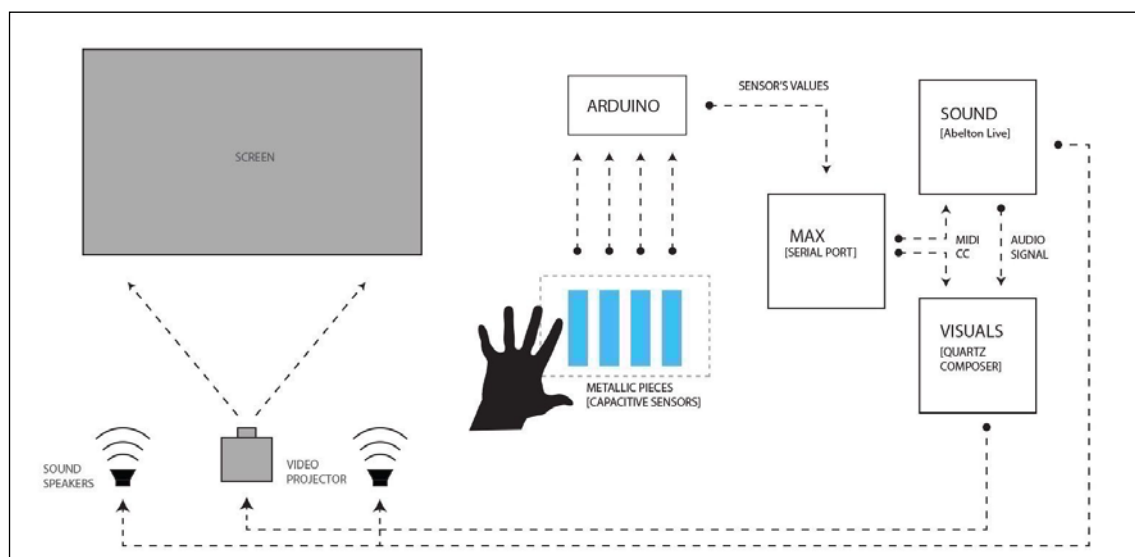
Fig. 75: Non Human Device #01 interactive system scheme.

In Quartz Composer a geometric three-dimensional shape is generated and projected on the front wall. The shape is composed by different arrays of cubes replicated around three axes. When interacting with the system the user controls the angles of replication on the different arrays, controlling this way the final shape of the virtual object.

Different combinations on the four parameters result on different outcomes with different shape characteristics and sizes. Apart from the parameters controlled by the device, the shape itself is constantly in motion and rotating, making the interaction with it unpredictable. Behind the geometric shape a background of dots and lines reacts to sound analysis by blinking and changing form in response to sound peaks. At the same time an Ableton Live project is running, playing a background drone sound and waiting for MIDI messages that will activate new channels and modulate sound filters.

Fig. 76: Left, the device with the four metal pieces on the top of a parallelepiped box; Right, a user interacting with the installation by touching on the metal surfaces.
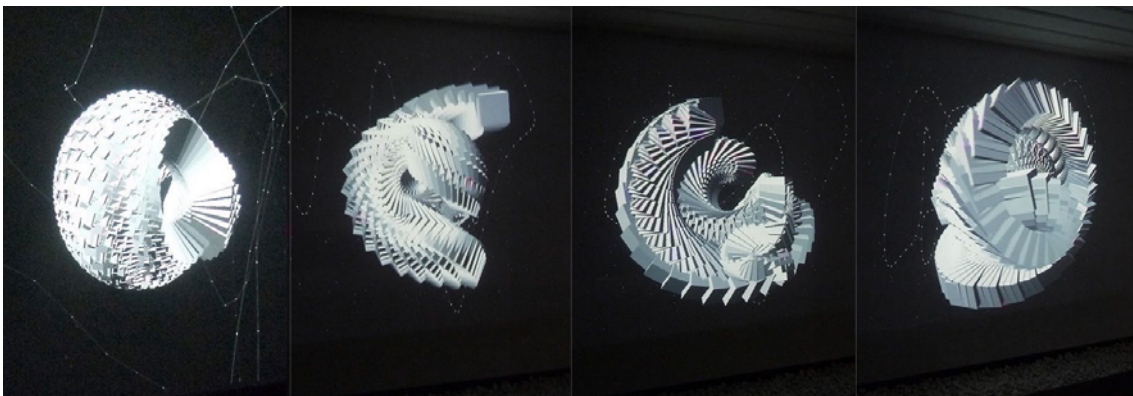
Fig. 77: Different moments of the visual shapes. While interacting with the device different parameters are manipulated resulting in different shapes on the visual output.

Besides the interaction with visuals and sounds the object itself also contains a visual light feedback. A bright LED light placed inside device illuminates its surface, when a user touches the device the light reacts with pulses.

The installation runs autonomously generating a constant and evolving visual and sonic outputs. The physical device, that works also by himself as an expository object, allows users to experiment with the installation as an explorative audiovisual instrument.

Credits: Rodrigo Carvalho (Visuals, Electronics, Interactive System); Miguel Neto (Music), 2013. A video documenting the interaction with the installation can be watched on the project's online documentation:
<http://visiophone-lab.com/wp/?portfolio=non-human-device-001>.

5.2.2.2 *NON HUMAN DEVICE #02*

On the second version of *Non Human Device* the audience interacts with sound and visuals in real time through a gesture based interface. This version was presented at xCoAx 2014 conference in Porto and at Mira Festival in Barcelona in 2015. As the previous version the project is based on a device found by Boris Chimp 504 on the surface Kepler22b, this time a luminous cylinder object. By moving the hands over a device users manipulate in real-time a three-dimensional virtual creature and interact with the sound parameters.
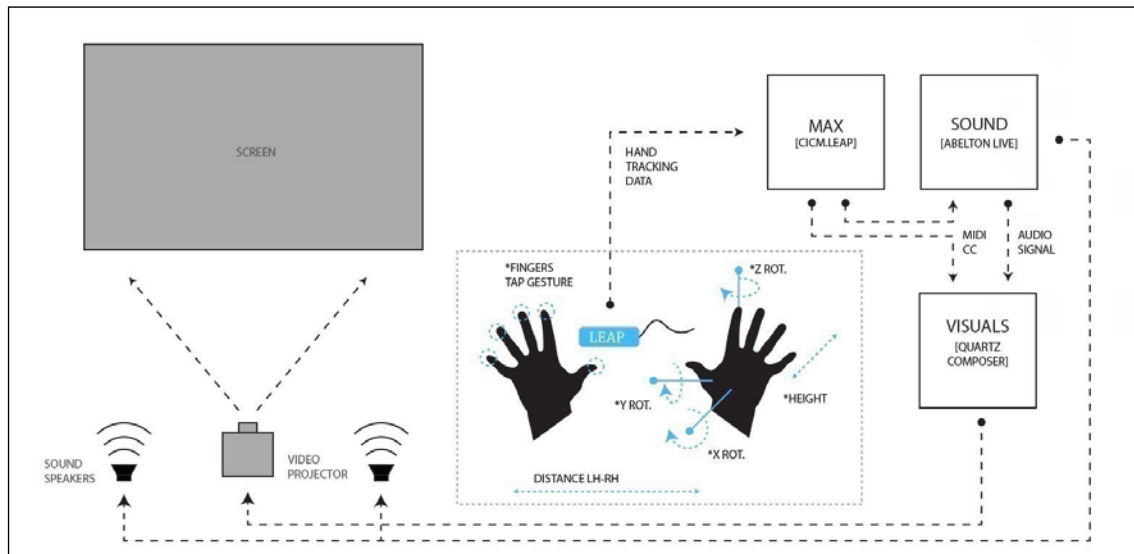
Fig. 78: Non Human Device #02 interactive system scheme.

Inside the luminous object there is a *Leap Motion* device, which is an infrared sensor that captures hand and finger gestures over it.

The setup and functioning of the installation is similar to the #01 version. It is constituted by a device placed in front of a video projection where a virtual is being shown. The shape of creature, which resembles a jellyfish, is built by the replication of groups of lines in a three-dimensional virtual space, it is continuously rotating and lies on a dark background with flickering points connected by lines. When a user moves their hands over the device a series of parameters are detected (hand ID, tap gesture, hand positions and rotation) and used as input in the interactive system.

Motion data is captured in Max with *CICM.Leap* object[7], the data is then parsed and sent as OSC to Quartz Composer to manipulate the visuals and as MIDI to Ableton Live to manipulate sound. The rotation of the hand controls the orientation of the creature in space and the height changes the size of its *legs*. When two hands and over the device the distance between both also changes the dimension of its body. The same parameters that are manipulating the shape are also being send as MIDI messages to an Ableton Live project that is constantly running a background drone environment and waiting for inputs to manipulate audio filters. Some specific visual elements like the dots and lines on the background and some graphical elements from the creature react to audio frequencies.

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7 Leap Motion Controller object for Max6. Developed by Eliott Paris at CICM (Centre de recherche Informatique et Création Musicale). <https://github.com/eliottparis/Leapmotion/tree/master/cicm.leap>. Accessed 2015.12.10
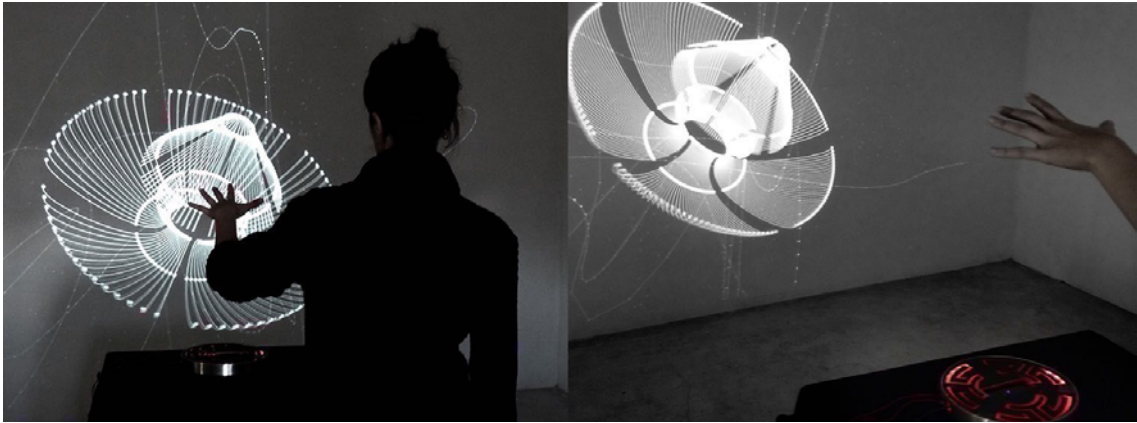
Fig. 79: A user exploring Non Human Device #002 by making hand gestures over the device.

Like the first version, *Non Human Device #02* is an audiovisual interactive system that is running autonomously, generating constant and evolving visual and sonic outputs, and waiting for human interaction. It is in the borderline between an exploratory sound and vision instrument, an art installation and gaming experience.

Credits: Rodrigo Carvalho (Visuals, Electronics, Interactive System); Miguel Neto (Music), 2013. A video documenting the interaction with the installation can be watched on the project's online documentation:
<http://visiophone-lab.com/wp/?portfolio=non-human-device-002>.

5.2.2.3 *NON HUMAN DEVICE #03*

Non Human Device's third version was developed and presented during an artistic residency, in April/May 2016, at GNRation[8] in Braga, Portugal. In this version the device is built based on an infinite mirror effect. A strip of LEDs is placed between two parallel mirrors, on the bottom a normal one (one-way mirror) and on the top a two-way mirror and mounted on the top side of a blackbox. This way the light from the LEDs reflects in both mirrors and bounces infinity, creating to the observers the appearance of an infinite light tunnel.

The device works in a similar way to *Non Human Device #01's.* A metallic part, placed on the top of the box, is used as capacitive sensor and when a visitor touches it, his electrical capacitance is detected and an analogue signal is sent to the system.

The values from the capacitive sensor is read by a Max application and it is then mapped to MIDI CC messages, and sent to Quartz Composer to control visuals in real-time and to Ableton Live to manipulate sound parameters.
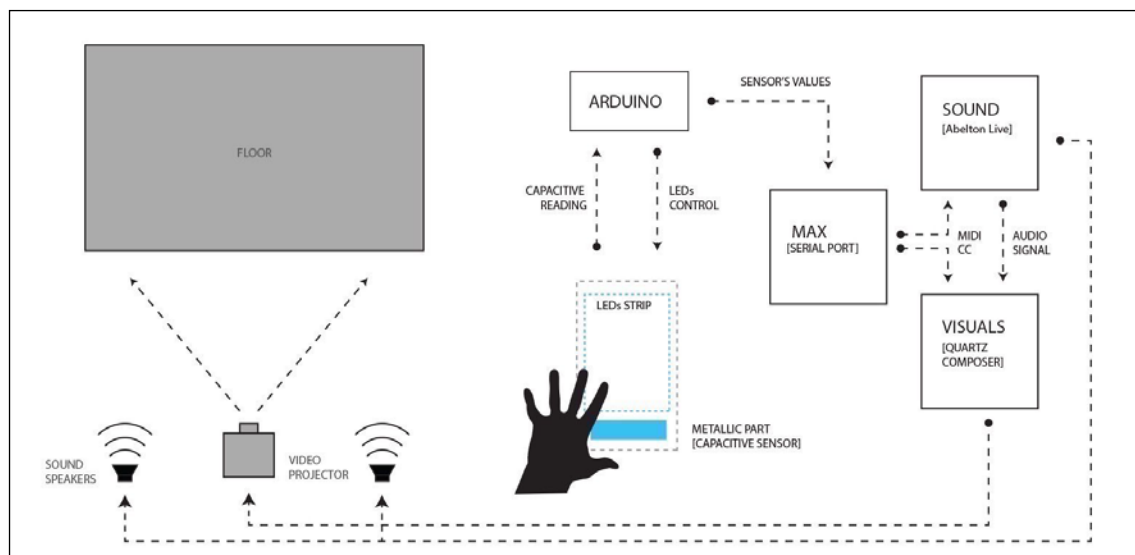
Fig. 80: Non Human Device #03 interactive system's scheme

The visuals are composed by an array of lines oriented to the center of the projection composing a circular shape. The size of lines is related to the sound amplitude. The first line of the array is directly connected to the sound amplitude, increasing and decreasing its size according to the current amplitude. Its value is then passed to the following line in the array, and so on, thus creating a spiral wave in a tunnel-like shape. In the background a mesh of points is also constantly moving and morphing its shape according to sound frequencies. The visuals are projected on the floor, and the tunnel like shape in the floor helped to create a sensation of a wormhole, a window to another dimension.

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8 GNRation, Braga. <http://gnration.pt/>. Accessed 2016.09.20

Fig. 81: User exploring the Non Human Device #03.

The lights array on the device produce a direct feedback to users' interactions. When no one is interacting, it is constantly and softly lightning up and down random lights. When a user touches its surface a fast light sequence is triggered, highlighting the infinite mirror effect and creating a strong visual relation by the infinite light tunnel effect visualized on the device and the visuals on the floor.

Credits: Rodrigo Carvalho (visuals, electronics, interactive System); Miguel Neto (Music), 2016. A video documenting the interaction with the installation can be watched on the project's online documentation:
<http://visiophone-lab.com/wp/?portfolio=non-human-device-03>

5.3 S+V+M ARTWORKS

5.3.1 *DANCING WITH SWARMING PARTICLES* (2011)

Dancing with the Swarming Particles is an interactive dance performance created and presented in 2011 at the research group SPECS[9]. In this piece a performer interacts in real time with an avatar made of a swarm of particles in a generative virtual world. The performance came out as a continuation of a previous SPECS's interactive dance performance called *Re[per]curso[10]*. The goal of the project was to create an interaction between a physical performer and his avatar, which is made of morphing flocking particles, in a mixed media space. It explores the potential of virtual reality and augmented feedback technologies as tools for artistic expression.

The performance's environment is a mix media space that includes a physical space and a virtual one. The physical space is the stage where the human performer dances, and the virtual one is a parallel world projected on a frontal screen, working a mirror of the physical one. It is composed by a virtual landscape and swarming particles that will shape the performer's avatar. The project intends to show and mix two similar parallel words (the real and the virtual one) in order to create a mixed media space. The performer must explore and discover the space and create a relation with her avatar.
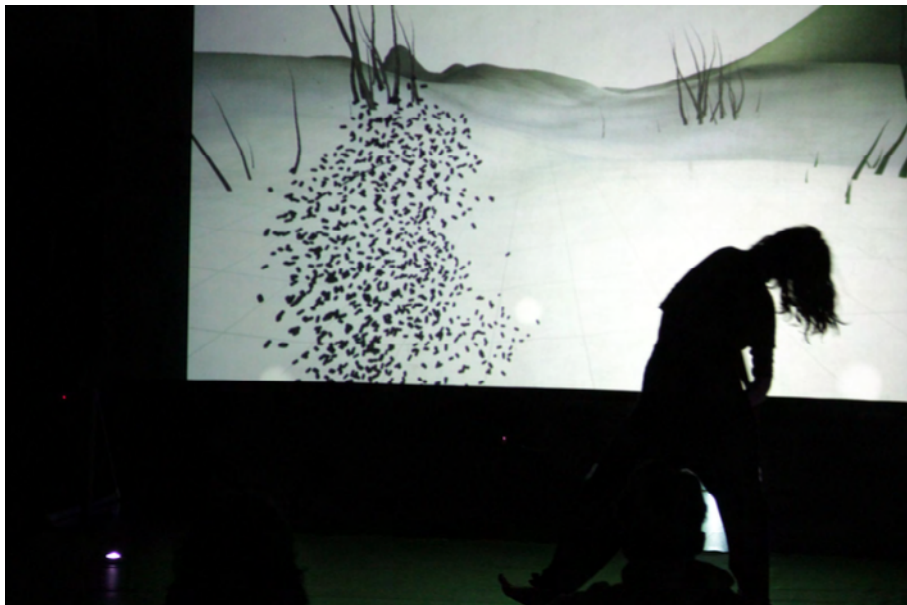
Fig. 82: Dancing with the Swarming Particles, interactive dance performance, Barcelona, 2011.

The narrative of the piece develops around the creation and destruction of an avatar in the virtual world, it is a loop of life creation and destruction to create again. In the beginning the performer enters the space and there is no avatar, the virtual world is composed

9 SPECS (Synthetic Perceptive, Emotive and Cognitive Systems group). Universidad Pompeu Fabra, Barcelona. Internship under the INOV-ART program (DGA-ARTES - Ministério da Cultura - Portugal)

10 "Re[per]curso" Performance presented in 2007 at the MACBA (Museu d'Art Contemporani de Barcelona) and in 2008 at the Art Futura festival at the Mercat de Les Flores. <http://specs.upf.edu/installation/548>. Accessed 2015.12.02

by an endless terrain and a swarm of particles floating around without any apparent order. The performer starts by exploring and discovering the space and, in the course of time, their movements start to feed the virtual world with data and the floating particles start to morph into the avatar's body. During this process, motion data from the performer is used to feed the system, and step by step the particles, that are originally moving randomly, become attracted to parts of the body and start to shape the avatar body which becomes a virtual version of the performer's. Particles fly all around the space moving nervously submitted to different and opposite forces. On the one hand the particles have their natural flocking flying behaviors, on the other hand, there are forces that attract them to form the avatar body.

In the end of the process all the particles are attached to the body and the avatar is created. The virtual world is now full of data and enters in chaos mode, its life circle is reaching the end and it starts to collapse. Strange gravitational forces are pulling the particles away and devastating the virtual world. The avatar's particles fall apart and the world is destroyed.
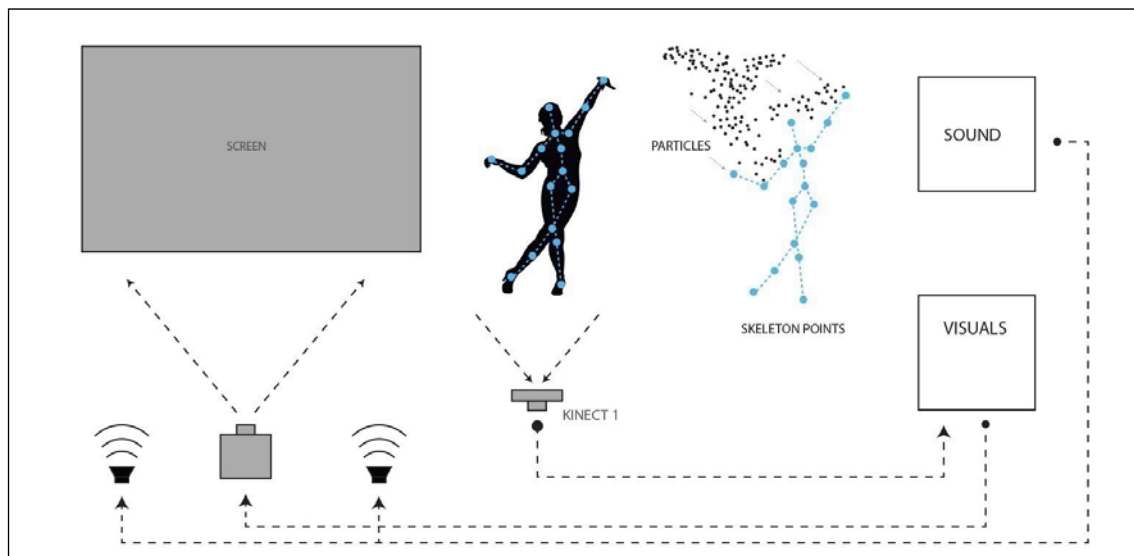
Fig. 83: *Dancing with the Swarming Particles* interactive system' scheme.

The interactive system is built using the 3D engine Unity3D, with which the landscape is generated, virtual cameras are positioned and the particle system is implemented. The avatar's body is composed by a cloud of particles that have flocking behaviors attached. The flocking system is an implementation of *Boids*[11] The flock is formed by 22 smaller groups of particles. Each group is composed by 20 to 40 individual agents that according to a set of rules to keep them flying together (separation, alignment, cohesion), following a common target for each group. In the beginning, the targets are flying randomly around the space, then over the course of the performance each target is pointed to a joint of the performer's body, leading the particle swarm to shape the avatar body. The body tracking is made using a Kinect camera. The skeleton data is then fed into the Unity3d, where all the content is generated and controlled.

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11 Boids refers to "bird like objects", the artificial intelligent system created by Craig Reynolds to simulate the flocking behavior of birds (1987)
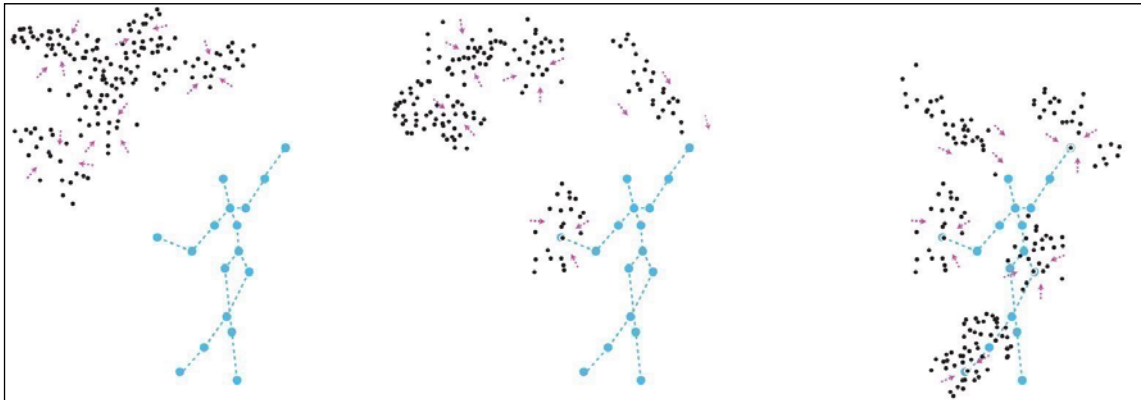
Fig. 84: Different groups of boids following its targets. On the left targets positioned randomly in the space, on the center and right side targets are pointed to the skeleton joints leading the boids to shape the body.

Fig. 85: Participants from the audience exploring the system after the performance.

The timeline of the performance is controlled by an external operator, placed outside the stage, that controls the time, the management of the different scenes and the sound. The performance goes through seven different scenes. In scene zero the performer enters and discovers the space and the particles flying around; in scenes one to five, groups of particles incrementally start to form the body (being the last one the full avatar body); and on scene six the destruction of the avatar is triggered. During the performance space and avatar evolve, rebuild themselves, and mutate depending on the user's behaviors. The ultimate form of the avatar and the virtual space result from the data generated by the performer and is represented by the graphic visualization of the interaction, in this way each interaction/performance has a unique outcome. In the end of the performance the audience was invited to explore the system and interact with their own avatar of dancing particles.

Dancing with Swarming Particles' interactive system is classified as **M >V, [S]** (performer's body is tracked and its motion data used to interact with the visuals, sound is autonomous).

Credits: Rodrigo Carvalho (Interactive Visuals); Tamar Regev (Dance and Choreography); Anna Mura (Coordinator), 2011. A video from the full performance can be watched on the project online documentation:
<http://visiophone-lab.com/wp/?portfolio=dancing-swarming-particles>.

5.3.2 *PREFALLL135* (2012)

Prefalll135 is an interactive audio-visual installation that uses the energy of falling water to make water mills rotate, thus generating sound and graphics.

It was developed between 2009 and 2012. The first prototype was created during the Digital Arts Master degree (Universidad Pompeu Fabra, Barcelona) as a project for the "Sound and Visual Generation" course unit, where the goal was to create a new interactive audiovisual sequencer. Later in 2011 and 2012 a new version was developed and presented at *Algoritmos Creativos* exhibition in Montemor-o-Novo and Lisboa (with the support of Ciência Viva) and at *Fabra-i-coats* and *Sonar festival* in Barcelona (with the support of Phonos Foundation).

