Title

Data Sonification Artworks:

A Music and Design Investigation of Multi-modal Interactive Installations

A Research Report submitted to the University of the Witwatersrand, Wits School of Arts.

In partial fulfilment of the requirements for the Degree of Masters of Digital Arts

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Supervised by

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Declaration

I declare that this is my own unaided work. It is submitted for the Degree of Masters of Digital Arts (Interactive Media) at the University of the Witwatersrand, Johannesburg. It has not been submitted before for any degree of examination in any other university.

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Abstract

Through three case studies this research report will explore the design and multi-modal attributes of interactive installations that feature characteristics comparable to those of musical instruments. It will briefly outline and define data sonification and the five sonification techniques: Audification, Auditory Icons, Earcons, Parameter-mapping sonification and Model-based sonification. Model-based data sonification will be more closely explored, as interactivity and the incorporation of multiple modes are key elements within these types of sonifications. Pre-existing knowledge of musical instruments, their multi-modal attributes and functionality will be analyzed in relation to the case studies. The design analysis will focus on the interaction and interface design while incorporating the three modes, namely: visual guidance, real-time physical/gestural interaction, and instantaneous acoustic feedback. To conclude, this research report will demonstrate, through the case studies, that the function and design of musical instruments can be suggestive in realizing a potential way forward for digital artists and their multi-modal interactive installations.

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Introduction

In a paper entitled *The Discipline of Interactive Sonification*, Hermann and Hunt (2004) express ideas and trends in the field of data sonification for future developments that explore real-time, multi-modal interactive systems (3). One such idea evaluates the design and central workings of traditional musical instruments that exemplify multiple modes of interactivity. This research report will aim to investigate the characteristics of interaction and interface design aspects observed in traditional musical instruments and compare them to those observed in multi-modal interactive installations.

Interactive installations form part of the genre of interactive art. Interactive art is a broad field, but this research report will focus on interactive installations that are sound reactive in digitally responsive environments. The designs of multi-modal interactive installations provide an interactive space for user involvement. The term multi-modal refers to the interaction possibilities within this space as including real-time tactile or gestural action, visual guidance and more importantly instantaneous acoustic feedback. The physical, visual and auditory modes are pertinent to this study as they will be observed and compared alongside musical instruments, which have been utilizing these modes for centuries.

When discussing musical instruments, I am primarily referring to acoustic instruments and how the physical object i.e. the instrument (e.g. flute, violin, piano) functions as a means for the player to interact in a tangible and visual manner that bestows upon the player an instantaneous acoustic result. The sounds emitted from these instruments are purely acoustic i.e. without electrical amplification. When dealing with sound emitted from a multi-modal interactive installation, I am referring to the representation of a digitally produced sound through an audio interface that is analogous to an acoustic result.

The types of multi-modal interactive installations that will be looked at are of an artistic nature but function based on the workings of computer interfaces. By the term computer interface, I am referring to the hardware and software components of a computer that operate together as an interface to program and execute tasks. An interface is defined as "…a surface that forms a common boundary between two things or a point of interaction between two components or systems" ("Interface" 1). In light of a multi-modal interactive installation the computer interface provides the medium with which the users can communicate (or interact) with the artwork. This medium can be excited in a tangible manner with an object or a non-tangible manner through body movements and simple gestures.

This research report aims to respond to a number of questions in order to explore the future development of real-time interactive systems that involve the use of multiple modes. Do multi-modal interactive installations show design features and characteristics similar to those of musical instruments? Can multi-modal interactive installations be viewed as new kinds of "instruments"? Would it be possible to conceive of multi-modal interactive installations as modern day extensions of musical instruments? Over the next four chapters this research report contextualises this area of research and uses the case study analyses in chapter five to provide possible responses to the questions posed above.

Chapter One presents a broad overview of the field of Data Sonification, as this is the starting point from which I begin to contextualise and discuss how real-time, multi-modal interactive systems have been developed. Within the field of data sonification I describe five different data sonification techniques that have been explored within the field. These include Audification, Auditory Icons, Earcons, Parameter-mapping Sonification and Model-based

Sonification. Model-based sonification will be defined and explored as the primary technique by which to analyse the multi-modal interactive installations. I have chosen to do so specifically because model-based sonification involves high data dimensionality (i.e. the existence of the use of multiple modes) and relies largely upon user participation and manipulation (i.e. user interaction).

Chapter Two discusses the classification of musical instruments and the technical aspects of how they produce sound. This discussion draws on the field within musicology known as organology. The construction and design of these musical instruments is discussed in connection with the way a player needs to engage and interact with the instruments in order for them to produce sound. A quick look at human-object interaction will help to explain the relationship between the instrument and its player.