Fig. 86: Picture from the installation. A user interacts by opening and closing the water-taps. On the back real-time visuals are projected.

Prefalll135 is an audiovisual instrument whose parameters are influenced by the kinetic energy of the falling water. The concept is to combine nature and technology and in this way explore the expressive results of these two interactions, so it works like a fountain or waterfall, it is autonomous and constantly working, the water flow never stops, but the human intervention will change and determine the outcome of the sound and images output.

The installation is composed by a transparent acrylic box, where an engine pumps the water to the top of the structure. The water falls through three different levels until the bottom of the box creating this way and endless close circuit.

In each level three taps enable the user to control the water circuit and define the path that the water will follow. Below each tap there is a water mill that rotates with the energy

of the falling water. By opening and closing the taps, the user is controls the water circuit and defines the path that the water will follow and on which mills it will fall. The rotation of each mill is read by sensors that send that data to the audiovisual system. This way by deciding the path of the flux of the water, the user is controlling parameters of the audiovisual generation.
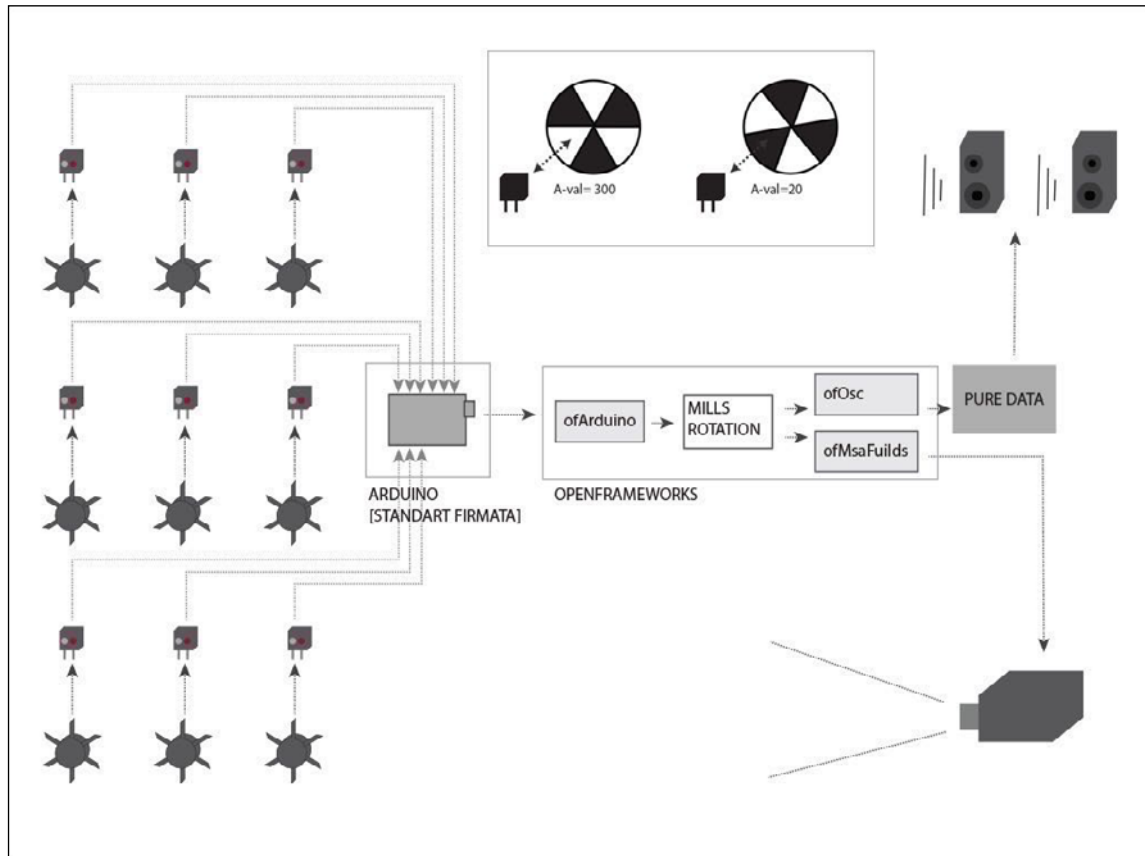
Fig. 87: Prefalll135's interactive scheme. Data from the rotating mills is captures on an Arduino, and sent to sound and visual applications.

Each mill has a small disk attached to its back, painted with black and white lines. When the mill is rotating, an infrared sensor facing the disc is used to read the refraction of light, which changes depending if it is reading a white or a black part of the disc. The difference between the values and the time is takes to change, between black to white, is used to determinate the velocity of the rotation of each disc. These values are then sent to the system to modulate dynamic evolutions of the sound and to generate visuals.

A virtual sound synthesizer, developed in Pure Data, is receiving OSC messages with the rotation values. Each mill affects concrete parameters of sound in a way that each one affects in individual ways the final composition. The sound generation is divided in three modules with different approaches to sound synthesis: Additive (which mimics the sound of wind); Subtractive (generates a rain-like sound); Granular synthesis (produces sounds similar to water drops).

Fig. 88: Close view, water falling from one tap over a mill. Below a reservoir holds the water.

On the back of the structure a video projection fills the entire surface with real-time graphics. The visual system is composed by two different outputs: a fluids simulation and a swarm system. The fluids simulation, based on the MSAFluid library[12], intends to represent the energy emitted by the mills when in motion, so being each one a dynamic fluid grows when the corresponding mill is in motion. At the same time a swarm of fish is moving around the surface and a gravitational force, also positioned behind each mill, attracts or repels the swarm depending on the rotation values being received on the system.

Prefalll135's interactive system is classified as **M>SV** (falling water makes mills move and its rotation data is used to generate sound and visuals).

Credits: Rodrigo Carvalho; Javier Chavarri; Katerina Antonoupoulou, 2012. A video documenting the installation can be watched on the project online documentation : <http://visiophone-lab.com/wp/?portfolio=prefalll135>.

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12 MSAFluid is an opensource C++ / Java / AS3 library for solving and displaying real-time 2D fluid simulations, by Memo Atken. <http://www.memo.tv/ofxmsafluid/> Accessed 2015.11.23

5.3.3 *BREAKDOWN* (2014)

Breakdown is an interactive audiovisual dance performance presented at the *Ears, Eyes and Feet* event in the B. Iden Payne Theater, May 2014, UT Austin, Texas.

The dance piece is performed by two performers on stage whose movement is used as an input to generate and manipulate visuals and sound. *Breakdown* explores a two-dimensional simulated world in which the physical rules are constantly being changed and manipulated by an external entity. An inhabitant of this world is in constant motion to adapt to its characteristics. He interacts with the physical rules and develops a dialogue with the entity who controls the forces. Eventually the inhabitant ends up breaking the world's rules and releasing himself into a new world, a new dimension.

The setup is composed by two Kinect cameras, placed on the stage front, a back projection and two computers managing each one visuals and sound. The two performers have different roles: the main performer dances, while the second sings and performs hand gestures that control the sound. The first Kinect camera tracks the dancer's movement and extracts their silhouette. An *Openframeworks* application running computer vision software is used to extract the dancer's body from the background and to extract an array of points around its silhouette. A group of five points is then determined, representing the central point of the body, the top point, the below on and the leftmost and rightmost. A list with the position in space of these points is then sent through OSC to the computer generating the visual content.
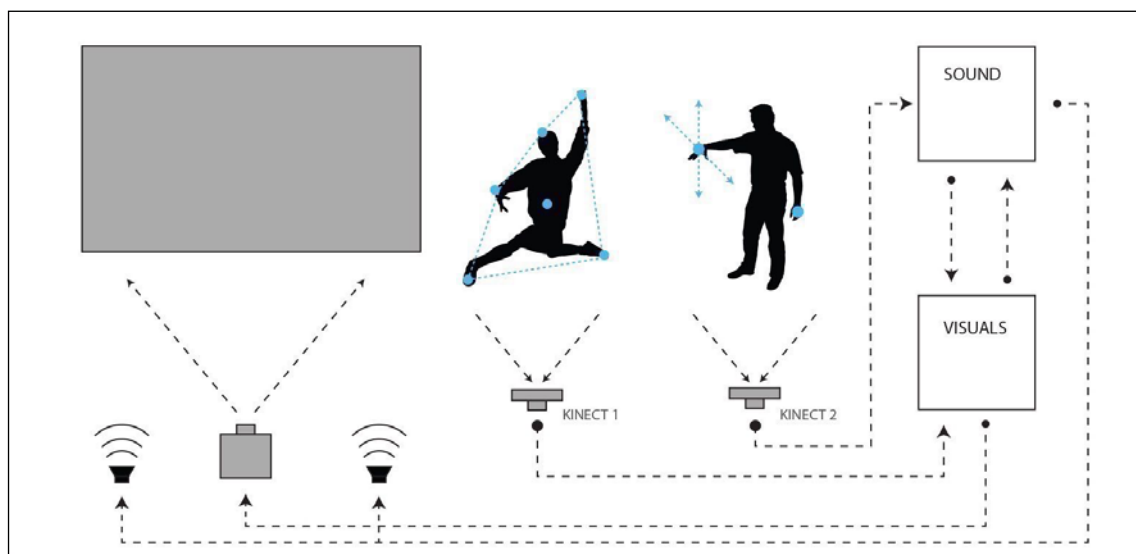
Fig. 89: Breakdown's interactive system's scheme.

The visual content, projected on the back of the stage, consists of a real time gravitational particle system simulation. It is developed with Processing toolkit and uses the *toxiclibs library*[13] to handle the particle system. The particles are exposed to different attracting and repelling forces, which influence their behavior and movement. These forces are divided in two groups: the world's gravitational forces which make the particles fall in

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13 Toxilibs, a collection of Java's libraries for Processing to work with physics, particle systems and geometry among others. <http://toxiclibs.org> Accessed 2015.11.16.

the floor, go up or float in the air; and a group of moving forces which are attached to the dancer's body movement. The position and shape of this group of moving forces correspond to the dancer's body points, which are constantly being updated with the stream of data, receiving OSC messages from the Computer Vision application. The forces attached to these points attract and/or repel the particles on screen, deforming and influencing the movement of the system.
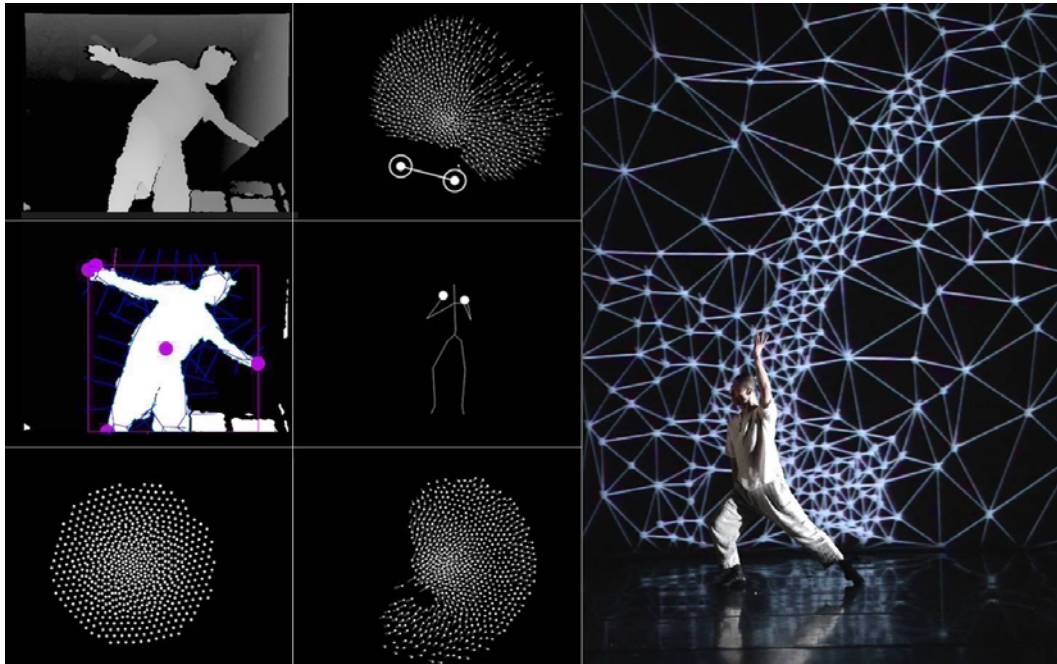
Fig. 90: Top Left: View from the computer vision's application. Body points extraction; Middle: Body points affecting the particles system; Bottom Left: Particle System on motion; Right: Dancer on stage with the particle system following his body movements.

The second performer sings on specific scenes and through gestures, captured by the second Kinect camera, controls different parameters of the soundtrack (modulate filters, trigger events), of the particle system (creating/erasing particles, changing the simulation rules and gravitational forces) and global parameters of the interactive system (changing scenes). The second performer's gestures are captured by NI-MATE[14], a Kinect based body tracking software, and sent to a custom application developed in Max which controls the soundtrack and the timeline of the performance.

The performance is composed by a set of different scenes, each with different configurations on the visual and sound parameters. In some scenes the particles are floating without gravity, on others they are affected by gravity, on some the dancer's body points attract the particles (forcing them to mimic the body's shape), on other scenes the body's points repel the particles forcing them to move away. The particles' features themselves also vary according to the scenes. On the beginning they are only points in space, later they are connected with lines as a Delaunay Diagram[15], and on others each point is independent and leave a line as a trail when in motion.

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14 NI-MATE. <https://ni-mate.com/> Accessed 2015.11.16.

15 An optimal triangulation of a given set of points. Named after the mathematician Boris Delaunay. Implemented using Mesh Library for Processing. <http://leebyron.com/mesh/> Accessed 2015.11.16

To conclude the performance, the digital particles on the screen disappear and are replaced by physical particles (ping pong balls) falling from the ceiling, wrapping the dance piece with a dramatic ending. Regarding the flow of data through the domains: motion data from the performers' movements are sent to Sound and Visual domain, and used as input to manipulated audiovisual content. Also between Sound and Visual domains data is exchanged, particles positions and velocity information are used to feed sound parameters and sound events are used to determine rules of the particles system.

Breakdown's interactive system is classified as **M > SV, S > V** (performers' bodies are tracked and its motion data used to interact with the visuals and sound, and the visuals also react to sound).

Credits: Rodrigo Carvalho (Interactive Visuals); Yago de Quay (Dance, Voice, and Music Composition); Sunny Shen (Dance and Choreography); Po-Yang Sung (Lighting); Meg Seidel (Videographer), 2014.
A video from the full performance can be watched on the project online documentation :
<http://visiophone-lab.com/wp/?portfolio=breakdown>.
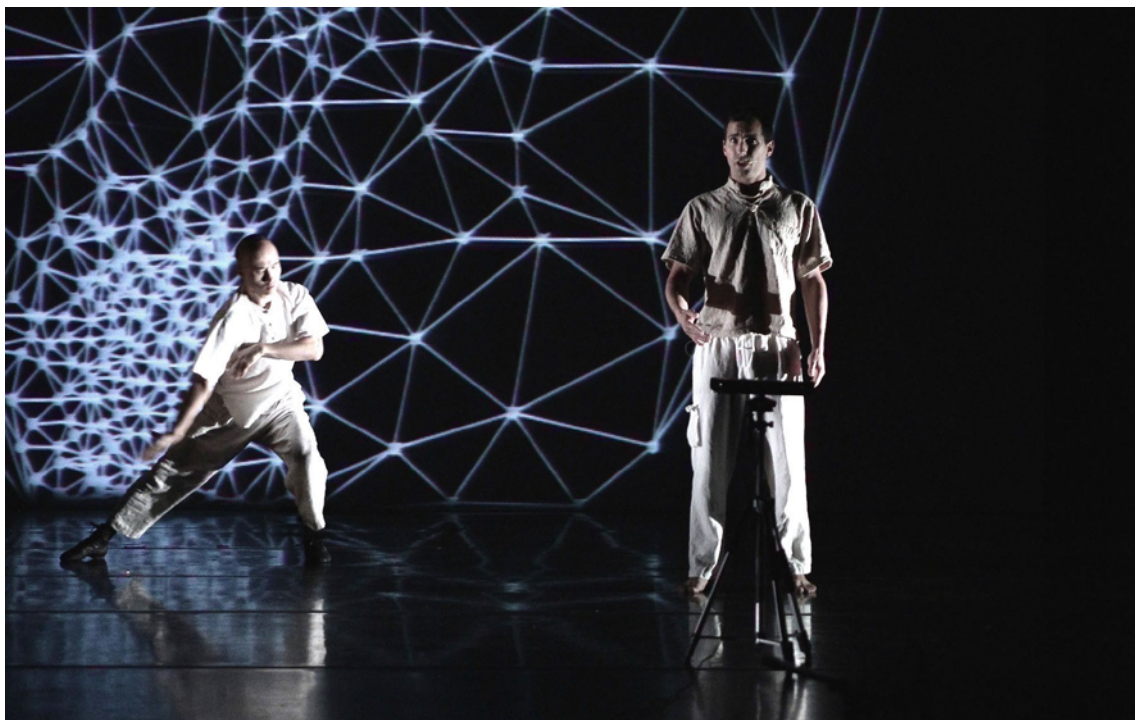
Fig. 91: Sunny Shen (left) and Yago de Quay (right) on stage. Particles being attracted to Shen' body points while de Quay sings and makes gestures in front of a Kinect camera.

Fig. 92: The Rain Scene: Particles fall from the top of the screen with a tail. The dancer has a negative force repelling the particles, creating an umbrella effect.
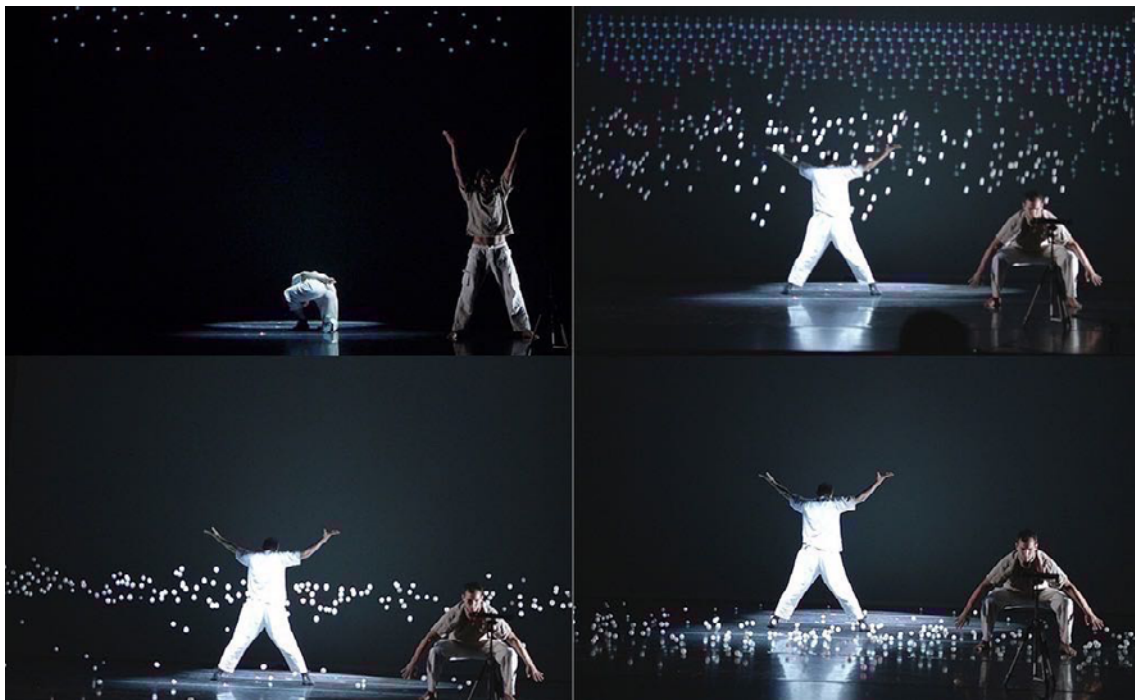
Fig. 93: The final scene: The second performer lifts up the particles in digital world, and then physical particles (ping pong balls) fall from the ceiling.

5.3.4 *THE INTERPRETER* (2014)

The Interpreter is an interactive installation that invites visitors to explore visualizations and sonifications of motion data from a pre-recorded dance sequence. It was presented at INTER-FACE: International Conference on Live Interfaces 2014 (Lisboa).

The project is based on the work developed during the *Motionbank* workshop[16], and it is a spinoff from the interactive dance performance *Breakdown ,* where during the rehearsals sequences of movements from the dancer were captured with a Kinect camera and saved to a database. The database was composed by a list of coordinates, representing points from the dancer's body silhouette, identifying the position in space in every moment of time of the dance sequence.
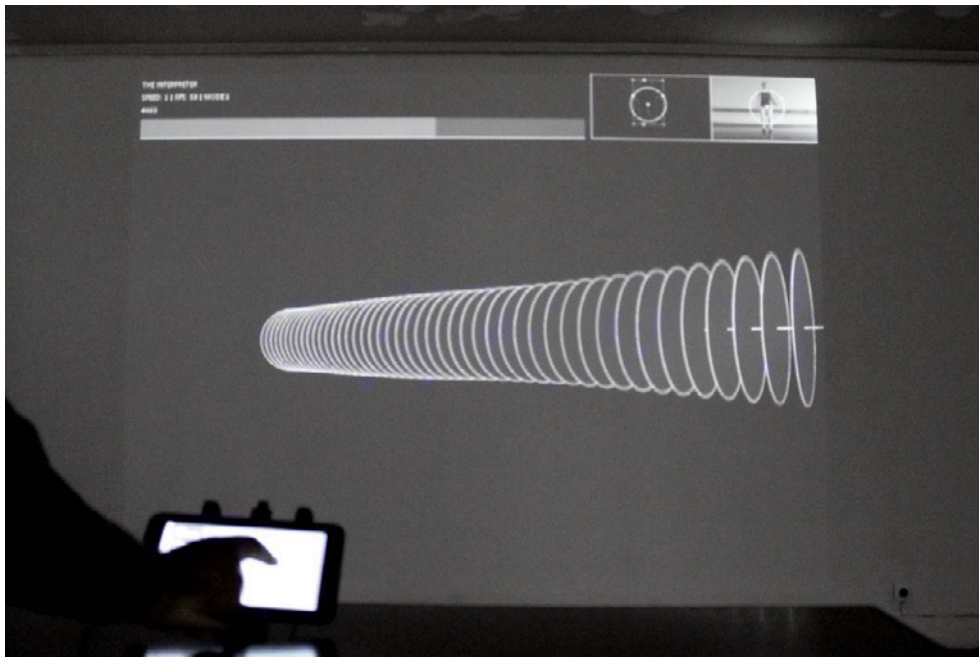
Fig. 94: Picture from The Interpreter. An user touches the device and interacts with the system.

The Interpreter intends to explore movement sequences by visualizing and sonifying motion-data to provide new perceptions, interpretations and outcomes. Due to its characteristics, digital data can be shifted, transformed and materialized into new forms, context and domains. The transmutability quality of digital data allows infinite possibilities, perspectives and metaphors from a dataset. This enables the exploration of visual and sound patterns that emerge when different mappings and abstractions are manipulated over time.

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16 Motionbank: The Choreographic Coding Lab Workshop, 2013, see APPENDICE
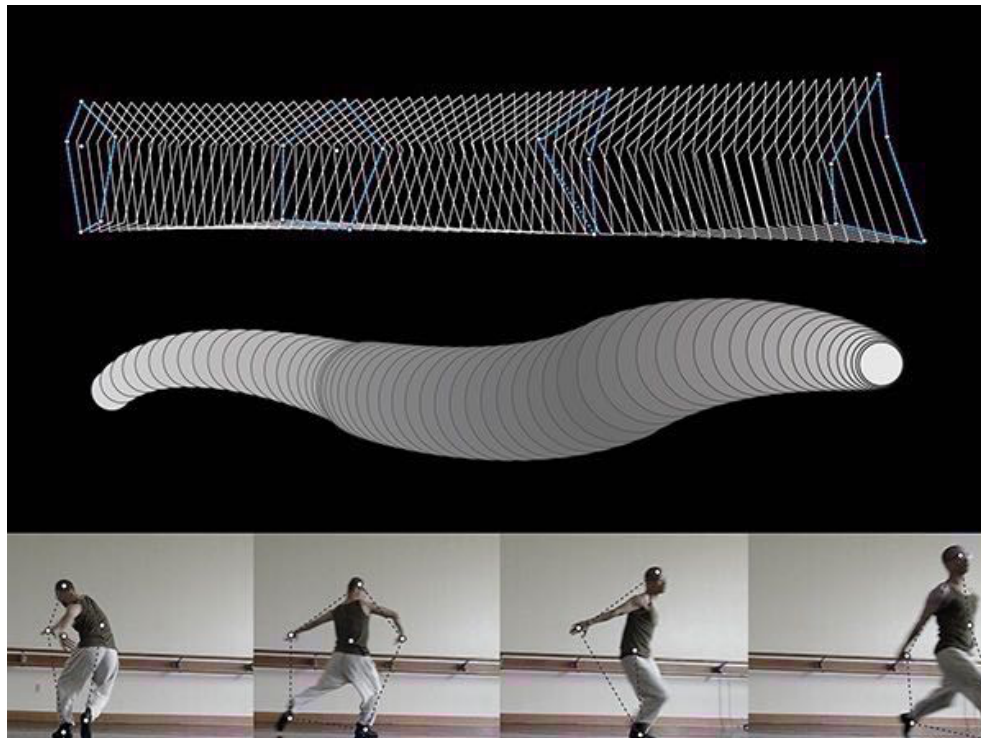
Fig. 95: Frames from the dance sequence's video. Relation between the body's and the geometrical shapes.

For the interactive installation an application was developed on *Processing,* where the motion data was parsed and used to generate real time graphic movement visualizations, paths from displacements in the space, morphing of the silhouette's shape over the time and geometric patterns by points and lines connected to virtual body joints.