Chapter Three will revolves around the topic of interactivity. A brief introduction and explanation of Human Computer Interaction leads into a discussion of what it means for a system to be interactive, a topic which is further discussed from the artists' point of view. I then consider Interactive Sonification as an example of how interactivity relates to this specific area. This is followed by a discussion around multi-modal interaction and how it can be used to enhance interactivity.

The design of interaction comprises Chapter Four. I begin by outlining the four different approaches to interaction design and then discuss the elements required for interaction design. I apply these design characteristics to musical instruments and show the resemblance between the design of musical instruments and interaction design. The differences between interface design and interaction design are discussed and compared.

Chapter Five presents the analysis of the case studies. The three case studies to be investigated are:

- Firewall (2012) by Aaron Sherwood and Michael Allison
- The Manual Input Workstation (2004) by Golan Levin and Zach Lieberman
- Model Hat Digiphony (2012) by Constantina Caldis

All three case studies feature multi-modal elements, are artwork installations and invite the use of interactivity. The case studies are described, analyzed and compared founded on the ideas presented by Hermann and Hunt in their seminal work *The Discipline of Interactive Sonification.* This is underpinned by the investigations and theories dealt with in the first four chapters of this research report. My aim is to show the similarities and differences of the interactive and design elements, in order to provide a comparison between musical instruments and the case studies.

To conclude, I discuss the findings of this research report and outline the information that has been presented in order to answer the initial question of whether it is possible to conceive of these works as new kinds of instruments. I also consider whether viewing them in this way might enable future digital artists to develop multi-modal interactive installations in new and innovative directions.

Chapter One: Data Sonification

This first chapter concisely outlines the history of data sonification and research that has already been done within this field. An additional discussion explains the five techniques of data sonification known as audification, auditory icons, earcons, parameter-mapping sonification and model-based sonification. Model-based sonification is further explored in order to provide a platform on which to analyse multi-modal interactive installations. The chapter concludes with a brief summary.

Data Sonification

Before the early nineties, only a few papers had been written on the field of auditory display and sonification, however through technological advancements in digital audio processing and the interests of pioneering researcher Gregory Kramer, this field was able to expand and categorize itself. Around 1990 Gregory Kramer began organising a group of researchers as a community which would discuss and archive all types of auditory subject matter. By 1992, a year and a half later, a forum developed for researchers to have discussions and find other people with similar interests and new understandings within the wider field of Auditory display. This is known today as the International Conference on Auditory Display (ICAD). In 1994, the key founder of ICAD, Gregory Kramer, compiled one of the first books on auditory display, entitled *Auditory Display: Sonification, Audification and Auditory Interfaces (1994)*. Many authors contributed to this book providing points of access and research in the field. During the time of Kramer's research he found that there was no clear distinction made between Auditory data display and what are known as Auditory interfaces. Kramer states:

> Sonification, or data-controlled sound, and audification, or the direct playback of data samples, are the general means used to display quantitative information. Auditory interfaces for general computing environments, teleoperation, virtual reality and other 'environmental' displays generally convey qualitative information. (xxiv)

However, it was eventually realised by Kramer that quantitative and qualitative information in an auditory environment actually form continuum (xxiv). Kramer explains this further through an example:

> An auditory display peripheral to my computer system might tell me that my cursor has encountered a text file (a qualitative, general interface issue). The auditory display might also tell me how large that file is (a qualitative issue). Furthermore, it is possible that both these pieces of information would be delivered simultaneously, as part of the same display. If the file were a database and I used the data to control the variables of a sound by routing the data to a sonification system, I will have shifted from a general interface with an auditory component to a data sonification. (xxiv)

This continuum of qualitative and quantitative data information exists within multi-modal interactive installations. The quantitative data information is used for coding the installations' computer interfaces, whereas the qualitative information is what is considered in the experience gained by the user. The information learnt and attained can also vary among multiple users. For example, the design of an interactive installation may calculate a sonic output and present a frequency tone of 261.63kHz (a quantitative value). The way in which the user/listener perceives this sound is dependant on their understanding of the spatial environment in which they hear the sound. A musician would easily identify this tone as

'Middle C[1]'. A non-musician may understand this to be just another low-mid frequency. If a visual were presented alongside this tone, the qualitative information would also adapt, as another mode of understanding this frequency, would present itself.

Kramer's edited book published in 1994 was considered to be the first of its kind and therefore the definitions of certain terms, such as sonification, audification, auditory display and auralization are not consistent across the various chapters by different authors. Furthermore some of these definitions are now dated due to ongoing ICAD conferences continued interest and investigations done by researchers and the fact that the amount of information available has increased within the field. Due to these advancements in the field, a new book with new definitions was urgently required and therefore in 2011 *The Sonification Handbook* edited by Thomas Hermann, Andy Hunt and John G. Neuhoff was published. Kramer holds this book in high regard referring to it as the first true reference handbook within the field of sonification (Hermann et al. iv).