Four different visualization modes were developed, each using a different geometrical designs to represent the body in the virtual space. In all modes a trail was visualized behind each current shape, in a way that the final visualization was a new shape composed by a smooth morph of different shapes from the dancer body over time. The four different visualization modes are: mode 0, where an array of points represented the silhouette of the dancer is visualized inside a bounding box representing the edges of the body; mode 1, where a circle is placed on the center of the body, the size of the circle is defined by dimensions of the dancer's bounding box; mode 2, where horizontal lines connect body ends; mode 3, where a four-sided polygon is drawn around the body ends.

The sound is generated by a granular synthesizer controlled by the dancer movements. The granulator re-processes the bass and emits discrete grains. The quantity of motion of the performer's hands is correlated with grain density. The area of the bounding box around the performer is correlated with the center frequency of a low pass filter. Also depending on the mode a different soundtrack is played over the background (taken from the *Breakdown* performance).
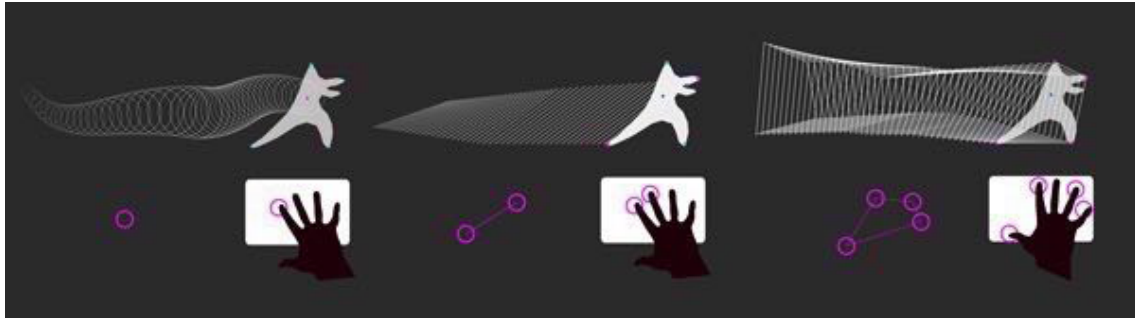
Fig. 96: Touchscreen interaction: One finger activates mode 1, two fingers mode 2 and three fingers mode 3.
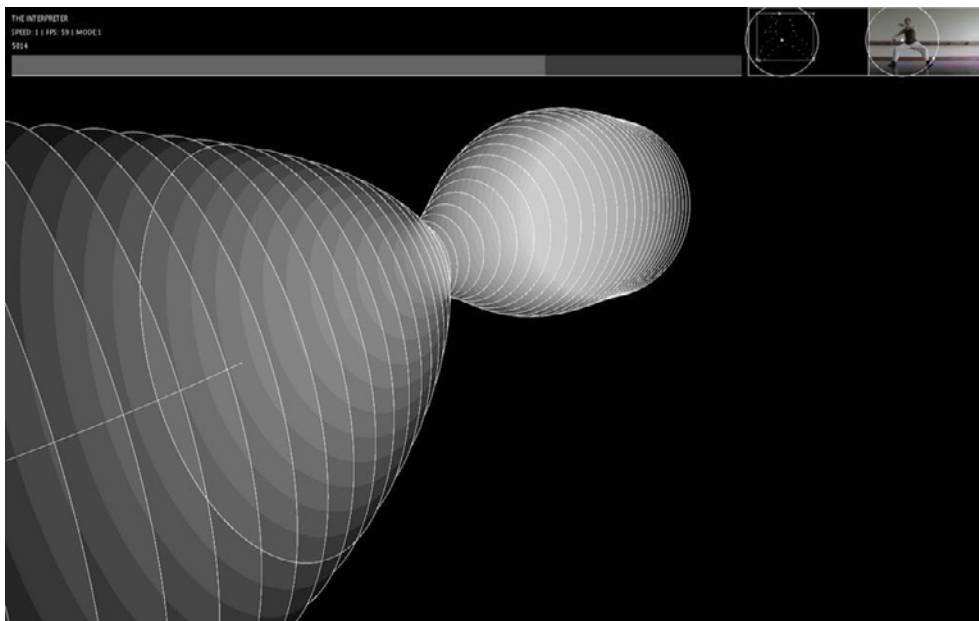
Fig. 97: Image from mode 1. A trail of circles if generated from body center point. Top Right: video from dance sequence with the graphic shape overlapped on the body. Top Center: Sequence timeline.

Through a touch-screen device the audience is able to rigger and manipulate specific audiovisual parameters. The number of fingers on the screen defines the visualization mode, and by moving the fingers vertical and horizontal it is possible to change perspective and viewpoints around the three-dimensional structure. These explorative interactions allow the visitors to experience first-hand the challenges and solutions afforded by new interactive technologies for live performance.

The interactive system is fed by movement data used to deconstruct the dancer's movements into abstract visualizations and sonifications that do not represent realistic representations of the body, but instead explorations of new geometric and sound patterns that emerge from the motion-data.

The Interpreter's interactive systems is classified as **M>SV** (collected motion-data is used to generate movement visualizations and sonifications).

Credits: Rodrigo Carvalho (Visuals, Interactive System); Yago de Quay (Music, Interactive System); Shen Jun (Dance), 2014. A video documenting the interaction with the installation can be watched on the project online documentation:
<http://visiophone-lab.com/wp/?portfolio=the-interpreter>

5.3.5 *FLOATING SATELLITES* (2014)

Floating Satellites is an audiovisual interactive installation where position data from a series of artificial satellites orbiting around Earth, is fed into the interactive system and used for graphic visualizations and sound control. The orbits of the satellites act like a visual sequencer and when the satellites cross specific coordinates, events are triggered into the audiovisual generation system. This interactive installation was presented at ISEA 2014[17] in Dubai.

There are currently thousands of artificial satellites orbiting planet Earth with different functions, orbits (polar or elliptical) and synchronies (helio-synchronous, sub-synchronous or geostationary). This interactive installation proposes to use the satellites' movement data as input to create a stream of audiovisual content, a continuous soundtrack of Earth's external artificial layers.
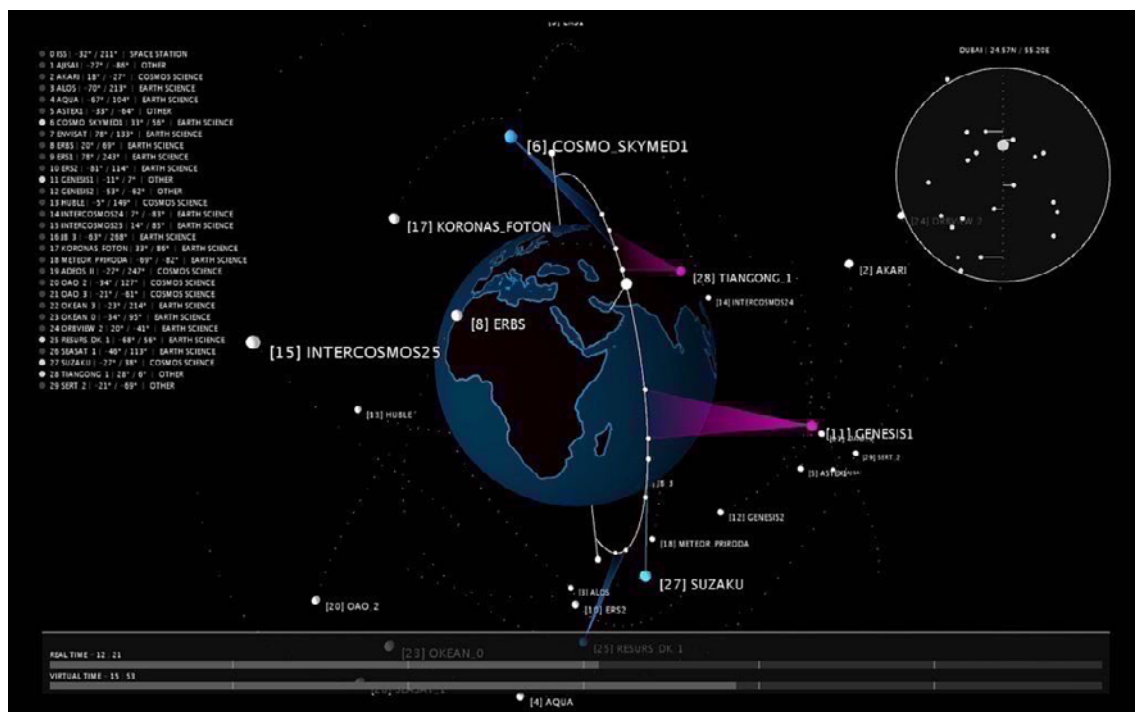
Fig. 98: Installation's visual interface. On the center is Earth, surrounded by the selected satellites orbiting around it. The white pin shows the physical location of the installation, every time a satellites crosses over its longitude (marked by a white arc) a MIDI note is triggered. Below two timelines showing the point in time related to the daily loop, one for the real-time position and the other for virtual one (virtual time is defined by the user, he can choose to speed up the daily loop or return to real-time).

A group of thirty satellites was chosen and divided in four groups according to their category (ISS/International Space Station, Earth Science, Space Science and Others). This group of satellites was selected due to the fact that they are low orbit satellites[18] that move faster than others in relation to the planet Earth, performing more orbits around the planet (as an example the International Space Station, that orbits at an altitude of 400km,

17 ISEA2014, (International Symposium of Electronic Arts). < http://www.isea2014.org/ >. Accessed 2015.10.15.

18 Low orbit satellites, have low altitudes, so they are closer to Earth. They are visible to naked eye, and called as "brightest satellites". A list of brightest satellites and live tracking at N2YO. <http://www.n2yo.com/satellites/?c=1>. Accessed 2015.10.15.

executes approximately sixteen orbits a day[19]). Therefore, they allow more interesting results in this interactive system, crossing more often over the specific coordinates and feeding the system with more data to the sound and visual system.

However even with low orbit satellites, the velocity and number of orbits performed is relatively low, when compared with the timescale of an interactive system, where users stay for a small amount of time exploring the system (ISS takes around ninety minutes to perform an orbit around Earth). For that reason, and in order to provide a more interesting interactivity experience for the users, instead of using real time tracking information the chosen strategy was to collect loops with position data of one day of orbits. This way when interacting with the installation the audience is able to travel back and forth at various speeds witin the current day's orbits and then came back to the actual real time position and speed.
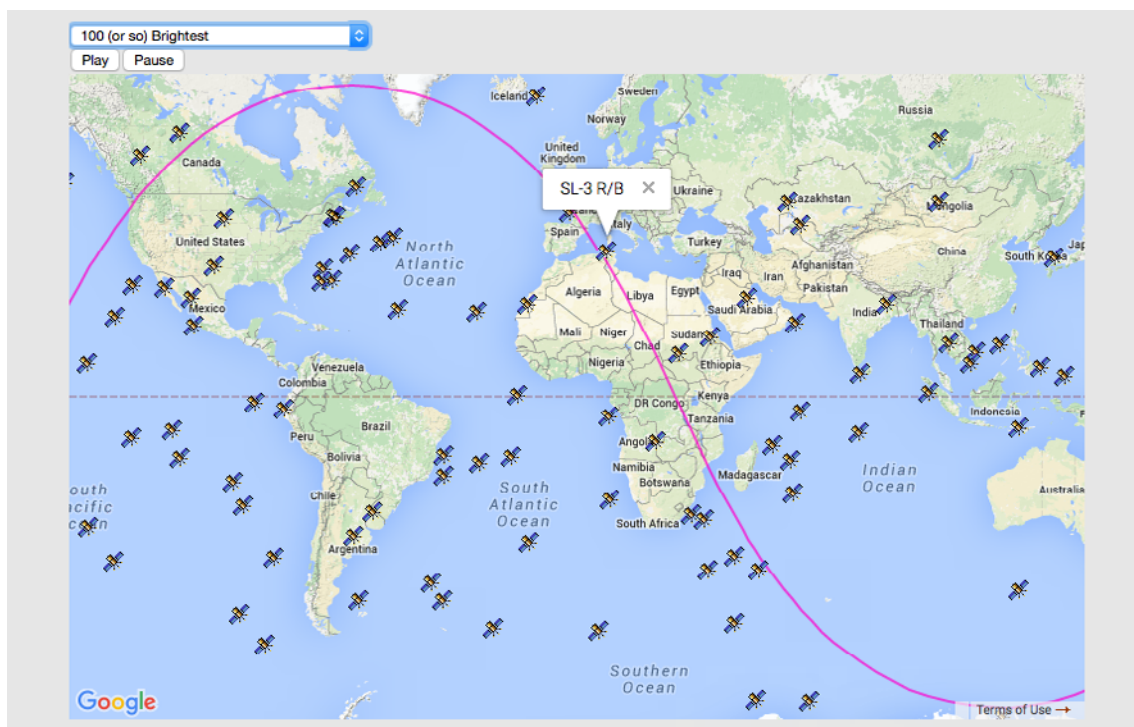
Fig. 99: Real Time visualization of satellites orbiting Earth. Live tracking on "Science.Nasa" websit.

The motivation to develop *Floating Satellites* came from the goal of exploring different types of moment data, apart from body movement that was used in many of the previous research works. In this project data from the motion of machines is collected and used to as an input into the Sound and Visual domain.

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19 NASA's information about the ISS. <http://www.nasa.gov/missions/highlights/webcasts/shuttle/sts111/iss-qa.html> Accessed 2015.10.15.
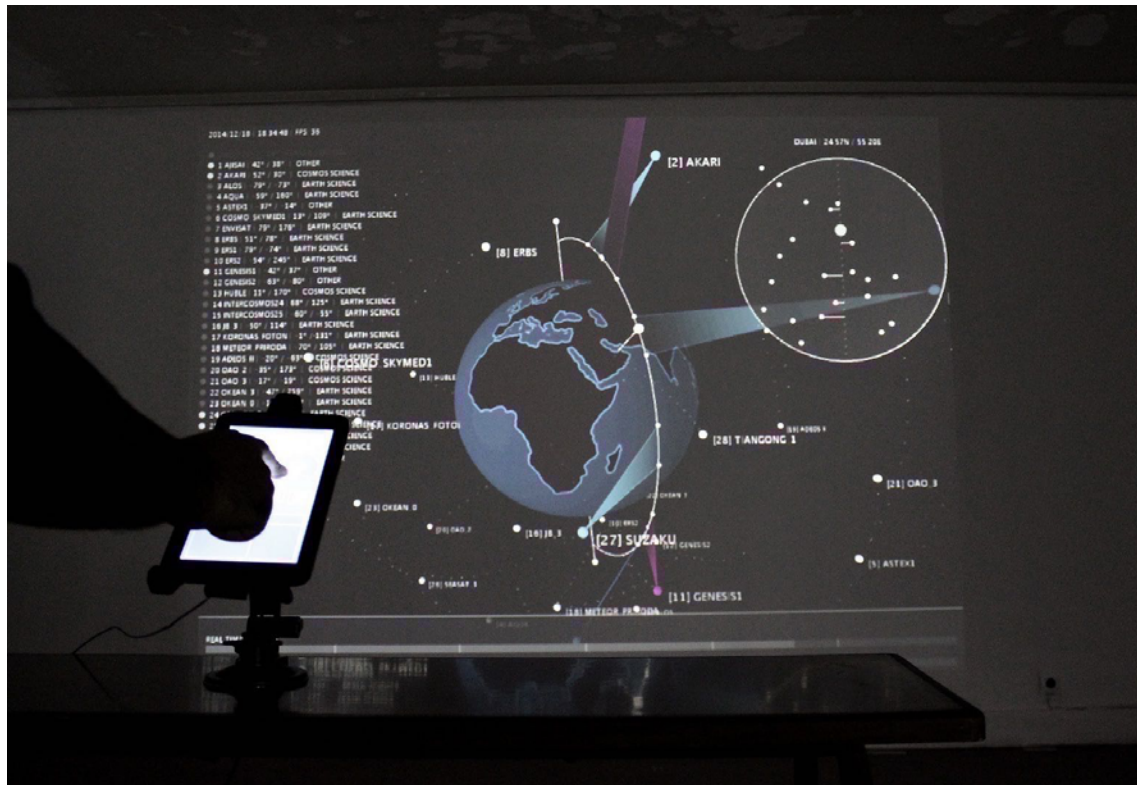
Fig. 100: Picture from the installation. An user interacts through the tablet, selecting groups of satellites, velocity or camera view.

Floating Satellites's interactive systems is classified as **M>SV** (motion-data from satellites orbiting around the planet earth is used to generate movement visualizations and sonifications).

Credits: Rodrigo Carvalho (Concept, Programming, Visuals); André Sousa (Sound), 2014. A video documenting the interaction with the installation can be watched on the project online documentation: < http://visiophone-lab.com/wp/?portfolio=floating-satellites >. The code used for the data parsing and visualization can be downloaded at the author's gitHub account: <https://github.com/visiophone/FloatingSatellites>.

5.3.6 *AD MORTUOS* (2015)

Ad Mortuos is an audiovisual dance performance. It was developed and presented at the Theatre and Dance Department of the University of Texas in Austin in March of 2015. The piece is based on the poem *Ad Mortuos* by Stephanie Pope.

> *Using elements of the poem the immortal soldier Athanatoi (Greek –'without death') sings on 'bright love,' weaving a voice of hope through the first tableau. Then Athanatoi falls into deep séance, conjuring thoughts of the afterlife and immortality. Projecting these thoughts solely through his brain images and sounds, he then emerges again in song.*[20]

The piece was divided in four sections designed to merge the physical with the virtual space, exploring design strategies of mixed reality performance. The section addressed in this dissertation was the third, called *EEG section*, where a performer in the center of the stage, wearing different technological devices, interacts with the visual space and sound in real time. A floor projection, involving the performer in a mixed reality space, is activated as a responsive environment.
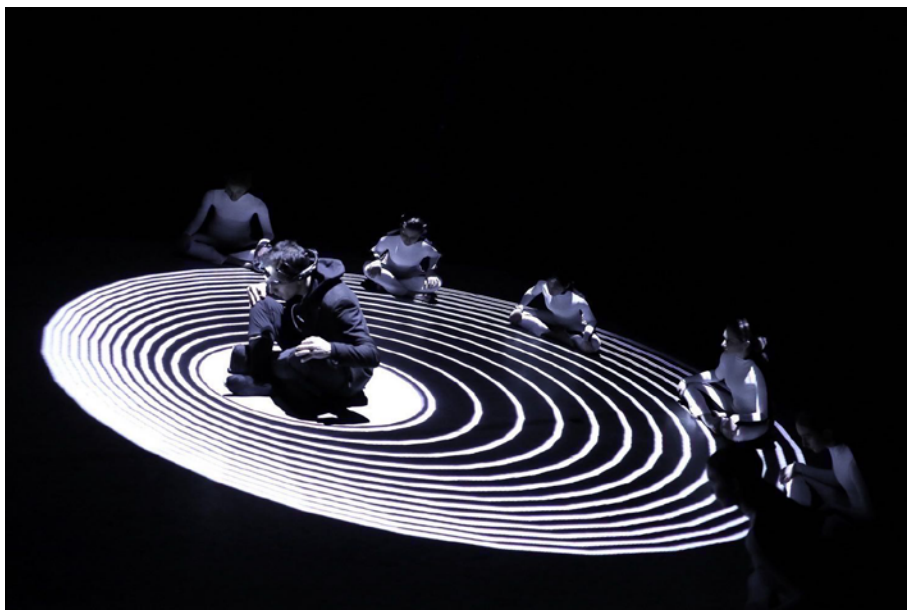
Fig. 101: Moment from Ad Mortuos live presentation.
Performer tilting forward and visuals following him.

The performer's costume included: an EEG reading brain waves to enable deliberate mental tasks and facial expressions; a gyroscope sensor on his upper chest, attached to the under shirt, reporting body orientation; a tablet, attached to his hoodie, collecting the data and broadcasting over a WI-FI network. Brain waves and orientation data were then collected by the visuals and sound dedicated computers and used to manipulate different visual and musical parameters in real-time.

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20 Notes from the composer and the choreographer (Bruce Pennycook and Yacok Shahir).
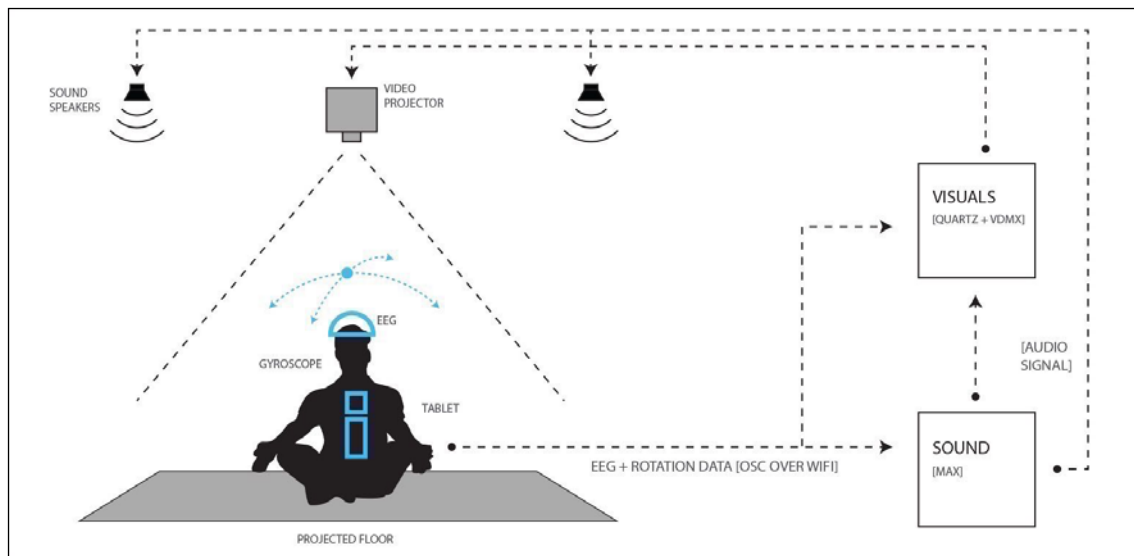
Fig. 102: Ad Mortuos interactive system's scheme.

The soundtrack was composed by a set of sound synthesis objects created in Max, which were being manipulated by data received from the EEG interface in real-time. Specific facial expression made by the performer (like blinking, smiling and raising eyebrows) as also cognitive actions (like lifting) were mapped to specific sound parameters which the performer could control in real-time.

Fig. 103: Moment from Ad Mortuos live presentation. Performer activating lifting cognitive action, and moving up the hand to express it to the audience. On the floor the virtual circles expand.

The floor visuals, Quartz Composer patches controlled live in VDMX, were composed by a sequence of white circles suggesting an infinite virtual floor below the performer. The orientation of the graphics was determined by the rotation data captured by the gyroscope and transmitted in real-time through OSC, in a way that when the performer tilted the body in one direction the graphics followed him implying a direct relation between the physical and the virtual world. Through facial expression he was able to deform the circle shape and with lift up or down commands the circle shape would expand or contract. Real-time audio analysis was used to deform certain aspects of the graphic output.

Some of the actions made by the performer and transmitted by the EEG data, like the cognitive trained commands as lifting, are very difficult to understand by the audience. The actions do not have any physical manifestation and on stage one could only see a performer with a special headset and the eyes closed. It is difficult to connect his actions with the sound and visual activities, the audience would not know if it is really affecting the system, if they are random or pre-recorded.

To address this issue there were some physical movements added to the choreography to create a visual and physical connection with the audience. As an example when the performer was sending the lifting command, which is a trained cognitive command achieved by controlling levels of concentration, he was at the same time moving his arm suggesting visually the up and down actions. This way the audience could relate it with the changes in the sound and the visuals under him.

Ad Mortuos was designed to merge physical with the virtual space and explore design strategies of mixed reality performance. The EEG creates a direct link between the performer who activates and modulate the audiovisual signal in real time by concentration levels of facial expression and additional minimalistic physical movement. With the aid of a gyroscope the visualizations follow the orientation of the body, creating the illusion of infinite space on the floor.

Ad Mortuos's interactive system is classified as **M > SV, S > V** (motion-data and brain activity from the performer are used as input for visuals and sound. Visuals also react to sound).

Credits: Ad Mortuos: Stephanie Pope, poet; **Choreography:** Yacov Sharir, **Music/ Sound:** Bruce Pennycook; **Live Visuals:** Joao Beira, Rodrigo Carvalho; **Lighting Designer:** Amber Rose Wall; **Costume Designer:** Kelsey Vidic; **Musicians:** Olivia Davis (Viola), Jacob Dupre (Piano); **Voice:** Yago de Quay; **Narration:** LaQuetta Carpenter; **Dancers:** Rebecca Bagley, Gianina Casale, Summer Fiaschetti, Katie McCarn, Allyson Morales, Emily Snouffer.

A video from the full performance can be watched on the project online documentation: <http://visiophone-lab.com/wp/?portfolio=ad-mortuos>.

5.3.7 *WITH OUI* (2015)

With Oui is an audiovisual dance performance presented at the *Ears, Eyes and Feet* event in the B. Iden Payne Theater, May 2015, UT Austin Texas.

The narrative develops around human communication and mutually supportive relationships. A bright object in the middle of the stage acts as source of knowledge and connecting link between the dancers. The object contains a hidden Wiimote controller, used as a motion sensor in specific moments by the dancers as a performative object to manipulate audiovisual content.

The interactive system is managed by two computers, one generating the soundscape and another one delivering the real-time visuals. The sound is generated in real-time with the live-coding framework *Supercollider*, where a series of different code functions of audio synthesis and algorithmic compositions are predefined for each scene of the narrative. During the performance the functions are triggered generating sound in real time. Data from the Wiimote accelerometer is received as OSC messages manipulating specific parameters of the sound. The visual system is composed by a real-time particle system with flocking behaviors attached, which contain different rules and physics forces that change along the performance, causing different particles movements and visual patterns helping to build the narrative along the piece. It was developed in Processing using the library *Plethora*[21] for the flocking particles implementation.
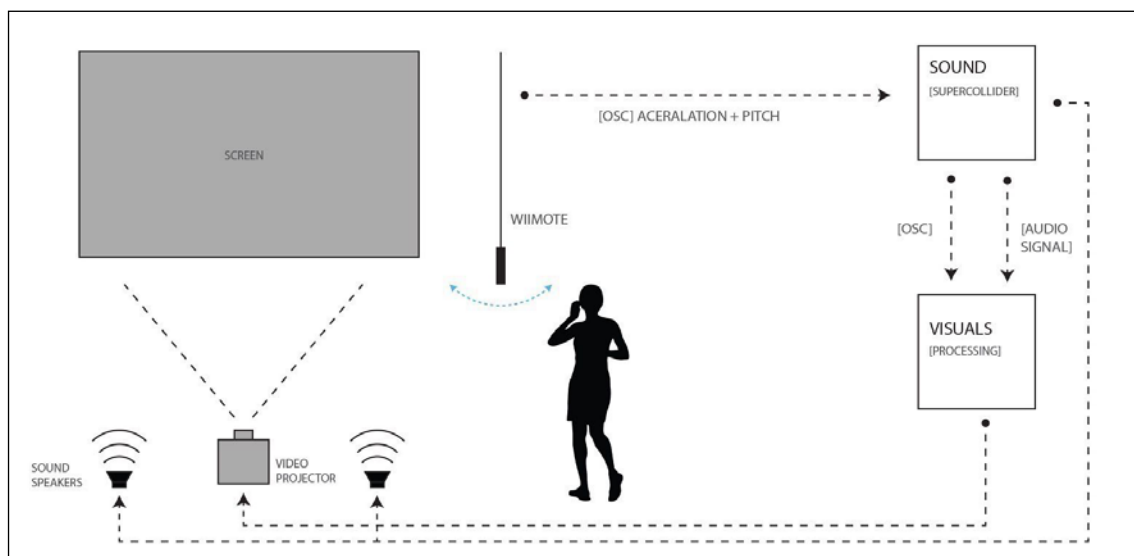
Fig. 104: With Oui's interactive system scheme.

The flocking system has set of rules for individual and group behaviors which are based on Craig Reynolds' *Boids* implementation to simulate flocking birds like systems (1987). The rules for individual behaviors, Cohesion, Separation and Alignment, define how each particle relates to other particles in a determined proximity range. Rules for group behaviors define who and to where the flock moves by making the agents follow specific virtual

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21   Plethora Library for Processing.
<http://www.plethora-project.com/Plethora-0.2.0/index.html>. Accessed 2016.01.20.

targets (like the center of the screen, top of the screen, etc.), follow graphic paths or wandering around without any specific goal.

Each scene of the performance has specific rules and configurations leading the particles to generated different visuals patterns which are used as a narrative element to follow the dancers' movements during the performance.
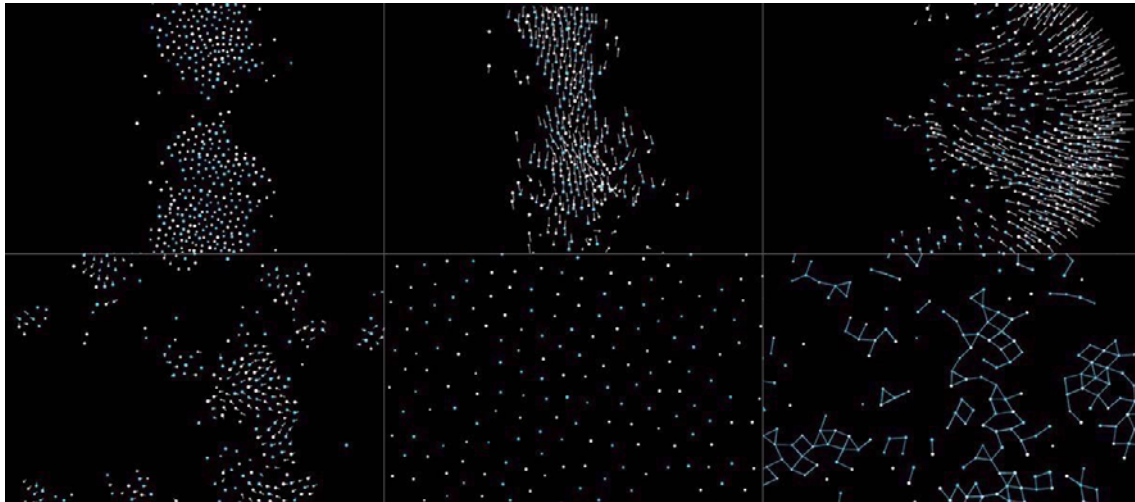
Fig. 105: Stills grabbed from the real-time visual system, exhibiting the particles moving in different patterns, creating different visual outputs.

Some of the parameters are pre-defined according to each scene specific characteristics while others, like velocity, cohesion, separation or alignment are reacting to audio in real-time.The sound spectrum is divided in three bands (high, low, medium) and their values are sent via OSC to the Processing application in real-time. The movements of the flocking group are always related to sound and the performance tension, and a strong synergy between sound and image was being transmitted to the audience.

Besides audio signals, the visual systems also receive some other data inputs from the sound domain. Triggers to create and remove particles are controlled by the sound, and sent via OSC message to the visual domain.

The motion device in the middle of the stage works as an expressive tool with whom the dancers are able to connect in real time with the sound and visual domains, establishing a real-time audiovisual environment in sound, visuals and movement collaborate in the creation of a performative narrative.
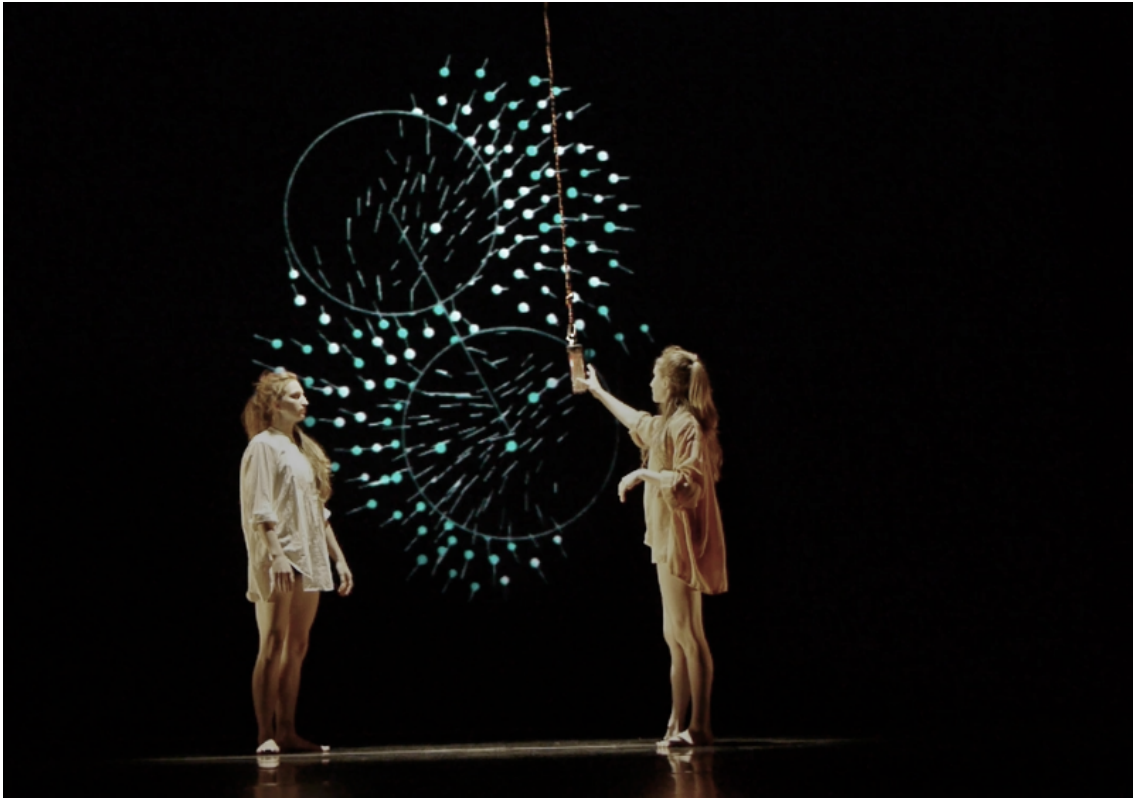
Fig. 106: Picture from the live performance. Two dancers on stage interact with the motion device leading to audio and visual interactions.

With Oui' interactive system is classified as **M>S>V** (motion-data from a device on stage is used to generate sound, and visuals react to sound).

Credits: Billie Secular, Ladonna Matchett (Choreography); Eli Fieldsteel (Sound); Rodrigo Carvalho (Live Visuals); Ya-Tai Chung (Lighting Designer:); Zach Khoo, Kelsey Oliver, Gianina Casale, Nick Kao, D'Lonte Lawson, and Sam O. (Dancers). 2015.

A video documenting the performance can be watched on the project online documentation: <http://visiophone-lab.com/wp/?portfolio=with-oui-2015>. The code used for the visual system can be downloaded at the author's gitHub account: <https://github.com/visiophone/withOui>.

5.3.8 *Δ∞ [INFINITE DELTA]* (2016)

Δ∞ [INFINITE DELTA] was the output of an artistic residency held by the puppetry group Alma D'Arame in Montemor-o-Novo, Portugal on December of 2014. The main goal of the residency was to explore reactive physical structures, motor, servos, electronics, sound and live visuals with the goal of finding a physical reactive mechanism that could be used in a live performance or installation. After the work developed during the 2014 residency, the piece went through some technical and creative updates and was officially presented to the public in 2016 at the IX *Encontro Internacional de Marionetas de Montemor-o-Novo*.

The first stage of this project was focused on the development and building of a physical structure that could be moved by servo motors, a structure that could change its shape in a wide range of possibilities in real-time. The second part was then focused on the development of interactive strategies and the creation of movement patterns, and finally everything was wrap up to fit on a performative narrative and presented to the public.

The shape of the structure is composed by a row of six white triangles made of polystyrene foam. The triangles' top tips are attached to a metallic bar fastened to the ceiling, suspending this way the triangles in the mid-air. The metallic bar also holds the servo motors, and the Arduino micro controller that is managing the electronic system. Each servo is connected to one individual triangle through strings that join the triangle's both side tips to the servo arm. By rotating the angle of each servo arm, we are able to swing the triangles sideways.
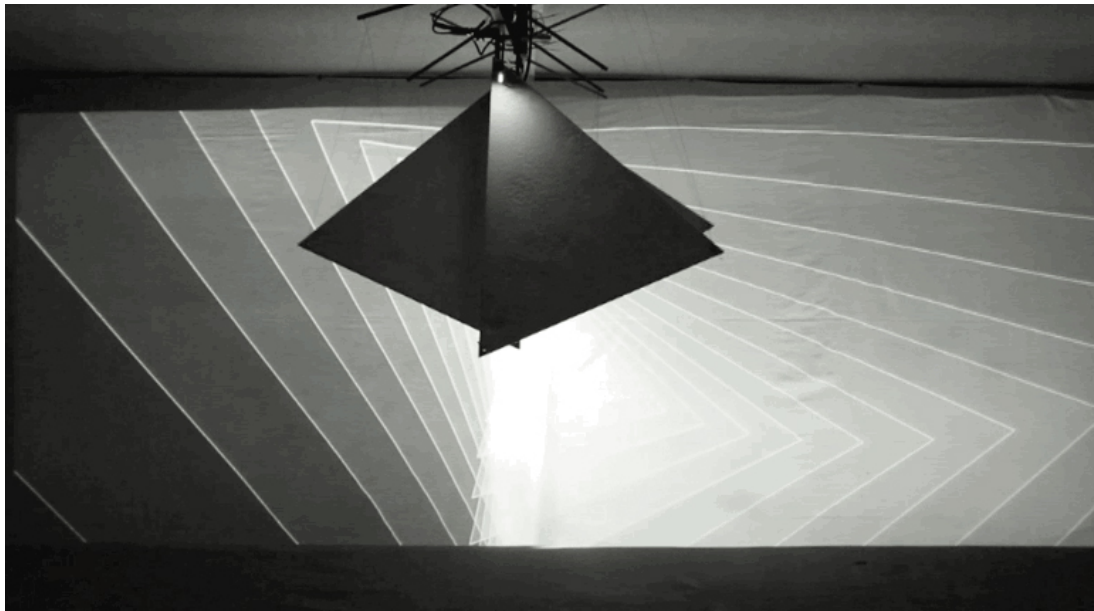
Fig. 107: Installation's frontal view, where a row servos manipulate the strings and swing the triangles.

Servo motors are manipulated by a *Max* patch, from where different types of data and interactions where explored such as: autonomous movements with pre-programmed oscillators and random movements; reacting to sound analysis; servos controlled by hand gestures through a *Leap Motion*; or reacting to distance and body movement with a Kinect camera.
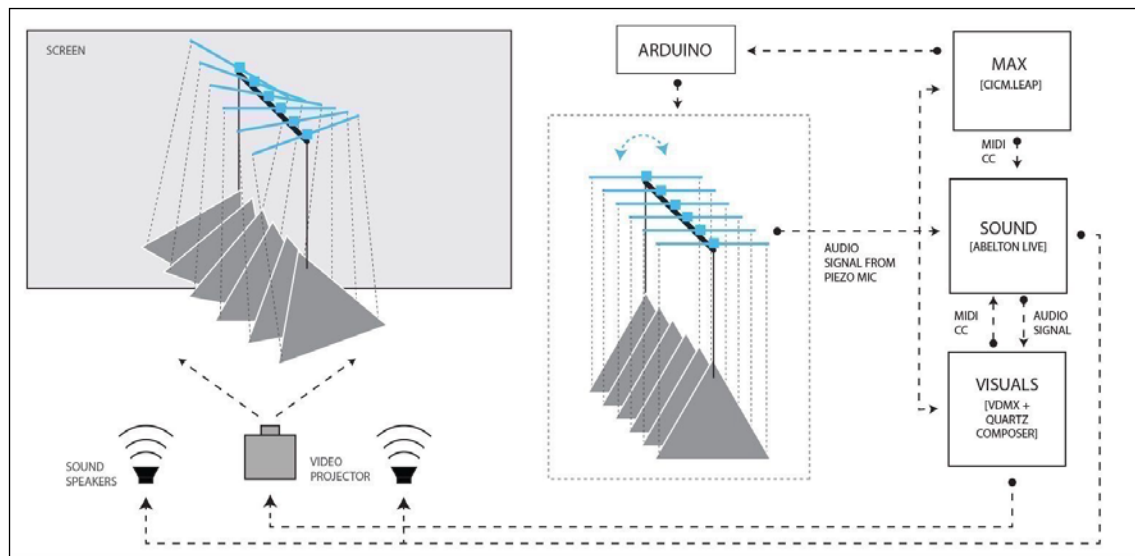
Fig. 108: Δ∞ [INFINITE DELTA] interactive system's scheme.

In the end, an audiovisual live performance was built to present the developed work to the public. The goal of the performance was to use the kinetic structure as the main performative element and integrate its behaviors and movement with live visuals and sound.

A range of different oscillator waves were defined to give different behaviors to the triangles' movements. Each oscillator defined the movement of each servo's arm leading to the swinging of each triangle. Along the performance different combinations of oscillators with different parameters were used to build a performative narrative. The triangles could swing at different velocities or with different apertures. They could swing all at the same time following the same wave, divided in groups following opposite waves, like a snake where each one follows with delay the previous triangle, or move in asynchronous or random ways. The data sent to generate the servos' movements is also sent via MIDI Control messages to the visual and sound domains. It feeds the background soundtrack with data that defines filters, effects and channels volumes, while at the same time defining the visuals behaviors that consist on virtual triangles that intend to create a connection with the physical structure by extending it to a virtual space.

A piezo microphone placed on the metal bar holding the piece captures the sounds of the physical structure's movements and it is also used in the live composition of the soundtrack. Some of the parameters from the visual domain are also reactive to sound, controlled by data delivered by real-time sound analyses.
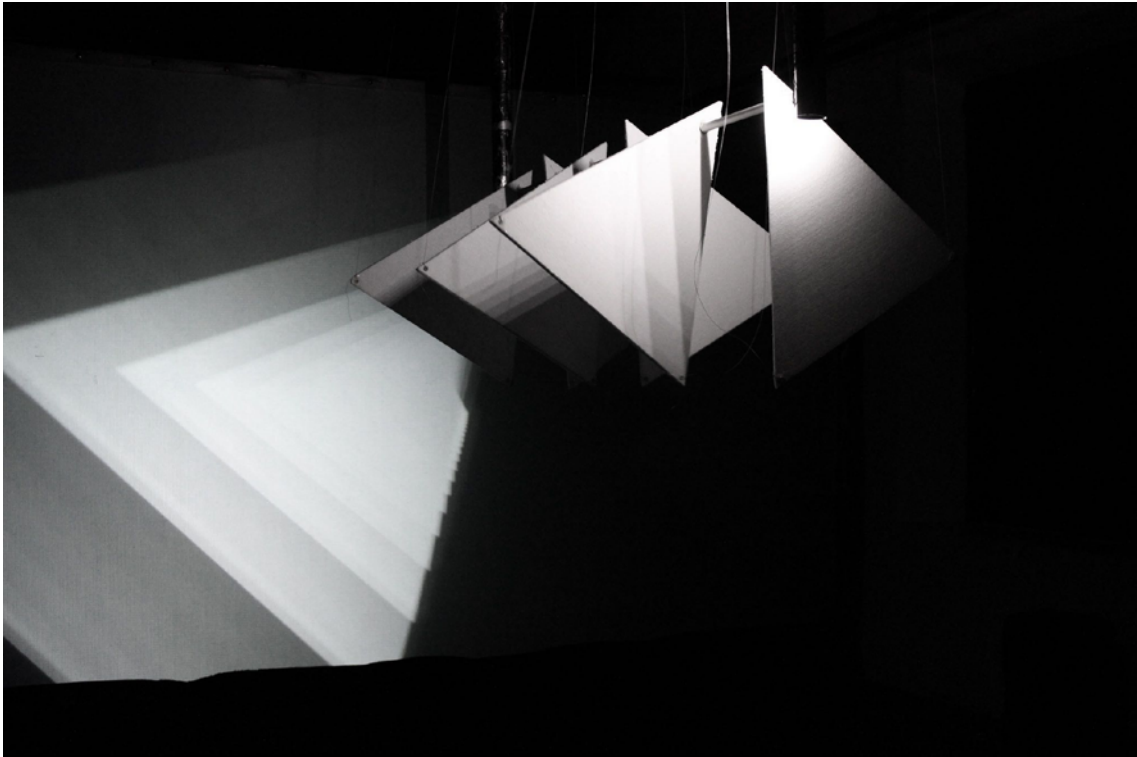
Fig. 109: Picture from Δ∞ [INFINITE DELTA]'s performance.
Triangles swing on different motion patterns, while in the back.

This project has two different operating modes: the performance mode (described in the text above), and an installation mode. After the performance, the piece stays active working in installation's mode reacting to the audience movements. A Kinect camera tracks movement near the front side of the structure, and uses its data as input making the structure reacts to people's presence. When presence is tracked, the system looks for its x's position and the structure reacts my moving to the opposite way. So, if someone approaches the piece by the left side it reacts my making a right side movement, creating this way a mirror like interactive relation between the audience and the kinetic structure.

Infinite Delta's interactive system (performance mode) is classified as **D > SVM, S > V** (Physical structure moves according to different pre-programed oscillators and live controls. Visuals and sound also reacts to the oscillators. Piezo microphones capturing live the physical movement is also used as input for sound). The installation mode is classified as **M > MS, S > V** (A camera tracks the movement of the audience in front of the piece and used its motion data as input to move the structure. Piezo microphones capturing live the physical movement is also used as input for sound. Visuals react to Sound).

Credits: Rodrigo Carvalho (Visuals, Electronics, Interactive System); Miguel Neto (Live Music); Amândio Anastácio (Physical Structure). 2016. A video documenting the performance can be watched at the project's online documentation: <http://visiophone-lab.com/wp/?portfolio=-infinite-delta >.

5.3.9 *DRIPPIGMENT* (2016)

Drippigment is a machine that allows users to control an array of servo motors for creating aquarelle artwork. The machine is composed by a wooden cubic structure, with one-meter-long edges, and an electronic mechanism made of one stepper motor and four servo motors, all driven by an Arduino micro controller. It was presented *Openfield* studio (Porto), *xCoAx2016* (Bergamo), *ISEA2016* (Hong Kong), *ICLI2016* (Brighton) and *FluxFactory* (New York).

The servo motors are responsible for releasing the ink on the painting, and their position is changed by the rotation of the stepper motor on the top. Each servo motor has a wooden stick attached, and each wooden stick has at its end a container holding powder paint inside. The containers, made of transparent plastic boxes, have on there faces small orifices that when are facing down will release the ink over a watercolor sheet on the floor, which has previously been moistened with water.

In this version the machine is controlled by hand gestures. A *Leap Motion* device, placed over the cube's frame, is used to capture gestures made by the performer. A custom application developed in Max[22] reads and parses the motion data and sends control messages to the *Arduino*, in order to make the motors move.
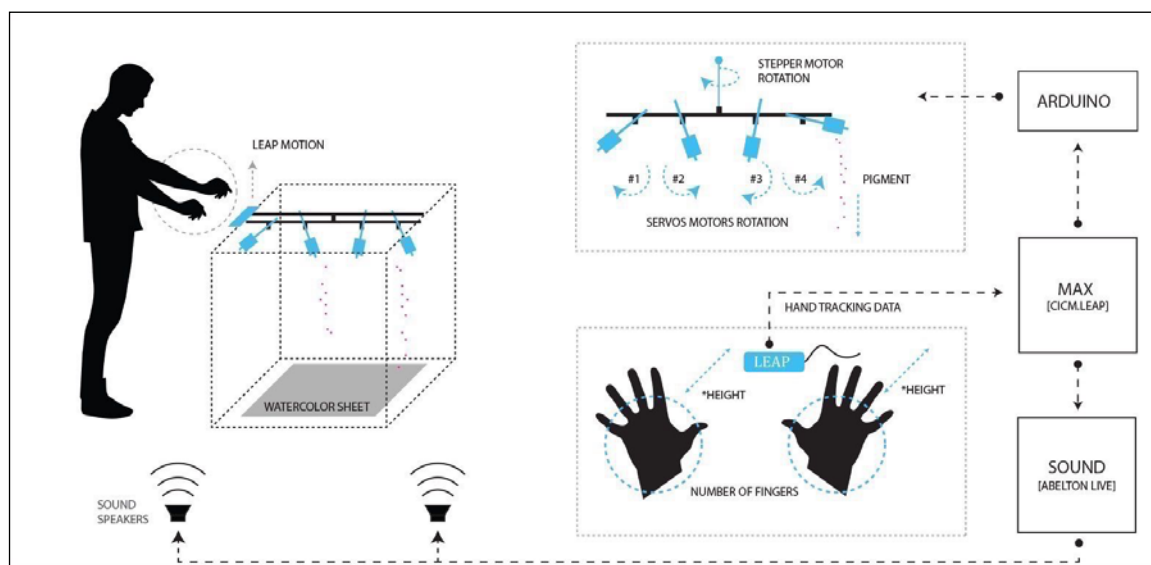
Fig. 110: *Drippigment* interactive system's scheme.

The interaction starts when the user/performer places both hands over the sensor. He has access to two different controls parameters: the ability to drop pigment and to rotate the position of the servo motors. The height of each hand, related to the device, defines the rotation values sent to each servo to rotate the wooden pole and make the ink fall. The number of fingers showed on each hand controls the rotation of the stepper servo on the top. For example, when making a fist (zero fingers visible by the device), the performer controls the rotation (right fist = clockwise; left fist = counter-clockwise). It is possible to configure the system in different ways, by changing its mappings (like making one hand control all the motors as an example).

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22 Max, a visual programming language for music and multimedia. <https://cycling74.com/>. Accessed 2016.01.02

Fig. 111: Artwork created with Drippigment.

As future work we plan to explore different interactions and data sources. Some possibilities are already outlined as an autonomous data-driven version, with no human interaction, resulting in actions driven by random generated algorithms; and the use of live data feeds from online sources (like weather, transportation or finances) used as input and translated into actions, providing aquarelle organic data-visualizations.

Drippigment's interactive system is classified as **M > MS, M > V** (hand gestures are tracked and used to move a robotic mechanism that drops ink to create images. Sound is also manipulated by the hand gestures).

Credits: Project developed at Openfield Creativelab by: Rodrigo Carvalho; Ivo Teixeira; Francisca Gonçalves; Tiago Gama Rocha and Nuno Alves de Carvalho. 2016. A video documenting the performance can be watched on the project online documentation: <http://openfield-creativelab.com/project/drippigment/>.

5.4 DISCUSSION

Table 16 compiles the pratice-research artworks developed under this dissertation's practice-based research with their corresponding *S+V+M* classification. The project *Infinite Delta*, receives two different categorizations due to the fact of having two different operating modes: performance mode and installation mode.

The majority of the projects presented have the *Movement* domain as the source of input data into the system. In fact, only one project does not use *Movement* as input, which is *Infinite Delta* (performance mode). The rest of the projects, in spite of sharing the same input domain, presented a wide range of approaches and types of *Movement*.

Dancing with Swarming Particles, *Breakdown* and *Infinite Delta* (installation mode) use a Kinect camera to track the position of the performance and visitor's body, and use their motion's data as input for visual and sound control. On *Ad Mortuos* the performer's body is also used as input, but on this case is movements are not captured by a camera, but yes by sensors attached to the performance's body and broadcasting data over WI-FI (an EEG interface on his head, and a device with a gyroscope on his upper-chest).