In *The Sonification Handbook*, Walker and Nees present the definition of auditory display as any type of display that uses sound to communicate information, and sonification as a subtype of auditory display that uses non-speech audio to represent information. The definition of sonification that has remained consistent since 1999 as declared by Kramer is "sonification is the transformation of data relations into perceived relations in an acoustic signal for the purposes of facilitating communication and interpretation" (Walker and Nees 9). Hunt and Hermann expand on this, defining it as "…the data-dependant generation of sound, if the transformation is systematic, objective and reproducible, so that it can be used as scientific method" (Hunt and Hermann 274). Walker and Nees conclude that

[1] "Middle C" is the fourth 'C' note/pitch on a standard size 88-key piano with a frequency of 261.63kHz.

> sonification seeks to translate relationships in data or information into sound(s) that exploit the auditory perceptual abilities of human beings such that the data relationships are comprehensible. (9)

The definition of sonification has undergone many adaptations as it has been utilized in many different situations. What is essential to take hold of at this stage is the importance of translating data information into auditory messages that are comprehensible to the user/listener engaging with a multi-modal interactive installation. But in order to translate any type of data information accurately, different methods are required for the many different situations presented. Within data sonification there are sub-sections that each follow a slightly different technique for translating information. I begin by describing the five different sonification techniques that have been delineated in *The Sonification Handbook* and discuss which pertains most directly to multi-modal interactive installations.

Sonification Techniques

The five different sonification techniques are presented in *The Sonification Handbook.* I provide brief descriptions of each technique and show how each technique is utilized for different types of sonifications. I then identify the most suitable technique with which to analyse multi-modal interactive installations and discuss this further.

The first technique is known as *Audification.* Dombois and Eckel in *The Sonification Handbook* define audification as:

> a technique of making sense of data by interpreting any kind of one-dimensional (or of a two-dimensional) signal-like data set as amplitude over time and playing it back on a loudspeaker for the purpose of listening. (302)

This technique is considered a direct alternative approach to visualization, whereby a data waveform can be directly visualized by placing it on a Cartesian graph. See Figure 1 below.

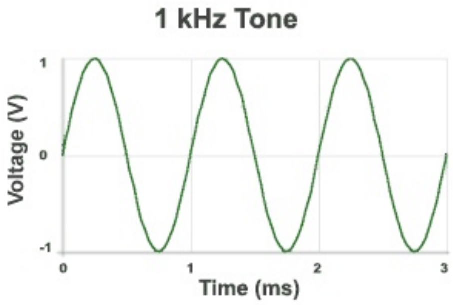

Figure 1: A Sine Wave

Visually when we look at this wave on the Cartesian graph we can accurately describe it as a 1kHz sine wave. The audification of this 1kHz sine wave tone is commonly heard at the end of a video or when a television station goes off air. Hence, audification and visualization can be seen as alternative methods of representing the same information as an exact translation of the data. Different types of data would obviously yield different types of sounds. Audification is commonly used when dealing with these four types of data groups. Sound Recording data, General acoustical data, Physical data and Abstract data. Sound Recording data are a series of numbers that are sampled digitally. These can then be played back through a Digital-to-Analog converter, which transforms the data into a continuous sound signal that we can listen to through a loudspeaker and understand. General acoustical data are described as all kinds of measurements in elastomechanics, which follow the same physical laws as an acoustic wave. For example, doctors use a stethoscope which amplifies the internal sounds of a human body, such as the heartbeat. Physical data can be described as electromagnetic waves. This data falls outside of the physical domain of being a mechanical wave and is unfamiliar to the human ear. Abstract data does not stem from any type of physical system. For example, a fax machine, a computer modem or stock market data can all be audified, but the user needs to learn the aural patterns, which can be easily understood if the data is arranged as a time-series (Dombois and Eckel 302-3).

Audification is usually seen as a starting point for all types of sonification projects but is later disregarded. When analysing the multi-modal interactive installations I consider the audification of sound recording data and general acoustical data. The reason for including a discussion on sound recording data is that the installations discussed require a medium (i.e. audio interfaces) to go through for the representation of the sound. General acoustic data will be discussed in Chapter Two with regard to musical instruments and how they produce sound as this assists in demonstrating the differences between the sound production of musical instruments versus interactive installations.