On *The Interpreter*, the approach is similar (the use of body movement data for sound and visual control), but the implementation is different. This case is not a live performance, but an interactive installation where the movement data was captured previously, stored in a database, and is explored as a tool during the installation to generate visualizations and sonifications. *Floating Satellites* is, in a way, similar to *The Interpreter*, as both use collected data as input to control sound and visual outputs in an interactive installation. But in this case, instead of data from body's movement it uses data from satellites orbits around the planet earth.

On *Prefalll135*, we have a similar structure, where *Movement* is captured and used as input for sound and visuals manipulation, but the setup and approaches are completely difference. In this case we do capture the movement of a human body, but yes of a physical object, a watermill. The strategy was to capture the rotation's velocity of a watermill through the use of an infrared light sensor. Rotational data was then used to control visual and sound parameters.

On *Non Human Device #02*[23] and *Drippigment* the captured movement came from hand gestures. By the use of a *Leap Motion* device, features like hands position, number of visible fingers or distance between right and left hands are used to manipulate a diverse set of parameters in the interactive system. On *Non Human Device #02* they control visuals and sound. And on *Drippigment* hand movement generates mechanical movement by controlling an array of servo motors, which in turn by releasing ink generate a visual output, an aquarelle paint. *Sound* domain is also generated by hand gestures data.

Infinite Delta (performance mode) is the only case that does not use *Movement* as input of data. Input data comes from outside of the *Sound*, *Visual* and *Movement* domains. A series of pre-programmed oscillations and live manipulation of different parameters generate data that is then used to generate *Movement* in the physical structure, as well as to control sound and graphics.

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23 Non Human device #02, was described on the Context section along the Boris Chimp 504 project, and not on the Case studies one, because of thesis's structure purposes. Although it should be also considered as a case study for the S+V+M framework as it contains interactions between all the three domains.

Table 16: Practice-base research's projects categorized according to S+V+M.

NAME	DESCRIPTION	CLASSIFICATION
Dancing With Swarming Particles (2011)	Performer's body is tracked and its motion data used to interact with the visuals. Sound is autonomous.	**M >V, [S]**
Prefalll135 (2012)	Falling water makes mills move. Its rotation data is used to generate sound and visuals.	**M > SV**
Non Human Device #02 (2013)	Hand gestures are tracked and used to manipulate visuals and sound. Visuals also react to sound.	**M > SV, S > V**
Breakdown (2014)	Performers' bodies are tracked and its motion data used to interact with the visuals and sound. Visuals react to sound.	**M > SV, S > V**
The Interpreter (2014)	Collected motion data is used to generate movement visualizations and sonifications.	**M > SV**
Floating Satellites (2014)	Motion data from satellites orbiting around the planet earth used to generate movement visualizations and sonifications	**M >SV**
Ad Mortous (2015)	Motion data and brain activity from the performer used as input for visuals and sound. Visuals react to sound.	**M > SV, S > V**
With Oui (2015)	Motion data from a device on stage used to generate sound. Visuals react to sound.	**M > S > V**
Infinite Delta (performance mode)(2016)	Physical structure moves according to different pre-programed oscillators and live controls. Visuals and sound also reacts to the oscillators. Piezo microphones capturing live the physical movement is also used as input for sound.	**D > SVM, S > V**
Infinite Delta (installation mode)(2016)	A camera tracks the movement of the audience in front of the piece and used its motion data as input to move the structure. Piezo microphones capturing live the physical movement is also used as input for sound. Visuals react to Sound.	**M > MS, S > V**
Drippigment (2016)	Hand gestures are tracked and used to move a robotic mechanism that drops ink to create images. Sound is also manipulated by the hand gestures.	**M > MS, M > V**

On *Table 17*, we can see the visual diagrams for each one of the practice research's projects, where we can easily identify similarities between their data's flow structures. As stated before, *S+V+M* framework allows us to group, compare and make relations between interactive systems with different characteristics, mediums, and outputs, but sharing similar interactions between Sound, Visual and Movement domains.

By looking at the diagrams we get a high level of abstraction related to the specifics details of each artwork and we can easily recognize similarities and establish common parameters between different systems. Like between *Prefalll135* (an interactive installation based on watermills), *Breakdown* (an interactive dance performance based the motion capture of the dancer's body), and *Floating Satellites* (an interactive installation based on the positions of artificial satellites around the planet Earth), despite the different

typologies all have in common that the data captured from *Movement* is used as input to generate and control sound and visuals.

Table 17: S+V+M diagrams related to the practice-base research projects

DANCING WITH SWARMING PARTICLES

THE INTERPRETER

FLOATING SATELLITES

PREFALLL135

NON HUMAN DEVICE#02

AD MORTOUS

BREAKDOWN

WITH OUI

INFINITE DELTA (PERF.)

INFINITE DELTA (INST.)

DRIPPIGMENT
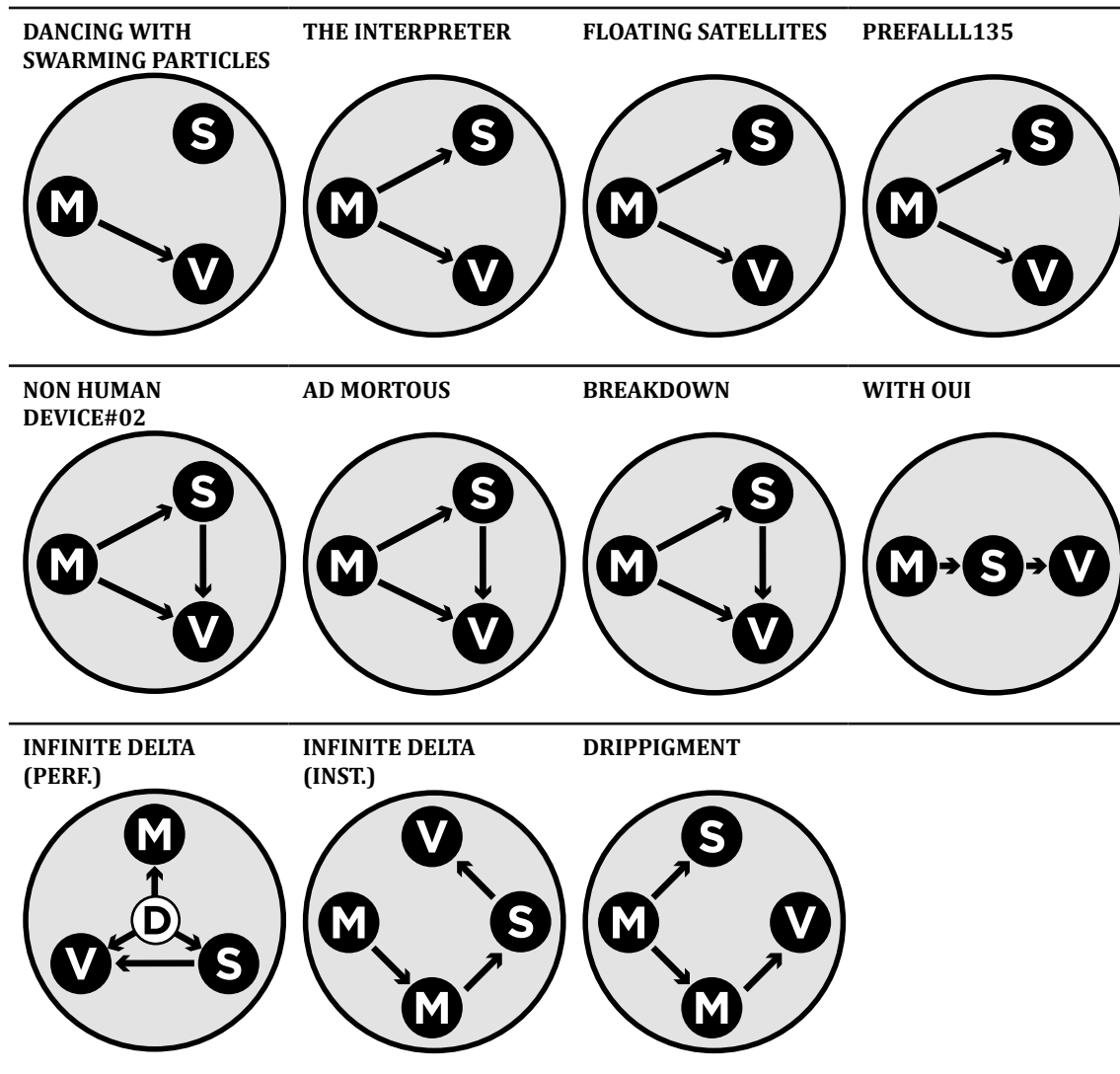
We should also highlight the case of the *Infinite Delta,* which as two different operation modes (performance and installation), and where in the same interactive system we can change the input source and completely change its data-flow and relations between the domains. From a situation where external data is used as input to *Sound*, *Visual* and *Movement* domains to perform a choreographed audiovisual kinetic performance (on performance mode), to another situation where a camera is tracking movement near the kinetic piece and using that data to generated movement on the structure and its movement generates sounds, which in turn triggers visuals.

David Zicarelli, founder of Cycling74[24], in an interview explaining Max's foundations perfectly describes the common feature on digital systems where everything are numbers,

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24   "David Zicarelli of Cycling74 (the company that develops Max software) discusses building Max with Juice". 2016. <https://www.juce.com/case-studies/max>. Accessed 2016.09.29

so "everything can be controlled with a simple stream of numbers (...) any kind of media or controller talk to any other kind of media or controller (...) to the Max user it's just numbers going from one place to other". This description characterizes perfectly the core idea behind the *S+V+M* framework of focusing on the data's flow and input/output relations between the domains. And how we can have the same setup, and use it with in different operation modes, produce different outputs or a wide range of interactions, by changing the inputs in the system and how the data-flows between the domains. Just like the *Infinite Delta's* case described before. In fact, during this project's development many alternatives where explored, in the search for the most interesting output and more fluid interaction and operation mode, as using gestures to manipulate the structure, or making the structure reacts to sound analyses, among others.

Drippigment is also a good example of how one system can have different flows of data, and how the exploration of different configurations can be used as a tool for creative expression. Currently it is used in a performance mode, where the performer uses gestures, that are used as input to generate sound and mechanical movement, which in turn produces aquarelle paintings. But from its beginnings, different operations modes have being though, has using live data-feeds as input, using randomized algorithms as generator, capturing with microphones the machine mechanical movements as sound source, among other possibilities.

5.5 FUTURE EXPLORATIONS ON SOUND+VISUAL+MOVEMENT INTERACTIVE SYSTEMS

The *S+V+M* framework, as a mechanism for categorizing interactive systems and processes, also has an importance as a tool for generating new projects and exploring new interactions. By analyzing interactive systems, and looking to the flow of data between the domains, patterns on input and output relations start to emerge, and new research and artistic questions appear triggering new projects and the exploration of new or uncommon interactions and Sound, Visual and Movement relations. So, besides the main goal of categorizing interactive systems and its processes, *S+V+M* framework also aims to be an important catalyst in the creation of new ones.

Below, two ideas for future audiovisual interactive projects are described, which were inspired and triggered during the development of this research work: The *S+V+M Machine* and *Shapeshifter*.

5.5.1 S+V+M MACHINE

S+V+M Machine is a "perpetual motion" machine that creates an endless feedback between *Sound*, *Visual* and *Movement* domains. It is an exercise of speculative design, where the *S+V+M* framework is used as concept for artistic creation.

There are still no drafts or outlines related to the shape and technical details of the machine, only at a conceptual and function level.

As reference, we can look at Dmitry Morozov's[25] conceptual sound machines. He builds surreal and useless machines with absurd functionalities, each one exploring a specific concept as a musical instrument, in fact he defines these machines as sound objects. As an example we can look up to the *Prankophone* (Vtol, 2015), a blend between a synthesizer and a telephone, a sound object that calls to random telephone numbers and plays them synthetic melodies. Another example is the *Collector* (2016) a kinetic machine that scans and records the sounds on the surrounding space, selecting the loudest ones and creating with them an algorithmic sound composition. Morozov calls it a reality remixer as it removes the silences between loud sounds and reinterpret reinterprets a new soundscape.
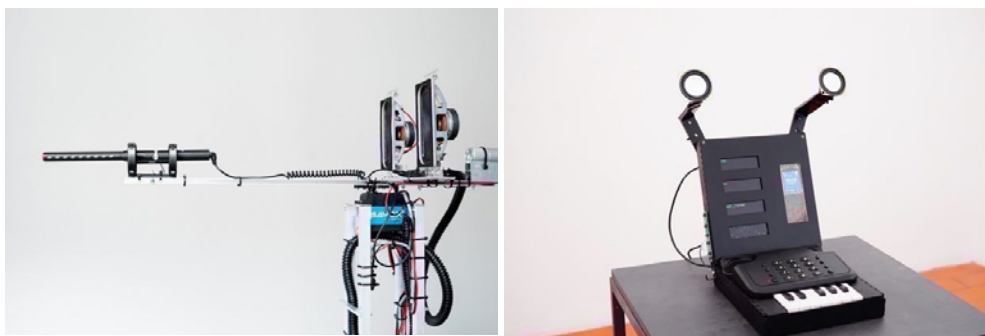
Fig. 112: Collector (Vtol 2016) on the left, and Prankophone (Vtol 2015) on the right.

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25 Russian media artist Dmitry Morozov, aka Vtol, <http://vtol.cc>. Accessed 2016.09.29

Both machines, in terms of features and technical operations, are relatively simple, and could be developed as software or as mobile phone app. But when they are presented as physical machines they gain a new dimension and become conceptual objects. Where its distinct operation mode is used as artistic aesthetics, and becomes the core subject of the piece, and not on the sound compositions that the machine performs.

S+V+M Machine follows the same idea of building a conceptual machine where the focus it is on its operation mode and functionalities and not on the content output. The core idea on the machine is to use the data transformations between *Sound*, *Visual* and *Movement* domains as artistic aesthetics. *S+V+M Machine* allows the creation of all possible combinations of input and output relations between *Sound*, *Visual* and *Movement* domains. Through a specific interface a user can select the desired transformation sequence, for instance **S > M > V**. This way the machine would use Sound as input to generate Movement, and Movement would create a Visual output. The Visual output would then feed the *Sound* domain again, creating this way a continuous feedback, making the machine work in perpetuity.

After selecting the desired operation mode, the user needs to provide an initial input to begin the machine interaction. In the described case, **S > M > V**. The user would have to perform a sound near the machine, a vocal sound as an example, so that the *Sound* domain can capture it, and then it would be translated into *Movement*. Here a mechanical system would move according to the sound frequencies and amplitudes, and the movements performed by it would generate content in the visual domain, as a drawing machine. The drawings would then be captured, and its visuals features used to generate new sounds, feeding this way the endless interactive loop. The user could at any point interfere with the feedback loop, adding new sounds to the systems, that would create variations on the outcomes. The user could also stop the interaction to begin a new one, or change the operation mode, turning it to **S > V > M**, or **M > SM**, as an example. The user could also leave the space and let the machine work forever.

5.5.2 SHAPESHIFTER

Shapeshifter is an interactive audiovisual performance based on movement's interactions between a human dancer and a group of flying drones.

The dancer, in the middle of the stage, has a large cloak attached to her body. The other end of the cloak is suspended by a group of drones. Each one of the drones holds a tip of the cloak, and their movements lifting it up and down generates three-dimensional shapes in space, augmenting the dancer's body. A camera tracks the dancer's movements, and her body shape is used to determine the position of the drones in the air. This way when the dancer lifts, as an example, the left arm, the drones on the left side move up. Drones act as an extension of the dancer's body, and together they form and control a new three-dimensional and artificial shape-shifter body in space, made of a floating cloak.

In addition a video projection mapped to the cloak's surface projects colors and textures, which are manipulated by the performer and drones generated movement, creating this way a visual feedback and adding a new level of perception and narrative possibilities. The motion data is also used to trigger and control the performance's soundtrack.
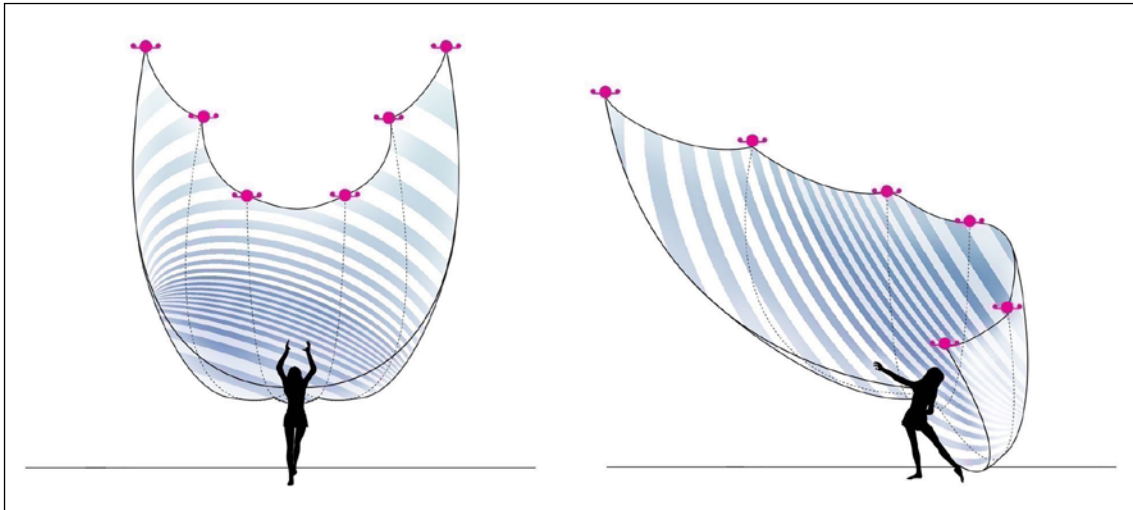
Fig. 113: Preview of Shapeshifter dance performance, demonstrating the relation between the dancer's movements, the drones flying patters, the cloak shape and the video projections on its surface.

Shapeshifter has a strong connection with Loïe Fuller's dance performance from the late 19th century, and beginning of 20th, on film on *Serpentine Dance* (Auguste and Louis Lumière 1886). Fuller was dressed with semi-transparent fabrics around her arms and body. By spinning her body, the fabric would rotate and float in the air, creating a perception of a new and extended body, morphing and augmented its shape and space around. Color light projections on the fabrics would add an extra sense of magic happening. When in movement the body of the performer was being dematerialized into traces and colors (Dixon 2007, 40).

Fig. 114: Still from Loïe Fuller dance performance, photography by Frederick Glasier, 1902

Another strong influence is the work of the Japanese research studio *Rhizomatik*s[26] with the dance group *Elevenplay*[27]. Together they have developed several interactive dance projects merging human performers with drones or robotic ones, as *Shadow* (2015), a dance performance where drones are used as flying spotlights. Three flying drones, holding spotlights and performing different choreographic flying paths around the human dancer, shoot sequences of flashing lights towards him, projecting the dancer's shadows on the background wall and floor. Along the performance, different flying light patterns are explored creating games of light and shadow in the space, and with the performance's body. Another good example is *24 Drones* (2015) where a group of twenty-four flying drones perform on stage choreographies alongside de human dancers. But perhaps the most interesting inputs are the videos from the research process[28], with explorations on interactions between flying drones and the human body.

In those videos we can watch a series of experiments, exploring interactions and developing human-drone choreographies, flying-drones as an extension of the human body, and also flying-drones performing alone by themselves.
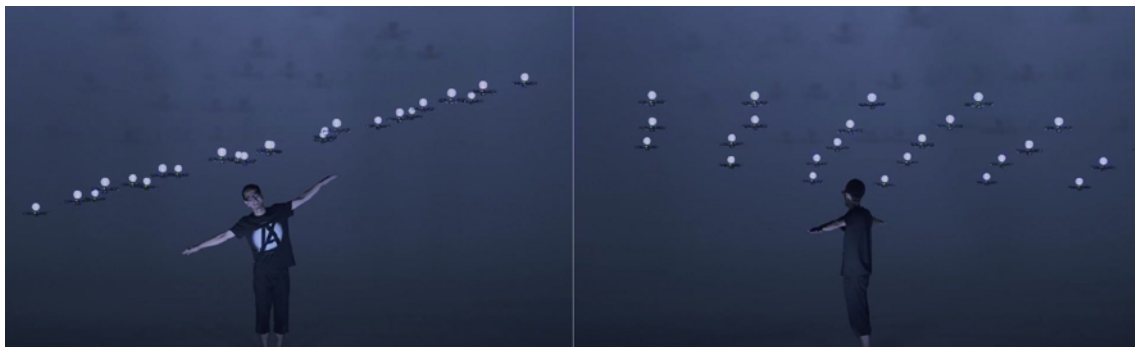
Fig. 115: Stills from Rhizomatiks's video "24 Drones Flight Test 0 "

As an example on *24 Drones Flight Test 0*[29] we can see a person, with open arms, rotating left and right, while the drones forming a line on the top and following the rotation patterns. On another video, *Drone Fail (24 drones flight test - 05)*[30], we watch a group of drones performing alone, exhibiting choreographed movements and forming shapes in the middle air. Suddenly after a few interactions we watch how they seem to have been shut down or lose contact with the system and fall on the floor. Which gives them in a way a sense of humanity, a connection with the fragility of the human dancer, who can also fail and fall on stage or forget about the choreography, and also tension and liveness to the real-time performance.

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26 Rhizomatiks <https://rhizomatiks.com/>. Accessed on 2016.10.18

27 Elevenplay <https://elevenplay.net/>. Accessed on 2016.10.18

28 Daito Manabe's Youtube channel: < https://www.youtube.com/user/daito/videos>. Accessed 2017.09.11

29 24 Drones Flight Test 0. <https://www.youtube.com/watch?v=SPcZmDTW8KU>. Accessed on 2016.10.18

30 Drone Fail (24 drones flight test - 05)
<https://www.youtube.com/watch?v=EhSY45GQL3U>. Accessed on 2016.10.18
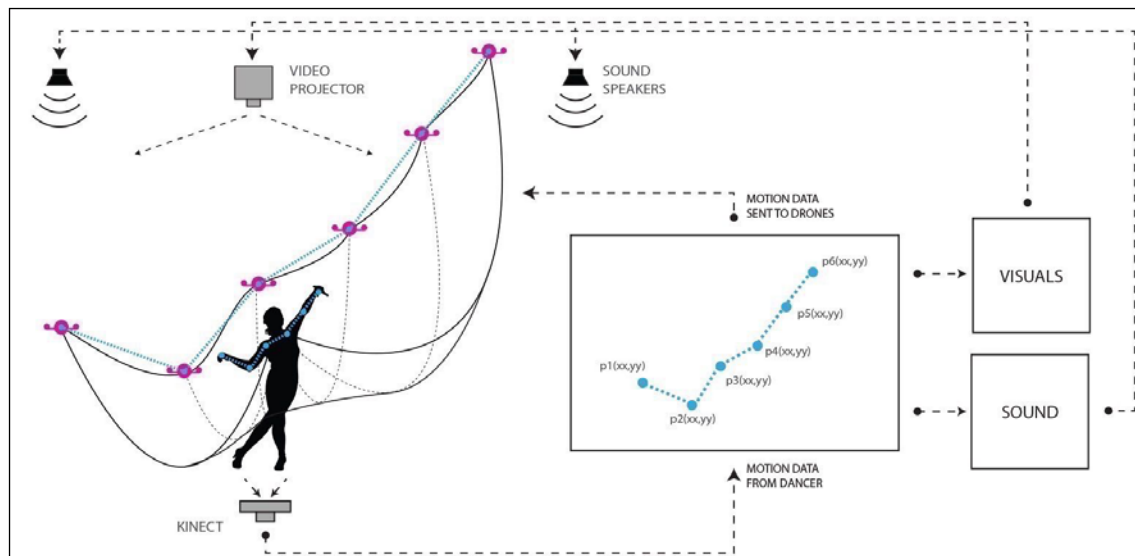
Fig. 116: ShapeShifter interactive system scheme.

Related to the *S+V+M* framework this project is classified as **M>SVM**, where motion data from the performer is used to generate and control *Sound*, *Visuals* and *Movement* (on the flying-drones).

On a further version of *Shapeshifter*, we could also explore the implementation an Artificial Intelligence system on the flying-drones. This could be integrated in the narrative, in a way that in the beginning of the performance the drones were following accurately the dancers's movement, as described before, and across the performance a learning system would be feeding the system with the motion paths and choreography, and gradually the flying drones detach from the performances movements, gain autonomy and start to develop their own choreography. Sound and Visuals in this case would be fed by both Movement inputs, the performer and the flying drones, so the *S+V+M* classification should be slightly different, as in this case Movement generates Movement, and both Movements (the dancer and the drones, which with the course of the performance became different identities, and generate different paths). In this case we have the following classification: **M>M, MM>SV**.

6. CONCLUSION

6.1 SUMMARY

The research presented in this dissertation explored the relations between the *Sound*, *Visual* and *Movement* domains in interactive systems, created for art installations or live performances. It is focused on the processes of interaction and transformation that occur across those domains (movement into sound, sound into visualization, movement into visualization, etc.) in each different system. This research proposed an approach to frame all the different systems in a common language, relating them between what they have in common, and bringing together projects that are often separated by technical details, relation with the audience,participation type, and levels of interactivity.

The main questions addressed in this research were:

> *Can interactive artworks be defined and categorized based on their input/ output configurations and the directions of the data-flow through their Sound, Visual and Movement domains?*

> *How can we frame interactive artworks with different characteristics in a common language? In a way we can relate, analyze and critique artworks presented in different media, with different setups, configurations, relations with the audience, and levels of interactivity.*

The target artworks of this dissertation are interactive systems made for dance performances, performing interfaces, installations and immersive spaces, where the three domains are present, and where processes of transformation and translation occur between them in real-time. The fact that these artworks have so many diverse characteristics from each other raises the question on how can we describe all these projects alongside.

This dissertation proposed a new framework, *S+V+M (Sound, Visual, Movement)*, which intends to classify interactive artworks based on the flow of data through their system. *S+V+M* does not intend to describe types or levels of interaction, data mappings, generative processes or other specific details of the systems, which have already been widely covered in several classifications and frameworks. Instead, it aims at providing a higher level of abstraction by looking at the inputs and outputs, transformations and data-flow occurring across the *Sound*, *Visual* and *Movement* domains inside the interactive system. It aims

not simply to attach labels but to recognize similarities and establish common parameters in artworks with different characteristics, so they can be evaluated and discussed under a unified perspective. The goal is to outline the interactive systems in a simple and descriptive way, considering the translations "across sensory-kinetic modes (sound into light, light into motion)" (Whitelaw 1998) as a unifying factor. In summary *S+V+M* allows to compare under the same scope projects with different typologies, setups and interactivity levels, so we can relate them together in a common language, through the processes of transformation between the domains.

This work was developed on two interrelated and parallel paths: a theoretical path, focused on collecting and cataloguing artworks' interactive systems, and in developing the framework; and a practice based research path, focused on the development of artworks exploring the relations between *Sound*, *Visuals*, and *Movement.*

The work started with the blog *S-V-M (Sound+Visual+Movement),*[1] the output of a daily process on searching and collecting transformations of data between different domains. The blog works as an informal list of projects catalogued in six main categories, grouping projects with similar features and processes of transformations between the *Sound*, *Movement* and *Visual* domain on their interactive systems. It is divided in: (1) *Motion Sculptures*, where motion is transformed into visual shapes and forms; (2) *Sound Sculpture*s, where sound features are used to create three dimensional physical shapes; (3) *Graphic Sound Visualizers*, for audiovisual live performances and sound visualizers; (4) *Shaping Sound,* where visual shapes are used to generate sound; (5) *Movement Sonification*, where motion is translated into sound and (6) *Kinetic Structures*, where the movement domain is the output, as in interactive kinetic sculptures and performing robotic agents.

The blog was used as a baseline to catalogue the transformations between domains, and to find projects and techniques which presented unique and interesting approaches to the interaction of between *Sound*, *Visual* and *Movement.* From that archive a group of twenty-two projects were selected with the aim of serving as case studies for the development of the framework. The selected projects cover a wide range of setups, configurations and interactions, also, in all the projects the three domains are present, and processes of transformation and translation occur between them in real-time. They were selected because they also have stood out on their technical, conceptual and artistic approaches, and proximity to this research interests.

Another important step in the building of framework was the definition of this research's perspective on interactive systems and to establish the limits and boundaries of the *Sound*, *Visual* and *Movement* domains. An essential task due to the fact of being a very multidisciplinary field, with many different definitions and approaches to similar terms from creators with diferent backgrounds. In this study the *interactive systems* addresses digital systems where processes of interation occur in real-time between the three domains. This definition allow us to to include an extensive spectrum of different systems in the framework, from autonomous interactive machines (as *Cloud Piano*), interactive installations (as *Laser Forest*), audiovisual shows (as *Soft Revolvers*), interactive dance performances (as *Anatta*) to robotic ones (as *Quadrotor show*). It was use as ground-base the definition given by Kwastek of the objects of her study on *Aesthetics of Interaction in Digital*

Art, where she uses the term "interactive" on every case where the processes of interaction are discussed, even if the system is not digitally mediated (2013, 9). However, this definition is more extended than Kwastek's, as it includes cases where human input is not a premise (as in *Cloud Piano*) and where the dynamics of the piece have been sequenced in advance (as in *Spectra-3*). Her definition excludes the systems that are not activated by humans, like self-sustained generative systems (271), even if they are real-time interactive systems producing artworks.

To expand the framework's definition we looked at Steve Dixon's definition on Digital systems, which helped framing a wide variety of artworks in his study of *Digital Performance* (2007) from live stage performance with video projections and robotic or virtual reality performers, to interactive or telematic installations. This research focus is on the interactive processes and aesthetics of digital systems "where computer technologies play a role rather that a subsidiary one in content, technologies, aesthetics, or delivery form" (3), or as Whitelaw described a category of artworks presented at the *Cybernetic Serendipity*[2] exhibition, the focus is on post-objects that are dynamic, processual, interactive or kinetic, covering artworks with systems that contain "processes of interaction and response, translation across sensory-kinetic modes (sound into light, light into motion)" (1998). The notion of *post-object*, defined by Jack Burnham on *System Esthetics* (1968) and *Real Time Systems* (1969*),* is also an important concept, as it proposes cybernetic organisms as artworks, it proposes art systems that contain real-time information processing and interactive dynamics resulting in pieces (Dixon 2007, 103). Just like Paul Brown stated "Previously ... I had seen artworks as objects. Now they became processes" (Ibid.).

In brief, the interactive systems approached in this research are post-objects with dynamic, interactive, digital, kinetic, computerized or electronic systems, or dance performances, performing interfaces, installations, and explorative spaces among others, where *Sound*, *Movement* and *Visual* domains are present, and processes of transformation and translation occur between them in real time.

Related to the boundaries of each domain, the *Sound* domain was defined as representative of all kinds of sonic activity, the *Visual* for all kinds of visual representation, and *Movement* relating to physical motion, either body motion and gestures, robotic or mechanical motion, or even natural elements. However, some doubts may arise when we break down the boundaries of each domain and question what should be included. Should the manipulation of an interface be considered as *Movement?* Or the vibration of a speaker? Should the image grabbed by a camera for computer vision be considered as part of the *Visual* domain? And the stage lights in a dance performance? This research approach follows Kwastek, as she states that "standard media configurations (mouse/keyboard and projector/screen), because they are familiar, replaceable, and purely functional elements, are usually not perceived as aesthetically effective components of a work" (2013, 144). In short it should only be considered as integral of a domain if it has a specific performative or artistic purpose for the project and not only a functional one.

As an example, on the dance performance *Appariton*, the stage lights should not be considered as part of the *Visual* domain, as their action if part of a functional and standard use, to light up the dancers on stage. However, on *Quadrotor Show* the light beams on stage are a central part of the performance, drawing visual shapes on the air by following

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2 Cybernetic Serendipity: cybernetic art exhibition held in London in 1968, curated by Jasia Reichardt

the movements of the drones and by reflecting their light on the moving mirrors that each drone holds. In this case, the stage lights should be considered a part of the *Visual* domain.

As a baseline for the building of the framework nine classification systems were analized. They were chosen from the literature of interactive and computer art fields, used to describe artworks and its systems based on their interactive proprieties. Each one of them with different approaches and methods and processes, but all overlapping the viewpoints of this research.

The framework *S+V+M* was then proposed. Its approach consists on textually describing the processes of transformation happening across the *Sound*, *Visual* and *Movement* domains, and which are input or outputs in the system, as *Visuals* to *Movement*, *Visuals* to *Movement* and *Sound*, *Sound* to *Visuals*, etc. The descriptions were transcoded to a symbolic system where each domain is represented by its initial (**S** for *Sound*, **V** for *Visuals*, **M** for *Movement*). The direction of data between the domains is represented by the "greater-than" sign (>), and a comma is used to separate each independent transformation. So as an example, *Soft Revolvers* (Bleau 2014) is classified as **M > S > V** (from *Movement* to *Sound*, and from *Sound* to *Visual*), *Manual Input Sessions* (Levin and Lieberman 2004) is **M > V > S** and *Cloud Piano* (Bowen 2014) **V > M > S**. As stated before, despite of being projects with different typologies, setups and interactivity levels, we can relate them together in a common language, through the processes of transformation between the domains. In this case, the three artworks share a similar data-flow structure, sequential data transformation from one domain to another, and from this one to the next one.

The framework also allows cases where the input does not have origin on one specific domain, but rather on an external stream of data, like *Spectra-3* (2016) where the events have been defined on a timeline as scored data, from which the interactions on the domains are triggered. In this case, we have an extra element on the symbolic system, the *Data* represented by the letter **D**, to be assigned for external sources to *Sound*, *Visual* and *Movement* domains. It could also be used for cases where the inputs for the interaction system come from data collected on the Internet (like weather or financial data), or for cases where an external interface is triggering data into the *Sound*, *Visual*, *Movement* domains, as in the performance *Epizoo* (1994). Both cases are classified as **D>SVM** (from external Data to Sound, Visual, Movement domains). In cases where one of the domains does not have any interaction with others, it should be represented inside brackets, meaning it is isolated or independent. Just like in the dance performance *Apparition* (2004): **M > V, [S]** (Movement to Visual, Sound independent).

It is also possible that elements from the same domain interact with each other, as *Movement* generating *Movement*. Just like on the drone performance *Quadrotor Show* (2012), where the movement of drones in middle air is tracked by cameras and used as input into the moving head lights, making them point the lights to the drones. In this case, we have **D > SVM, M>M** (*Data* to *Sound*, *Visual* and *Movement*; *Movement* to *Movement*).

Alongside the theorical research work there was also a practice-based research path, focused on the creation of interactive projects exploring the relations between the three domains. Both research paths (the practical and the theoretical one) where developed in parallel, but always interconnected, with the practical work feeding inputs and informations to the theoretical, and helping in building the framework. And in the opposite direction, as the framework was a catalyst for the creation of interactive projects, with many of them being created with the aim of exploring a specific relation between the three domains, or testing some new approach on the relations between *Sound*, *Visual* and *Movement* in real-time. The projects presented are composed by four interactive dance performances (*Dancing with the Swarming Particles*, *Breakdown*), one audiovisual live performance (*Boris Chimp 504*), six interactive installations (*NonHumanDevice #01*, *#02* and *#03*, *Prefalll135*, *The Interpreter* and *Floating Satellites*) and two kinetic artworks (*Δ∞ [Infinite Delta]* and *Drippigment*).

Dancing with the Swarming Particles and *Prefalll135* had a particular importance on this dissertation, has they were created just before the beginning of the doctoral program, and were the trigger to the core ideas behind this research. Specially *Prefalll135,* an interactive installation where the rotation data of a series of watermills is used to control sound and visual parameters. The installation setup and its functionality, where movement generates sound and visuals, originated the first discussions on the relations between *Sound*, *Visuals* and *Movement*, and on the different configurations possibilities.

Boris Chimp 504 also had particular importance as it was a continuously work-in-progress and free-platform for audiovisual interactions explorations. Originally an audiovisual live performance, the project evolved to other forms as the interactive installation series *Non Human Device*, and the kinetic performance *Δ∞ [Infinite Delta]*. Also it allowed for numerous opportunities to participate in new media festivals, exhibitions and residencies, which provided important inputs and background to this research.

The three interactive dance performances created during the stay at UT Austin as invited researcher, were developed with the aim of exploring different interactive setup approaches for stage performance. On the first one, *Breakdown*, we used Kinect cameras to track the performers' bodies and used it as input for controlling sounds and visuals. On the second one, *Ad Mortous*, we explored two different devices, placed on the performer body. An EEG device, reading brainwaves and detecting deliberate mental tasks (as up, down, etc..) and facial expressions, and a gyroscope sensor placed on the performer's upper chest detecting body orientation. Both devices were collecting and broadcasting data, which was then used to interact with the visual space and sound in real-time. On the last performance, *With Oui*, the strategy consisted on using a motion device (*Wiimote*) suspended in the middle of the stage, with which the dancers interacted. Its motion data was then broadcasted and used to manipulate and generate sound in real-time, and sound parameters were then used to control the visual system.

In all the three performances the focus was on exploring interactive technologies as expressive tools and not just as background or wallpaper for the performance. The goal was to establish an interactive system which was also part of the creation processes, and with which the performers could explore as use as a tool in the creation of the performance narrative and influence the choreography.

The Interpreter and *Floating Satellites* are two cases which were created with the aim

of exploring a specific aspect on the relations between the *Sound*, *Visual* and *Movement*'s domains. The first one was a spin-off from the dance performance *Breakdown* which uses as source recorded motion-data captured from the performance's rehearsals. The motion-data, composed by a list of coordinates representing points from the dancer's body silhouette along the time, is used as input to control sound and visuals in an interactive installation. On *Floating Satellites* the main goal was to explore different approaches on the *Movement* domain and show that all physical movement can be considered as part of Movement domain, specify feeds from transport data. In this case we used position data from satellites in orbit around the planet Earth, which was used as input for sound and visuals for an interactive installation.

Lastly, with the aim of exploring systems where the *Movement* domain acts as an output (in all the other projects created the *Movement* domain is an input of data) we created two kinetic artworks based on interactive mechanisms that could generate movement according to different interactions and data inputs. *Infinite Delta*, a kinetic performance/installation where a physical structure moved by servo motors, and placed in the middle of the stage could change its shape in real time according to different sequences, patterns and oscillators that were being triggered by the system. And *Drippigment* a robotic painting machine that allows users to control, through hand gestures, an array for creating aquarelle artwork.

A series of side projects and experiments, that were not part of the case studies list, were also presented (see Appendix). These projects were not included in the case studies list due to different reasons as some were just free experiments or unfinished projects or others do not fill the scope of interactive system where *Sound*, *Visual* and *Movement* domains are all present and interacting with each other. However, they were an essential part of this research as they provided essential knowledge and inputs for this dissertation.

In the end the case studies were analyzed under the *S+V+M* framework, their patterns, and data-flows pinned up. As an outcome of the process of categorizing interactive systems and stating their data-flows, an important role of the *S+V+M* framework emerged, which is a tool to trigger new projects focused on the exploration of *Sound*, *Visuals* and *Movement* relations. As a result, two ideas for future projects, inspired by the *S+V+M* processes, were described. The first one, the *S+V+M Machine*, is a speculative design artwork where the *S+V+M* framework and the relations between domains are used as concept for artistic creation. It consists on a perpetual motion machine, that creates endless feedback between the three domains. The other, *Shapeshifter*, an interactive performance, where the dancer's body is augmented by a large cloak attached to his/her body and suspended by a group of drones flying in the mid-air and reacting to the dancer's movements.

6.2 DISCUSSION AND LIMITATIONS

6.2.1 DISCUSSION

As said before the main goal was to provide a tool to analyze and compare under the same scope interactive projects which are by their characteristics and typologies taken apart, but that we can relate in a common language. Just as Dorin et al. stated on their framework for generative art: "the medium and experience of these works appear to be quite different. Yet, when we look carefully we find that the underlying generative processes are remarkably similar." (2012)

When we observe the artworks presented in this dissertation from the *S+V+M* perspective, we get a high level of abstraction related to the specific details of each artwork, and we can easily recognize similarities and establish common parameters between different systems. From these observations, a series of patterns and connections emerge:

1) We can find three different typologies of how the data-flows between the domains and establish input/output relations: a) The data-flow starts in one domain and diverges to the others, just like in *Floating Satellites* (Carvalho and Sousa 2014), where the flux goes from *Movement* to *Visual* and *Sound*; b) Data from different domains converge into one, like in *Messa di Voce* (Levin and Lieberman 2003), where *Movement* and *Sound* converge intro the *Visual* domain;c) The domains are sequential, one domain triggers another, and from this one to the next one, like on the *Manual Input Sessions* (Levin and Lieberman 2004), where it goes from *Movement* to *Visual* to *Sound*;

2) From the analysis on the case studies, as from the artworks developed, one can also identify patterns related to which domains are primary inputs or outputs. One finds that the *Movement* domain is input in most part cases (twenty-four artworks), external data sources are the input origin in seven cases, the *Sound* domain in two and the *Visual* one in one case. We can also find that most common data-flow structure is: *Movement* to *Sound* and *Visual* (**M>SV**), present in eighteen artworks. This structure is present in many of the dance performances studied in this dissertation, like *Breakdown* (Carvalho, deQuay and Jun 2014), *Anatta* (Delev and Gruberska 2014) or *Luxate* (Beira 2015), where the performer's body is tracked by cameras or sensors and its data used as input into the *Sound* and Visual *domains*. We can also find the same structure in some of the interactive installations as *The Interpreter* (Carvalho, deQuay and Jun 2014), *The Trace* (Lozano-Hemmer 1995) or *Laser Forest* (Marshmallow Laser Feast 2013). The predominance of the **M>SV** structure can be justified with the fact that interactive dance performances (or other body based interactions) are one of the focus of my artistic practice.

The second most common flux structure (present in seven cases) is **D>SVM**, where data from an external data source is inserted in the system and used to trigger *Sound*, *Visuals* and *Movement*. We can find this structure specially in the kinetic projects as: *Deep Web* (Henke and Bauder 2016) and *Spectra3* (Field 2016), but not exclusively as we find it also on the interactive performance *Epizoo* (Antúnez Roca 1994).

Another common structure is the sequential one (present in four artworks), where one domain is translated into another, and from this one to the next one. We find it in *With Oui* (Carvalho et al. 2015) or *Soft Revolvers* (Bleau 2014) where in both the flux goes from *Movement* to *Sound*, and from *Sound* to *Visuals* (**M>S>V**).

3) The data-flow typologies listed above allows us to group and make connections between projects with different characteristics, like: *Floating Satellites* (Carvalho and Sousa 2014) an interactive installation based on the positions of artificial satellites around the planet Earth, with *Prefalll135* (Carvalho, Antonopoulou and Chavarri 2012) an interactive installation based on the rotation of watermills, with *Luxate* (Beira 2015) an interactive dance performance, and *Laser Forest* (Marshmallow Laser Feast 2013) a responsive immersive environment. Despite their different characteristics, operation modes and type of movement (one uses position data from satellites around Earth, other uses the gravity of falling water to make mill rotate, the other captures body movements, and the last one the mechanical vibration of a series of rods) all share the same data-flow, from *Movement* to *Sound* and *Visual* (**M>SV**), and all of them are similar under the *S+V+M* framework.

Another good example is the case of *Cloud Piano* (Bower 2014), *Soft Revolvers* (Bleau 2014) and *Manual Input Sessions* (Levin and Lieberman 2004). *Cloud Piano* is an autonomous robotic piano that maps pictures from clouds to a robotic mechanism that plays piano keys, *Soft Revolvers* an audiovisual interface based on rotational data of a series of tops, and *Manual Input Sessions* a gesture based instrument where hands gestures create visual shapes, that are then translated into sound. All these artworks have in common the fact that they are based on a sequential data-flow, where data from one domain is translated into another, and from this one to the next one. However, in each case the sequence of transformations is different: *Cloud Piano* goes from the Visual domain to Movement, and from Movement to Sound; *Soft Revolvers* from Movement to Sound, and from Sound to Visual; and *Manual Input Sessions* from Movement to Visual and from Visual to Sound.

When observing these patterns and connections new research and artistic paths emerge, driving us into the exploration of new projects with different interactions and *Sound*, *Visual* and *Movement* relations. Which lead us our last research question:

> *How can we use the relations between Sound, Visual and Movement domains as a catalyst in the creation of new interactive artworks?*

When we analyze the cases on this research, we can perceive that most of the collected artworks, as also the developed practice based projects, used *Movement* as an input, and not as output. This led to pursuing systems with *Movement* as output and to explore mechanism, motors and kinetic systems. The first step was *Warning: A Wearable Electronic Dress Prototype*[3] (Carvalho and Weller 2014), an experimental project with the goal of exploring wearable interactive technologies to be used on stage performances. Where a costume, composed by a shape shifter collar, is controlled by servo motors that react to a proximity sensor, and an interface painted on the costume's fabric that allow the interaction in real-time with sound.

A number of projects were then created with the main goal of developing an interactive kinetic system with *Movement* as the output of the system, as *Infinite Delta* (Carvalho, Neto

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3   See Appendix: Experimental & Other Projects

and Anastasio 2016) and *Drippigment* (Carvalho et al 2016). In both artworks a kinetic system responds to diverse inputs and performs movements. On *Infinite Delta* a series of triangles create morphing physical shapes on stage as a performative element, on *Drippigment* a robotic arm rotates in order to drop ink and create a painting.

Another example of how the search for relations on *Sound+Visual+Movement* domains influenced the creation and implementation of artworks were the cases of the interactive dance performances created during the research periods at UT Austin, Texas. The first one, *Breakdown,* used a standard stage setup, camera tracking the dancers' positions and using the motion data for visuals and sound manipulation. In the following ones, there was a need of exploring different configurations and explore new interactions, but always with a strong expressive and performative outputs in mind. On *Ad Mortuos* the data-flow was similar to *Breakdown* (**M > SV, S > V**), however the strategy to capture the performer's movement was different (with motion tracking devices placed on his body), allowing this way to new expressive and choreographic possibilities. On the last one, *With Oui*, a different approach was used, and instead of directly capture the performers' movements, there was a device placed on stage whith which the dancers interacted. The device, a *Wiimote* broadcasting motion data, was used by the dancers as an expressive tool with which they were able to connect in real time with the sound and visual domains. In this piece the data-flow was **M>S>V**, where motion data from the device was used to manipulate generative sound parameters in real-time, and sound frequencies and amplitude analyses were used to control parameters on the flocking system present on the visual domain, transforming this way its behaviors.

The section *5.5 Future Explorations on S+V+M Interactive Systems* emerges as the result of the *S+V+M* framework as a potential tool in the creation of new projects. As by analyzing and categorizing *Sound*, *Visual* and *Movement* domains, new exploration paths and ideas are triggered. In this way, the framework *S+V+M* apart from the main goal of categorizing interactive systems and its processes, also aims to be an important catalyst in the creation of new ones.

S+V+M, as a tool for categorizing interactive systems, intends to be useful also for the audiences (and not just experts, scholars and creators) who due the high level approach of *S+V+M*, are able by observation to relate and make connections between different types of interactive artworks. It intends to work not just "a purely theoretical model", but a tool to "elaborate criteria - based on the concrete observation of exemplary artistic project - that facilitate the description and the analysis of interactive art." (Kwastek 2013, 62)

6.2.2 LIMITATIONS

One of the limitations in this research, and specially related to the proposed framework, is the fact that classification systems are often subject to a variety of discords and criticism, which leads to disagreements related to the its terms, typologies, scopes and definitions. There are frequent divergences related to the definition of *interactive systems*, as well with the boundaries of the *Sound, Visual and Movement's* domains. It was taken a special effort on section *4.2 Sound, Visual and Movement Interactive Systems* in stating and defining *interactive systems* and the scope and boundaries of the *Sound*, *Visual* and *Movement* domains.

One of the main reasons that leads to these divergences, different perspectives and definitions is the fact that interactive art is a very multidisciplinary field, composed by practitioners from many different areas, with diferent tools, media, processes and backgrounds.

Another limitation is related to the fact that in most artworks the interactions and processes happen inside a *blackbox*. The code and processes that create the interactions are usually inside a machine or computer, a "closed box with which one interacts through input and output channels" (Carvalhais 2010, 126). To be able to understand the system's processes and classify the artwork the audience needs technical information from the authors, in this case "it is easy for any viewer to incorporate the knowledge about the core process (even if the precise technical details of the implementation may be unknown) into the analysis of the artifact and into its aesthetic fruition." (335). In artworks which lack documentation the viewer has to speculate and rely on his suppositions about the interactive processes happening inside the said *blackbox*. (Kwastek 2013, 29)

Another potential criticism can be pointed to the research scope (interactive systems containing the three domains) and the selected case studies (mostly stage performances and audiovisual interactive installations). These choices have artistic motivations as they are directly connected with my artistic practice, on this specific field within interactive art, which represent the source and motivations of this research. The development of the framework emerged as a theoretical structuring support to my artistic creation, therefore the types of interactive systems focused and artworks are strongly linked to the artistic path. Yet I am confident that this research's scope and presented case studies cover a wide spectrum and that the conclusions and classifications that it led are to substantial.

Although the focus is on interactive systems that include interactions between all the three domains, we believe that the perspective of this research (on looking into the dataflow and input/outputs in the system), could be also used in other contexts and with different number and types of domains.

6.3 CONTRIBUTIONS

This dissertation provides three main contributions:

1) The *S+V+M* Framework
The proposed framework for the classification of interactive artworks contributes with an update of the literature review on the field, as well to expand the theory on the study of interactive systems and the relations between sound, visuals and movement in real-time. The approach on looking into a higher level of abstraction in order to frame projects separated by technical setups and type of levels of interactivity in a common language, intends to provide tools that help the creation of critical and methodological thinking on the field, and the evaluation and discussion of interactive artworks under a unified perspective. It is expected that the framework can be useful not just for scholars, creators and experts but also for the audiences, and help them to relate and make connections between different types of interactive artworks. It is also expectec that the framework can be usefull in the creation of new projects, by triggering new ideas and paths on the exploration of relations between *Sound*, *Visual* and *Movement* domains.

2) Practice-Based Research Artworks:

During this study there were created a series of interactive artworks related to my practice-based research on the relations between *Sound*, *Visuals* and *Movement* in interactive systems. This dissertation presented documentation on a set of thirteen projects, ranging from audiovisual installations and kinetic systems to interactive dance performances and kinetic. The documentation provides insights on techniques, software, hardware and critical analysis for the development of interactive artworks. It addresses a series of topics like motion tracking, sensors, electronics, motion data, interactive devices, gesture base interaction, servo motors, kinetic mechanisms, and sound visualization among others. When relevant the computer source code is also provided, and shared with the public on the *Github[4]* platform.

Besides, in the <u>*Appendix: Experimental & Other Projects*</u>, there is also a report on a set of small, experimental, explorative or parallel projects that due to theirs characteristics were not included as case studies, but were an essential part of the practice based process and provided essential knowledge for the research. It reports on a set of topics related to interactive systems such as visualization of motions data, sound visualization, visualization of drums vibrations, in body sensors, wearables technologies, facial features as interactive device, exploration of interactive moving head lights, and lasers.

It is hoped that the documentation, and insight details on the practice based work, can provide a practical guide for the creation of interactive artworks[5].

3) *S-V-M*[6], the blog:

The blog started as a notebook to structure and support the searching and collecting of interactive artworks and its correspondent processes and interactions between domains. It works as an informal list of projects with the main goal of compiling and organizing interactive audiovisual projects.

Over time the blog started to gain attention from many online communities related to audiovisuals and interactive art, leading to several e-mails and messages with feedback, comments, and pointing to new projects. Also, requests for interviews, and an invitation for a public talk at Mira Festival 2015[7] in Barcelona, titled "Sound+Visual+Movement".

What started to be a personal notebook to structure the research has become a public archive of interactive art where artworks are catalogued according to its characteristics and give to the general public a tool for critical and methodological thinking on the interactive artworks field explored on this research.

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4 GITHUB, web-based hosting service for version control. < https://github.com/>. Accessed 2017.04.17

5 A digital archive containing video documentation and code samples is provided in attachement with this dissertation

6 <http://s-v-m.tumblr.com/>. Accessed 2017.04.17

7 Mira, Digital Arts Festival <http://www.mirafestival.com/>. Accessed 2017.04.17

6.4 FUTURE WORK

The guidelines for future work focus on extending the presented work and exploring new paths on the interactive art field and specifically on the relations between the *Sound*, *Visual* and *Movement* domains, expressed both on developing new artworks as on expanding and improving the framework. As already stated, the framework does not intend to be a closed system, but a flexible one, open to new designations that can help to describe the interactive systems. Taking into account new paths and trends on the interactive art field (described below) new dimensions and domains could be added to the framework, and adapt it to different contexts. As an example, the framework element **DATA [D],** that is used to describe in general, a data source from outside of the system, is an aspect that could in the future be improved, and be more specific about its source.

In recent years, there are some emerging trends that could give new perspectives on the field. These trends, which are the result of an easier access to technologies - as augmented and mixed realities, flying drones, kinetic mechanisms, or artificial intelligence applied to interactive artworks - have been pushing forward the field into new directions and possibilities. One example is the work developed by *Ars Electronica Futurelab* with swarms of drones flying, performing choreographies and drawing shapes. They are named *Spaxels[8]*, referring to pixels in space, where each drone holds a LED light in a way that each one is a three-dimensional pixel flying in the air, forming an image together with the rest of the drones. It works as a dynamic display in the middle air, capable of drawing shapes, perform choreographies and abstract dynamic visual compositions along music. The *Visual* and *Movement* domains have here a very tight relationship, *Visual* domain is not only on a projection screen but is light is space composed by the *Movement* of flying pixels.

Fig. 117: Test flights, rehearsing for a Spaxels performance in Rock in Rio 2017 (2016) (Left); 100 drones ready to flight for the event DRONE 100 (2015) Tornesch, Germany (Right).

Artworks using choreographed flying drones performing shapes in the air, were already referenced in this dissertation, as in the case of one of the cases study *Quadrotor show* (Marshmallow Laser Feast 2012), and also on the section *5.5 (Future Explorations On Sound+Visual+Movement Interactive System)*, where we made reference to the work of *ElevenPlay & Rhizomatics,* where dancers and drones perform together in stage. On the same section we also described an idea for a future project (named *Shapeshifter*) where a dancer

8 <www.spaxels.at> Accessed on 2017.04.14

interacts with a group of flying drones, which hold a large cloak attached to the danc-er's body, and that by moving would lift the cloak, generating this way three-dimensional shapes in space, augmenting the dancer's body.

Another interesting topic is the emergence of Artificial Intelligence systems in inter-active art projects. This is obviously not a new phenomenon, but recently the appearance of easier to use algorithms and libraries, opened this topic to artists and other creative people. As an example we can look to *Tensor Flow[9]*, an open-source artificial intelligence engine by Google, or the *Kadenze[10]*, an online educational platform in the fields of art and creative technology, that holds a series of courses in on this topic named: *Creative Applica-tions of Deep Learning with TensorFlow[11]*. A good example of the use of artificial intelligence approaches on interactive artworks is the dance performance *Pattern Recognition* (Akten 2016). On this piece, we assist to a dialogue between two dancers and a machine learn-ing system that controls an array of moving head lights. The system watches and learns the dancers' movements, and predicts future movements or how an human dancer would respond to a certain move.
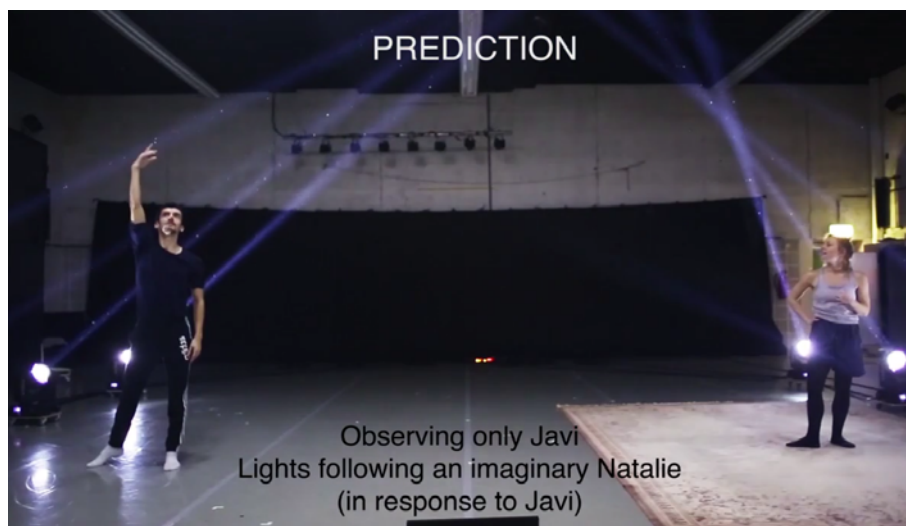
Fig. 118: Still from *Pattern Recognition* R&D session. <https://vimeo.com/181115064>

One more focus of interest are also the exploration of a series of new devices that are appearing in the market for augmented and mix realities, such as the *Hololens[12]*, or the *Magic Leap[13]*. This is also not a new topic (in fact it has been a trend for decades now) but recent advances and new devices brought the field to a new range of possibilities, and pro-vided a new layer of mix-reality to immersive audiovisual experiences. With these devices one could easily imagine audiovisual performances or installations where the sound could be visualized in space, and not only on a projection screen. The audience members would wear a pair of augmented reality glassed and would see three-dimensional graphics

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9 <www.tensorflow.org/>. Accessed 2017.04.16.

10 <www.kadenze.com>.Accessed 2017.04.16

11 <https://www.kadenze.com/courses/creative-applications-of-deep-learning-with-tensorflow-i/info>. Accessed 2017.04.16

12 <https://www.microsoft.com/en-us/hololens> Accessed 2017.04.16

13 <https://www.magicleap.com> Accessed 2017.04.16

visualizing the sound in the real space. Shapes would flow from the sound-speakers and cross the real space, reflecting in its walls and crossing the audience bodies.

An innovative dance performance that uses virtual and augmented reality and literally immerses the audience is the project *Border* (Rhyzomatiks and Elevenplay 2016). Here ten members of the audience take part of the performance on stage. They are seated on a personal automated mobility ride, which is controlled by the interactive system and moves along the space. Each one of the ten persons wears a headset formed by a virtual reality display and a real camera on top. This way the audience watches the performance through the headset which mixes real images with virtual and augmented ones. On stage the dancers and the audience riding the automated rides form choreographed movements along music which are shape by layers of augmented visuals and data, enhancing spatial and physical expression.
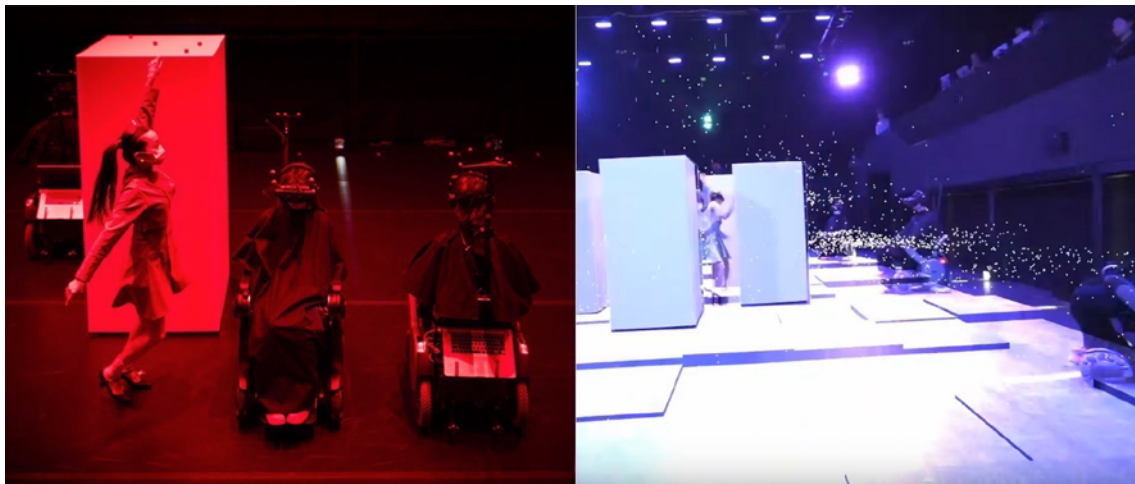
Fig. 119: Pictures from Border (Rhyzomatiks and Elevenplay 2016) dance performance.

Section 5.5[14] described two ideas for future projects that explore new perspectives on the relations between *Sound*, *Visuals* and *Movement*, and where inspired and triggered by the *S+V+M* framework, which express its contribution as a tool to generate new artworks. Future projects to be developed should follow this same idea of experimenting with new technologies and media, and at the same time explore new or uncommon interactions between *Sound*, *Visual* and *Movement* domains.

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14 see "5.5 Future Explorations On Sound+Visual+Movement Interactive Systems".

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APPENDIX I: EXPERIMENTAL & OTHER PROJECTS

Below is a selection of projects that were not considered as case studies in this dissertation. This was because some are unfinished, free experiments, or explorations of a certain technology, technique or approach. Or because some do not fill the scope of interactive system where *Sound*, *Visual* and *Movement* domains are all present and interacting with each other, on which the focus of the *S+V+M* framework. Despite of not being qualified as case studies, these projects were an essential part of the research and practice based process and provided essential knowledge for the following projects.

1. THE CHOREOGRAPHIC CODING LAB Workshop (2013)

In November of 2013 I took part of the Choreographic Coding Lab[1] (CCL), an exploratory laboratory focused on translating aspects of dance and choreography into digital forms. CCL events are an outcome of *MotionBank*[2], a dance and technology project of *The Forsythe Company*[3] focused on the creation of online digital scores for dance.

In this event, a group of visual artists, musicians, coders and dancers from different countries gathered in Frankfurt for a week of free exploration on topics related to the fusion of dance and technology. The topics were diverse and included themes as the choreographic language of code, choreographic video composition or movement visualization. During this week I worked on two different prototypes that explored movement visualization and choreographic visual languages. The prototypes presented at the end built the groundwork for the dance project *Breakdown*[4] and interactive installation *The Interpreter*[5] developed in the following year.

Fig. 120: Picture taken during the CCL event. A performer dances inside an interactive space tracked by cameras, while participants experiment audio and visual outputs with the real-time motion data.

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1 Choreographic Coding Lab <http://choreographiccoding.org/>. Accessed on 2015.12.28

2 Motion Bank. <http://motionbank.org/.> .Accessed on 2015.12.28

3 The Forsythe Company <http://www.dresdenfrankfurtdancecompany.com>. Accessed on 2015.12.28

4 Breakdown, Interactive Dance Performance, 2014. See section 5.3.3.

5 The Interpreter, Audiovisual Installation, 2014. See section 5.3.4.

The first prototype, *Lines*, explored the visualization of movement based on motion data captured from the performance *Seven Duets (2013)[6]* by Jonathan Burrows and Matteo Fargion, where we watch a gesture dialogue between both performers. This performance was part of the MotionBank project, so extensive documentation, video and skeleton tracking data was available on MotionBank's archives. Focused on the gestures made by the performers the goal was to visualize graphically the paths drawn by their motions. White lines were used to connect different body joints and extract graphical patterns based on their gestures over time. The output was an animated geometrical graphical dialogue, a visual abstraction of the original performance.

This work was inspired by the project *William Forsythe: Improvisation Technologies: A Tool for the Analytical Dance Eye* (1999), a CD-ROM containing a series of video segments demonstrating a choreographic vocabulary connecting body, space, time and movement. With the purpose of training his company's dancers, Forsythe produced a video dictionary demonstrating a geometrical approach to each class of movements. Each video segment is focused on a class of movement, where we see Forsythe performing the movement and overlaid over Forsythe's body a series of animated lines drawing the movement of the body in space. A similar approach was used on *Lines* where a new geometrical and spatial dimension of the performance was revealed by having animated lines following the performers' body joints.

Fig. 121: Frames from William Forsythe video sequences, where animated lines are overlaid on the video revealing geometric patterns (1999).

The starting point to develop this experimental prototype was a Processing project, created by Florian Jenett[7], were skeleton tracking data from both performers was parsed and time-coded. From there, several visualizations experiments were made by connecting different joints with lines and watching its motion over time. Some of the experiment included connecting left hand with right hand, connecting head with both hands, or connecting both hands with a fixe point in space.

The prototype developed was a real-time application where a geometric dialogue between both performers is explored. The application is continuously running on the background through the time-coded motion data from the performers, and on screen a series

6 SEVEN DUETS (2013) - fragments, movements and insights from the interplay between Jonathan Burrows and Matteo Fargion. <http://motionbank.org/en/content/jonathan-burrows-matteo-fargion>. Accessed on 2015.12.28

7 Processing files from working with Jonathan Burrows and Matteo Fargions choreographies and data by Florian Jennet, one of the Workshop Organizers and part of the MotionBank project team. <https://github.com/motionbank/burrows-fargion-processing>.Accessed on 2015.12.28

of five different visualizations are displayed. Users are able to choose between the different visualization modes by clicking on the correspondent key-number on the keyboard. The available modes are: 1) One horizontal line for each performer, formed by connecting to right hand to the left one; 2) A triangle shape for each performer, formed by connecting three points (head, left and right hands); 3) A group of horizontal lines connecting both performers. Results of connecting matching joints from both performers (heads, spines, hands, knees, feet and shoulders); 4) Two rhombus shapes made by connecting the middle point on the top of the screen to both performer's hands, to a middle point on the bottom of the screen; 5) Curved lines, four for each performer, connecting the head to the corresponding elbows and hands.
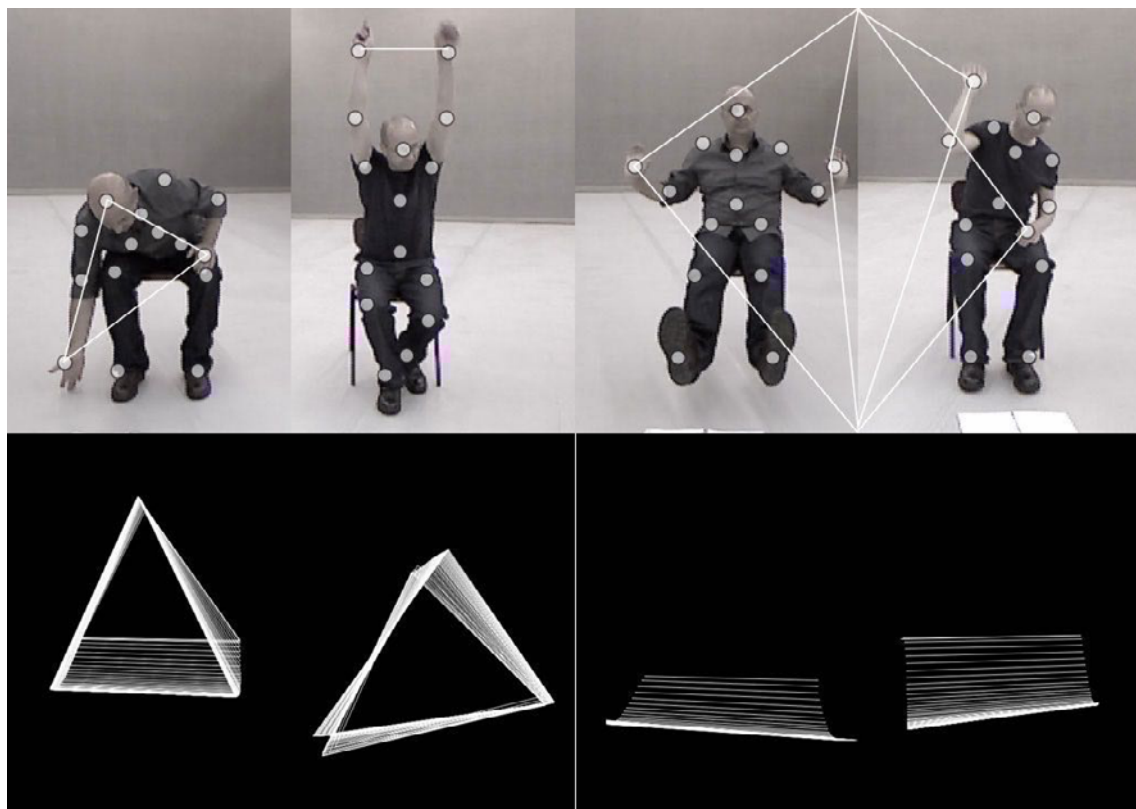
Fig. 122: On the top, stills from the performers with the skeleton joints over imposed and white lines connecting different joints; On the bottom, graphic output of the animated lines connecting head with both hands (bottom left) and right to left hand (bottom right);

As output, apart for the real-time application, a set of posters were created collecting different moments in time for each visualization mode. The processing code for the application, a video render and more images can be found at the project's report online[8].

8 Report from The Choreographic Coding Lab, Motionbank. Frankfurt 2013
<http://visiophone-lab.com/wp/?p=384>.Accessed on 2015.12.28

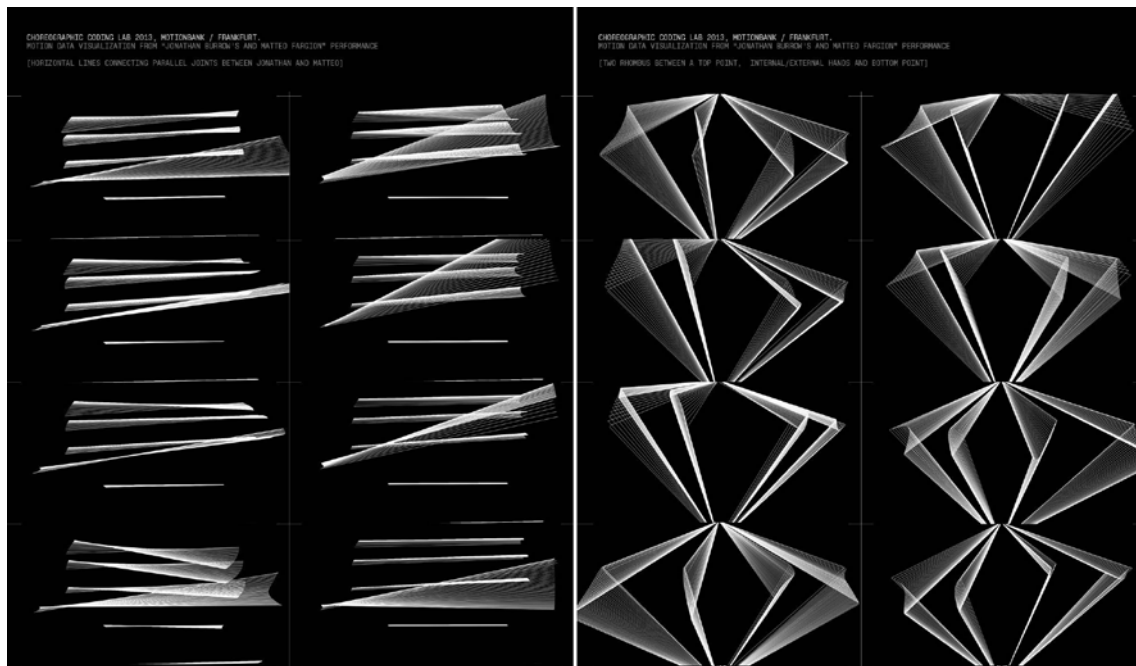**Fig. 123:** Two posters created from the graphic visualizations. On the left collecting visualizations from mode 3, with horizontal lines connecting matching joints from booth performers. On the right collecting visualizations from mode 4, with rhombus shapes made from connecting specific points on the screen with the hands of booth performers.

Gravity, the second prototype developed during the workshop, is a visual interactive system for a dance performance. It is a Processing application made from a gravitational particle system[9] of white dots that move inside a virtual two-dimensional world. The goal was to create a visual system with whom a dancer could interact and improvise with. More than a motion visualization system, the aim was to create a tool that is fed from the dancer's movement and replies back, in a way that it interacts with the dancer and influences his following movements and the final choreography. A tool in the borderline between a visual tool and a gaming experience.

The system is composed by a set of approximately seven hundred particles, each composed by a white dot (the body of the particle) and a tail (a white line connecting the body to its previous positions in space). The size and position of the tail vary according to the movement of the particle itself, if the particle is stopped the tail is invisible, when the dot moves the tail smoothly drags after it.

The virtual world has a series of gravitational forces attached, which influence the movement of the particles. There is one fixed force located in the middle of the screen and three dynamic ones, one corresponding to the mouse position and another two to be connected with external sources (initially receiving in real time, via OSC, the position data from both hands of a performer). Each force could have a negative or positive value, so depending on the case particles would be attracted of repelled by them.

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9 Physics managed withToxic Physics library for Processing. <http://toxiclibs.org/downloads/> Accessed on 2015.12.28
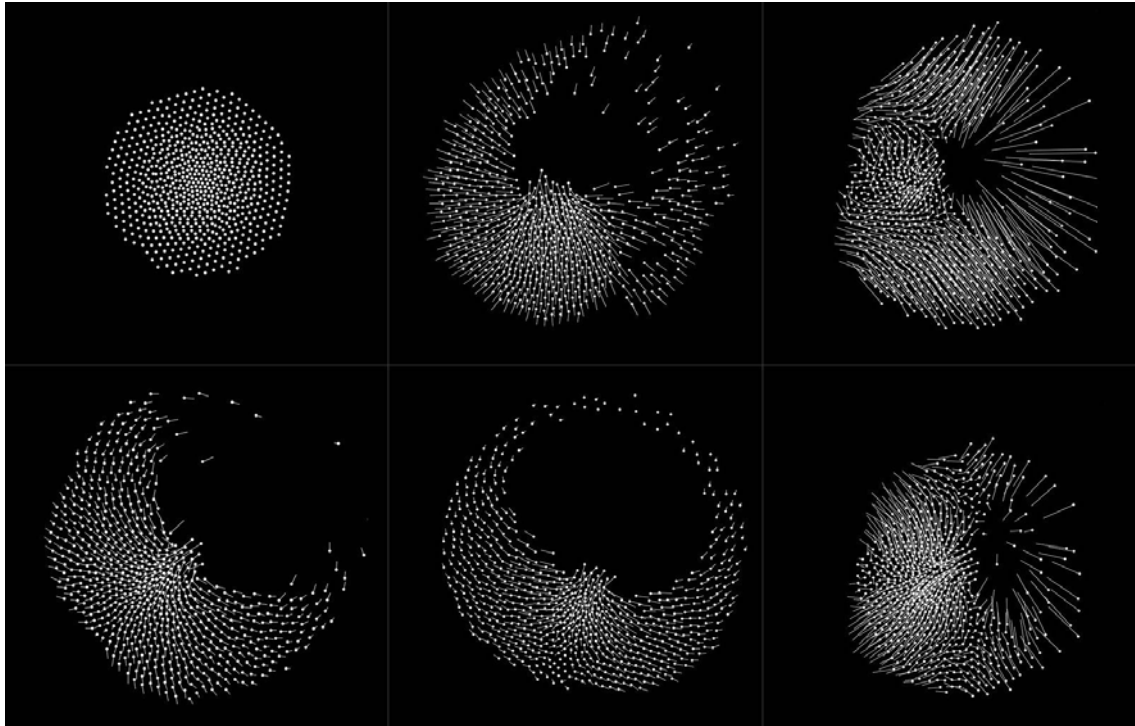
Fig. 124: Stills grabbed from the real-time application, exhibiting the effects caused by the gravitational forces on the particles. In this case a positive force attracts the particles to the center of the screen while a negative and moving one repels them.

During the event an interactive space was build where dancers or visitors could go inside to explore, and where theirs bodies were tracked by cameras and its data broadcasted over WIFI to all the participants. In this way different experiments and prototypes where being developed in parallel from the same motion data sources.

The final visual output delivered by the gravitational system resembles a living abstract organism, whose shape is constantly morphing smoothly. By changing the characteristics of the world and gravitational forces' parameters it is possible to create a wide rage of graphical outputs and interactions.

Processing code for the application, a video render and more images can be found at the project's report online:< http://visiophone-lab.com/wp/?p=384 >.

2. X-GRAVITY (2014)

X-Gravity is an interactive audiovisual installation developed and exhibited at AXA building in Porto, 2014. It was created based on *Gravity* prototype, created previously at the CCL event. It uses the same gravitational particle system, but in this case the input into the system is not motion data but audio signal.

X-Gravity works as a sound visualization artefact, where a soundtrack is played and in real-time its sound frequencies used to manipulate the values of the gravitational forces on the visual system, attracting and repelling the particles inside the projection space and creating this way a visual relation between the sound and the particles in motion. Beyond the sound visualization aspect of the project, that runs in loop and autonomous, the installation setup also contains a gamepad device that allows visitors to interact with the system by changing parameters and manipulating extra gravitational forces.
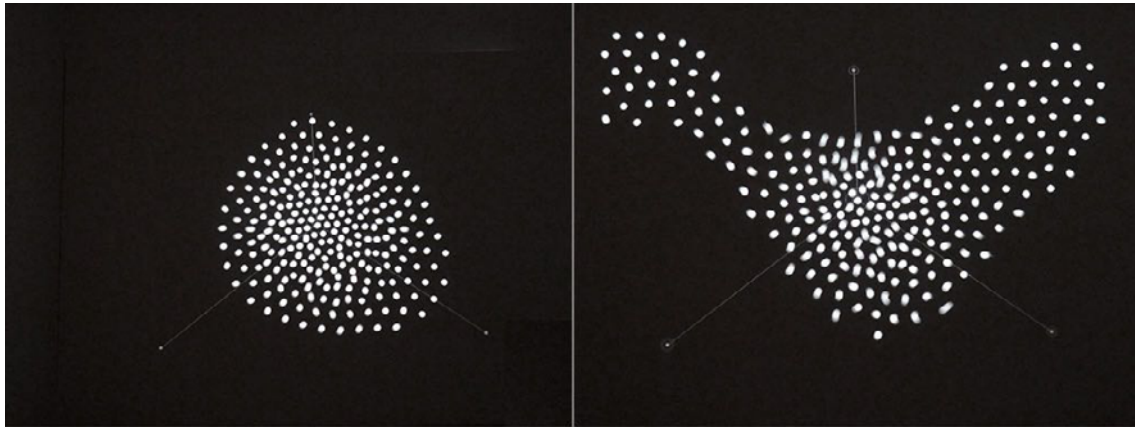

Fig. 125: Pictures from the installation's video projection. Distinct gravitational forces causing movement on the particles (on the center the attraction force, placed around it three repelling ones).

The system is composed by five gravitational forces: Four with a fixed position on the screen (one in the center and the other three placed around the first one forming a triangle); and a dynamic force which position is controlled by the visitors through the gamepad. On the four fixed ones its values are determined by real-time sound frequencies. The sound spectrum is divided into four frequency bands, from low to high, where the force in the centers reacts to the first band with an attraction force, and the remaining ones react to the other three bands with repel forces.

The dynamic force is controlled by a gamepad that is made available for the visitors and placed in the middle of the installation space. With the arrows users control the position of the force in the visual system space and with trigger buttons distinct force values are applied (attraction or repulsion).

A video of the installation can be accessed at the project's online page: <http://visiophone-lab.com/wp/?portfolio=x-gravity>. The soundtrack used was: "Tools that are no good" by Gustavo Costa, 2006.

3. UNTITLED.001 (2013)

Untitled.001 was an experimental prototype developed in 2013, in collaboration with the drummer Jorge Queijo, with the aim to visualize drum vibrations. The goal was to establish a dialogue between the drummer and the visual system, not through the sound frequencies emitted by the drums itself but through the vibrations caused by the drummer hitting each drum section.

Four piezo sensors were attached to different sections of the drums (bass drum, snare drum, floor drum and splash cymbal). The values of each piezo was read by an Arduino and sent to the visual system developed in Processing. Similar to the previous experiments (*Gravity and X-Gravity*), on *Untitled.001* the visual system was composed by a gravitational particles system, and the values sent from the piezos used as input to modify forces and gravity parameters on the system.
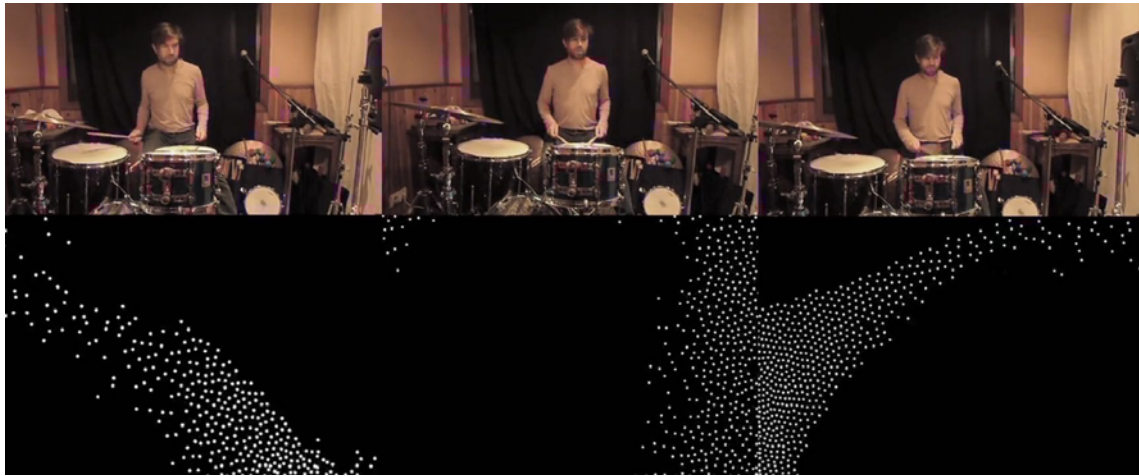

Fig. 126: Stills capturing the experiments, on the top the drummer hits different drums sections, bellow the corresponding visual reaction on the particle system.

On the screen there here placed four different gravitational forces, each receiving the data from one independent piezo. When the drummer hits the different sections, the correspondent gravitational force emits a repulsing force moving away the particles.

The result was a dynamic output where the particles form fluid visual shapes. By looking at the visual outcome, while playing the instrument, the drummer is constantly influenced by the shapes that are being created, subordinating this way the musical expression to a desired visual output.

A video documenting the outcomes can be watched online:
<https://vimeo.com/75788989>.

4. WARNING: A WEARABLE ELECTRONIC DRESS PROTOTYPE (2014)

Warning: A Wearable Electronic Dress Prototype is the result of an experimental project developed during developed in collaboration with the costume designer Kristen Weller, during the spring semester of 2014 at UT Austin, Texas. The goal was to explore wearable interactive technologies to be used on stage performances. The output was a costume prototype that could act as an extension of the performer's body and as an expressive tool.

The costume is composed by a shape shifter collar, controlled by servo motors that react to a proximity sensor, and an interface painted on the costume's fabric that allow the interaction in real-time with sound.

The collar, inspired by both the Australian frill-necked lizard and the fashionable Elizabethan "whisk" collar, has a fan shape covered with fabric and on the inside four servo motors attached to the collar's articulations. The rotation of the four servo's arms define the shape of the collar. Servos are controlled through an Arduino by a custom application developed in Max. The Arduino also receives data from an ultrasonic sensor, placed in the front side. When a determined proximity is detected, the servos start reacting by moving and/or their motion pattern, modifying this way the collar's shape.

The ultrasonic sensor, besides of being used to detect activity in front of the performer, can also be used by the performer itself as a body interface. By positioning the hand in front of the sensor at different distances, he will be controlling the values and interacting with the collar's motion and behaviors.

Fig. 127: Pictures from the of the prototype demonstration session. On the left side a close up, showing the conductive areas painted in black on the costume, the ultrasound sensor placed on the front and the collar on the shoulder; On the right side a general view of the performer and the Max application on the laptop, managing all the interactive data.

The costume's fabric has six black areas painted with conductive paint[10]. These areas work as an interface made of capacitive sensors, where the human body capacitance is used as input. When the performer touches these conductive areas, an Arduino detects the variations on the capacitive sensor's values, which are then translated into MIDI messages and sent to Ableton Live, where a setup previously prepared triggers notes, controls audio channels volumes and modulate filters over a background soundtrack.

The main goal of the prototype development was to learn and explore technologies and tools that have never been used before in my artistic practice, namely the use of servo motors and physical structures reacting in real-time.

In the end of the project a demonstration of the prototype was made and recorded in video for future documentation, which can be watched on the project documentation page: <http://visiophone-lab.com/wp/?portfolio=wearable-dress-prototype>.

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10   Electrically conductive paint by Barepaint <http://www.bareconductive.com>. Accessed on 2016.01.06

5. ADAMASTOR (2012)

Adamastor is an interactive audiovisual installation that explores a relation with a smaller scale world. The audience acts like the master of the forces of Nature, Adamastor[11] itself, embodying his power to create, interfere or even destroy a world.

This installation prototype was developed in 2012 as a group project of the course *Multimedia in Performing Arts* from the doctoral programme in Digital Media - Universidade do Porto (Rodrigo Carvalho, Henrique Serro, Luís Salgado, Manuel Meirinhos, Francisco Pedro, Katarzyna Sobolewska, Tiago Santos).
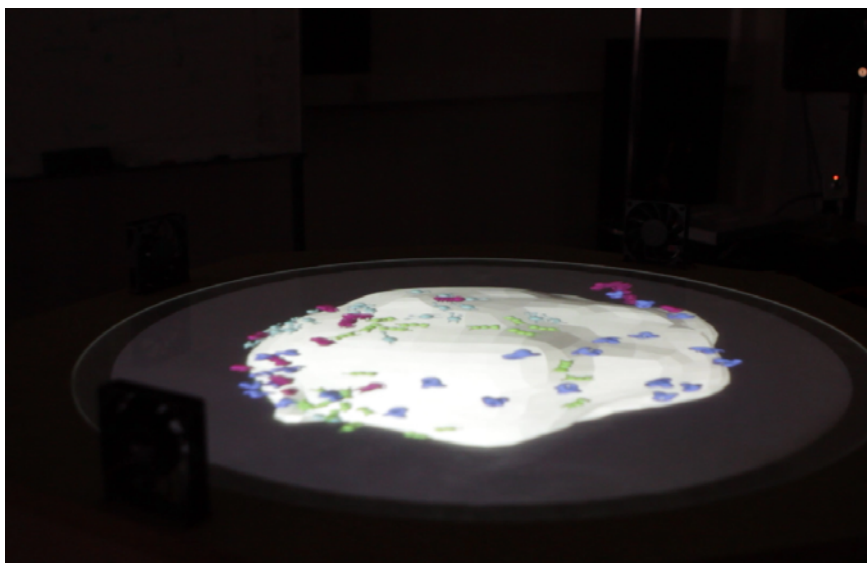

Fig. 128: Top view of the installation, where the planet and its inhabitants are projected.

The installation is composed by a wooden structure in the shape of an octagonal prism, with one-meter-high and a diameter of eighty centimeters. Inside, a computer manages the interactive system and a video projector and a mirror display the virtual world on the structure top, which is made of translucent acrylic in a way that the projected image is visible from the outside and hiding all the gear inside the structure. The top of the prism has on its edge four computer fans that are used as an interface to interact with the installation.

The audience observes on the top of the structure a virtual planet which initially is empty, but that in the course of time starts to receive inhabitants. The inhabitants (which are *Boids[12]* agents moving in a swarm flocking system) move around the planet and start to multiply continuously. When the planet reaches a certain level of inhabitants it collapses. The audience has the power to rewind this process in order to save the planet. When a user blows in a fan, generates wind inside the system, that will pushes away is inhabitants. If the user is consistent producing wind, we will be able to reduce the planet population,

11   Adamastor, a character from the Greek mythology, popular in the portuguese culture duo to the epic poem book "Os Lusiadas" (Luis Vaz de Camões 1572). The book tells the adventures of the Portuguese sailors in the 15th and 16th centuries exploring the seas. Adamastor represents a monster from the seas, that lives in "Cape of Good Hope" (south of Cape City, South Africa), and his the responsible for the storms that the sailors must overcome.

12   Boids: referring to "bird like objects", the artificial intelligent system created by Craig Reynolds to simulate the flocking behavior of birds (Reynolds 1987)

and extend the life of the planet.

The audience has the option to just observe or interfere with them by blowing in the windmills generating wind inside the digital ecosystem. The wind will act as a physical force interfering with the *Boids* behaviors, pushing them way or event destroying them.

Fig. 129: Top of the structure, where a group of four fans allowed the interaction with the system by blowing on them.

Each fan has a DC motor inside, when in motion the DC motor generates energy and returns an electric charge. By connecting the fan to the analog port of an Arduino, we are able to read its electric charge, use it as an input of data inside the virtual system. The virtual world is placed inside the software Unity3d, a 3d engine that manages the planet and its elements. Here the data captured from the fans is used to simulate digital wind over the planet. It is translated to physical forces that affect the virtual world elements, like the planet rotation and the position of its inhabitants. At the same time the same wind data and the boids' position and velocity data being sent custom Max/MSP path where an audio synthesizer generates the soundspace.

This installation works as an experiment in interactive narrative exploring a mixed media reality. A video documenting the installation can be watched online: <<https://vimeo.com/45391178>>

6. CONTROLLING VIDEO WITH FACE MOVEMENT (2013)

Explorative project made with the application *FaceOSC* by Kyle McDonald[13], an open-source face tracking tool for face-based interaction. *FaceOSC* is able to track, through a web-camera, the position and orientation of frontal faces and a series of features like: width and height the mouth, jaw openness, eyes openness, eyebrows height and nostril flate. All these parameters are then broadcasted via OSC messages.
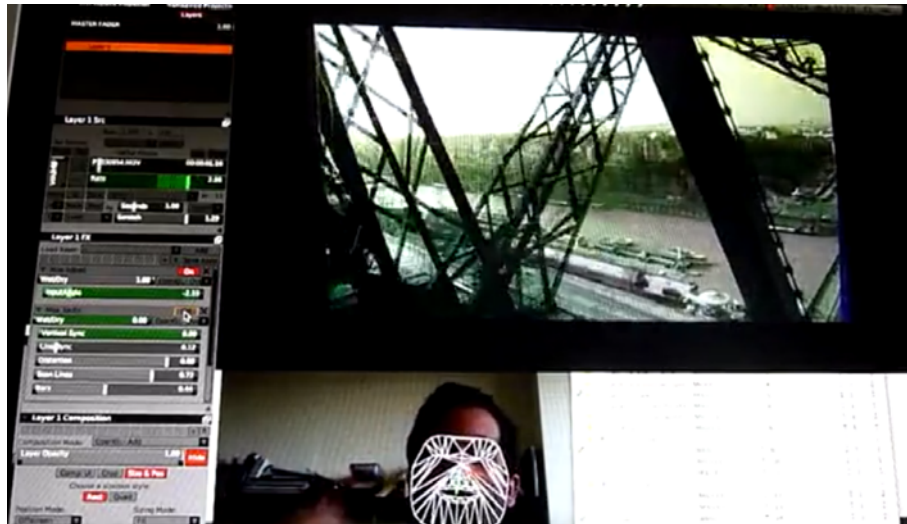

Fig. 130: PrintScreen from Controlling Video with Face's Movements.
On the left, a series of sliders with the video parameters that are being controlled.
On the center, a live feed from face tracking. On the top the videoloop on motion.

It this test the goal was to prototype and explore the use of a series of face features to manipulate video in real time. A group of videos were imported into VDMX, a VJ software, and OSC messages coming from FaceOSC were mapped into video parameters: Vertical orientation of the face controlled the video speed rate; jaw openness controlled the hue value; distance of the face controlled a "bad TV" distort effect; and hiding and show the face triggered a new video loop.

As a future project the intention is to develop an audiovisual performance focused on the real-time manipulation of sound and visual by a performer with his face.

A video documenting this experiment can be watched online:
<https://vimeo.com/64719480>.

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13 FaceOSC. <https://github.com/kylemcdonald/ofxFaceTracker/releases> Accessed on 2016.07.25

7. X-FILES' ALIEN SPACESHIP (2016)

X-Files' Alien Spaceship was an interactive light and sound installation created for the promotion of *The X-Files[14]*' new season on Portuguese television. The TV show, which follows themes around science fiction, had as promotion a model of an alien spaceship crashed in a public square in Lisbon. The project consisted on creating an audiovisual experience, integrated with the spaceship, that would attract passers-by to observe and explore the crash zone. Around the spaceship there were placed groups of twenty moving head lights, which were choreographed in sync with an ambient and spacey sound design. The light patterns performed by the lights together with the sound and the smoke machines created an immersive and uncanny place. In front of the spaceship there was also developed an interactive area that reacted to presence. A corridor with six moving head lights pointing to the center of the spaceship worked as activation zone. This area had two ultrasound sensors sending data through an Arduino to the computer. When someone entered the activation zone, the moving lights rotated towards the "intruder", the spaceship's interior would light up with a green light and the *TheXFiles*' main melody was triggered.

Fig. 131: User entering the activation area from X-Files' Alien Spaceship

The moving lights were controlled in real-time with DMX protocol from a computer through DMXIS[15], an interface wich allowed to control directly the lights with MIDI messages, and to easily sequence the moving and light patterns in sync with the soundtrack. Also when the activation area was on, a MIDI message was sent to the lights with a rotation control message, to make them move towards the center. Although being a commercial project, it had great value to the research as it grants an opportunity to learn and explore with moving head lights and DMX protocol, and on how to control them in real-time and integrate them in an interactive system. Which will be very useful for future projects.

A video can be watched at the project's online documentation: <http://visiophone-lab.com/wp/?portfolio=x-files-alien-spaceship>. Produced by Solid Dogma, and developed by Rodrigo Carvalho (Lights + Interaction) and Miguel Neto (Sound).

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14 The X Files, TV serie by Chris Carter (1993-...)<http://www.imdb.com/title/tt0106179/>.Accessed on 2016.07.25

15 DMXIS interface <http://www.enttec.com/index.php?main_menu=Products&pn=70570> Accessed on 2016.07.25

8. LASERS DE SÃO JOÃO (2016)

Lasers de São João, was an immersive laser installation created in the city of Porto to commemorate the city's patron, São João. The installation was presented from June 17 to 25 at General Humberto Delgado's square, in front of the town hall.

The visual and sound content was predefined in a timeline, running in twenty-minutes loops. The score was divided in four sections, each one of the them related to four different sections related to S.João's folk and pagan traditions and symbols (bonfire, waterfall, summer solstice and fireworks). In each section the colors, visual shapes and soundscapes were different relating to the section's theme.

The installation's setup was composed by two RGB Laser beams, placed on the top of the square, a sound system and an array of eight haze and smoke machines. The shapes drawn by the lasers were developed and triggered on Phoenix[16], a software that allows the creation of shapes and animations on a timeline and then translates it to the lasers beams under ILDA[17] protocol, while the soundtrack was running on Ableton Live.

Fig. 132: Audience watching Lasers de São João's installation.

The haze and smoke machines displayed around the public square wrapped the space in a misty ambience and transformed the beams of light in volumetric structures and three-dimensional graphics shapes. The synchronized soundtrack amplified the experience, wrapping the audience in a state of synaesthesia, creating this way a multi-sensory immersive experience.

Project developed at Openfield Creativelab: Rodrigo Carvalho (Art Direction, concept), Francisca Gonçalves (Sound), Ivo Teixeira (concept, production), Tiago Gama (documentation), Nuno Alves de Carvalho (production). A video documenting the installation can be watched at the project's online documentation: <http://openfield-creativelab.com/project/lasers-de-sao-joao/>

16 Phoenix, laser control software. <http://www.phoenix-showcontroller.de/en/>. Accessed 2017.09.11

17 ILDA (International Laser Display Association), it is a protocol for computer control of show laser light systems.

9. INTO THE VOID (2015)

Into the Void is the first of a series of audiovisual installations exploring physical structures creating light and shadows in immersive audiovisual spaces. This first version was presented in 2015 in the closing show of AXA building, in the city of Porto.
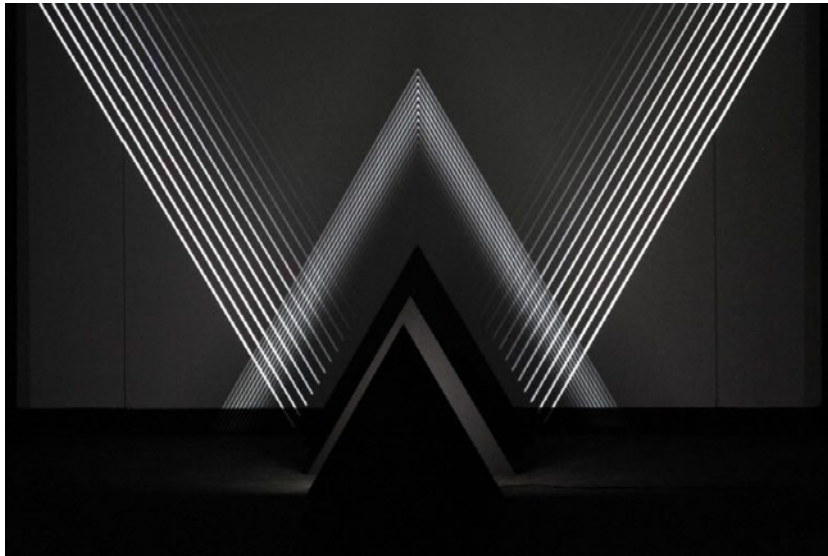

Fig. 133: Into the Void's setup: the row of triangles in a dark room,
the light triggered in one of them,and the back video-projection.

An array of six triangles was placed in a row on the floor, in the middle of a darkroom. Each triangle was made of black K-Line cardboard with a height ranging from 30 to 100 cm approximately, and had a white LED strip on the back. When triggered the LED strips created a backlight, revealing the shape of each triangle and creating distinct light and shadow shapes across the space.

Besides the triangles with LED strips, the setup was composed by an Arduino micro-controller, managing the lights' intensity, a video-projector and a laptop computer controlling the interactive system, running Ableton Live, Max and Processing.

On Max, a series of random numbers with different probabilities were being generated. These numbers decided which triangle would light on and off. When a number was triggered, a signal was sent to the Arduino to light the corresponding LED strip, and at the same time a MIDI message was sent to Ableton Live, triggering notes on a set of MIDI instruments, and also an OSC message was sent to Processing, generating a visual output.

Future versions of the installation will explore new physical shapes, creating different possibilities of light and shadow across the space, and also will explore interactivity with the visitors by the use of motion sensors to interact with the system.

Developed by Rodrigo Carvalho (concept, electronics, code and visuals), Ana Duarte (build and production), André Sousa (soundscape). A video can be watched at the project's online documentation: <http://visiophone-lab.com/wp/?portfolio=into-the-void>

10. SUBMERSIBLE COMPUTER CENTER

Submersible Computer Center, was a sound visualization explorative project developed with *Stallion,* a 328 Megapixel tiled display system built by TACC Visualization Laboratory (Texas Advanced Computer Center at University of Texas, Austin)[18]. The system is composed by eighty full HD displays, and it was built to help researchers to visualize huge amounts of data in a single screen.

The goal was to explore the massive dimensions of *Stallion* and its cold and brutalist look as an aesthetic resource. Different sets of visuals where created, where each of them reacted to sound frequencies in different way, and transformed each one of the eighty displays in a visualization unit, reacting to a specific range from the audio frequencies.
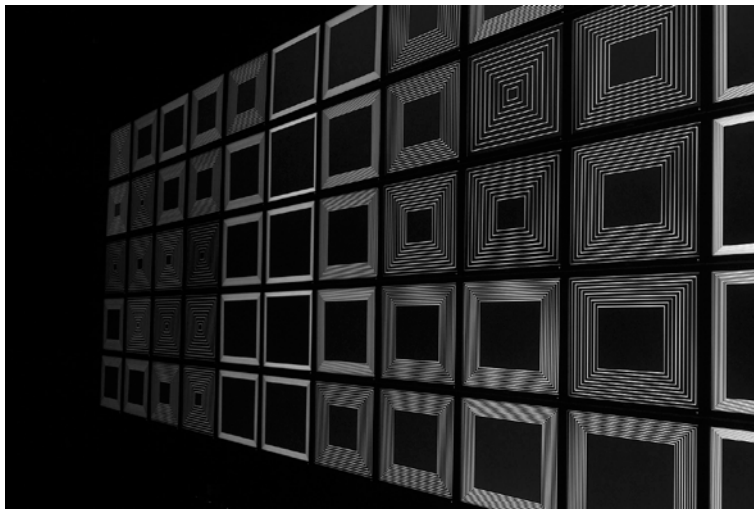

Fig. 134: Detail from the Stallion tiled display.

The audio reactive visuals were created with Processing, and to allow the visuals to extend over the multi-screen system, we used the library *Massive Pixel Environment[19]*, a Java library developed at TACC/ACES Visualization Lab made for extending Processing sketches to multi-node tiled displays.

Developed by Rodrigo Carvalho (concept, code and visuals) and Tim Stutts[20] (Music). A video can be watched at the project's online documentation: < http://visiophone-lab.com/wp/?portfolio=submersible-computer-center >. The code used for the visual system can be downloaded at the author's gitHub account: <http://github.com/visiophone/staliumVizz>.

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18 Stallium at Texas Advanced Computer Center, UT Austin. <https://www.tacc.utexas.edu/vislab/stallion>. Accessed on 2016.09.20

19 Massive Pixel Environment library. <http://tacc.github.io/MassivePixelEnvironment/>. Accessed on 2016.09.20. Library based on "Most Pixels Ever" by Daniel Shiffman.

20 Track: "Submersible" by LordX / Tim Stutts <http://lordx.bandcamp.com/>. Accessed on 2016.09.20

APPENDIX II : DIGITAL ARCHIVE

List of contents on the digital archive:

Video Folder:
01_BorisChimp504_teaser2017
02_BorisChimp504_LiveSonar2017
03_NonHumanDevice01
04_NonHumanDevice02
05_NonHumanDevice02b
06_NonHumanDevice03
07_DancingWithSwarmingParticles[extracts]
08_DancingWithSwarmingParticles[fullPerformance]
09_Prefalll135a
10_Prefalll135b
11_Breakdown_[highlights]
12_Breakdown_[Full Performance]
13_TheInterpreter
14_FloatingSatellites
15_FloatingSatellites[screenGrab]
16_AdMortuos_[extracts]
17_AdMortuos_[shortVersion]
18_WithOui_[extracts]
19_WithOui_[fullPerformance]
20_WithOui_[screengrab]
21_InfiniteDelta_a
22_InfiniteDelta_b
23_InfiniteDelta_[makingOff+Installation]
24_Drippigment_[performance]
25_Drippigment_[demo]
26_ChoreographicCodingLab_Gravity
27_ChoreographicCodingLab_Lines
28_X-Gravity
29_Untitled001
30_WarningAWearableElectronicDressPrototype
31_Adamastor
32_ControlingVideowithFaceMovements
33_X-FilesAlienSpaceship
34_LasersSaoJoao
35_IntotheVoid
36_SubmersibleComputerCenter

Code Folder[1]:
breakdown
choreographicCodingLab
FloatingSatellites
submersibleComputerCenter
theInterpreter
withOui

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1 Code for *Processing.* < https://processing.org/>. Accessed on 2018.01.19