I now move on to a discussion of the second sonification technique known as *Auditory Icons* presented by Brazil and Fernstrom (325) in *The Sonification Handbook.* In the late 1970s testing began with only the visual display of an icon being utilized via desktop computer interfaces. Visual iconic information is able to represent a lot of information in a small amount of space. Huggins and Entwisle discuss in their book *Iconic communication: An annotated bibliography* that, "Iconic communication is successful because its imagery relies on the human ability to quickly perceive natural form and shape" (1). A visual icon of an existing object is easy to recognise, therefore audio messages should also aim to draw from existing natural sounds that the human ear understands. Bill Graver was one of the first to begin experimenting with adding sounds to computer interfaces. He called these sounds Auditory Icons (Brazil and Fernstrom 325). Auditory Icons are short moments of non-verbal sound that represent an icon that relates directly to its meaning in a user interface. For example, when emptying the visual "trash" icon of an Apple Computer, the sound heard is that of documents being crumpled up and thrown away. This direct relationship between the sound created and the action initiated is found in natural acoustic environments and for this reason should be considered when developing a multi-modal interactive installation as it provides an instinctive and understood auditory experience. The input (action) directly relates to the output (auditory experience). The easier the association between the sound, the visual and the action, the quicker the user develops an understanding of the data.

The third sonification technique is known as Earcons. McGookin and Brewster in *The Sonification Handbook* provide a definition and examples for this technique. Earcons are similar to Auditory icons as they are also utilized with computer interfaces and are non-verbal representations of sound. The main difference between Auditory icons and Earcons is that Earcons are short, structured musical motifs. These produce sounds that need to be learnt by the user. The relationship between the sound and icon is indirect. A good example of an Earcon can be heard through mobile phone interfaces and their ring tones. The user of the mobile phone can set different ring tones for each different contact number. When the mobile phone rings, the user can instantaneously know who is calling because he/she made the association with the contact number and the ring tone. Once this association has been established then the relationship becomes direct but only for the private user (McGookin and Brewster 339).

With multi-modal interactive installations the user is often not the creator. When engaging with multi-modal interactive installations, it is important to the user that every action results in a re-action that relates somewhat to their initial action. Initially this relationship can be indirect, but then time must be provided for the user to learn the relationships that are inherent in understanding the data within the installation. Therefore through a process of learning, Earcons can eventually demonstrate direct relationships and insightful interactions.

Grond and Berger (363) present the fourth sonification technique known as Parameter Mapping Sonification in *The Sonification Handbook* as an event-based approach whereby the data is mapped to specific sound parameters. Parameters such as pitch and volume operate within the interface dependant on the multivariate data utilized (Grond and Berger 363). An example would be to create an accurate temperature gauge for a kettle reaching boiling point. The rising variation in pressure increases the temperature gauge that can be precisely mapped to specific pitches/frequencies (although this is a subjective mapping style) until the final whistling of the kettle heard signifies boiling point. These types of mappings are extremely involved and detailed, creating an exceptionally direct mapping and an outcome so mathematically intense that only the creator would understand its meaning. The user would need to learn which frequency heard signifies what temperature has been reached. In many scenarios, multi-modal interactive installations are using mathematical data sets as a basis for the programming of the visual and sound data, but the outcome of these mappings is not obvious (Grond and Berger 364) and needs to be learnt. The outcome for multi-modal interactive installations should rather show direct mappings that the user can recognize, as the subjective mappings set out by the creators makes this type of sonification rather difficult to decipher for the user.

The last sonification technique to be discussed is Model-based Sonification. Hermann and Hunt outline this technique in *The Discipline of Interactive Sonification* and present it as one of the latest types of techniques within data sonification, one that has been experimented with since 2004. Hermann and Hunt describe model-based sonification as:

> A dynamic system, formed from the data under scrutiny, plus a set of interactions determining how the user may excite the system plus a fixed

> mechanism describing how the resulting dynamic behaviour determines the sound. (1)

This type of sonification involves high data dimensionality and relies largely upon user participation and manipulation. Interactivity and multi-dimensionality are two key elements which contribute towards model-based sonification. And it is these two key elements of model-based sonification that will be shown to feature within the multi-modal interactive installation case studies.

Audification, Auditory Icons and Earcons represent different ways of sonifying information, however neither of them provide any physical interactive elements that allow the user to alter the sonifications. Parameter-mapping sonifications provide efficient and precise data information as sound, however it is not always intuitive to the user. The multi-modalities used in model-based sonifications allow the user to experiment with the precise data information to which they are subjected and then lean towards active manipulation and transformation with the data in order to gain a better understanding and working of the sonification.

To summarise, I have defined and presented Audification, Auditory Icons, Earcons, Parameter-mapping sonification and Model-based sonification with the intention of outlining which technique is best suited for the analysis of multi-modal interactive installations. Audification is useful as a starting point as multi-modal interactive installations express sound recorded data as an outcome, which is essentially a digital sound. The general acoustic data presented as an audification can be compared to musical instruments and will be further discussed in Chapter Two. Auditory Icons and Earcons present the notion of portraying direct and indirect relationships of sound. Parameter mapping sonification provides solid mapping techniques for data information, but can become overwhelming and highly complex. In multi-modal interactive installations it is important to utilize these complex mappings but keep them hidden from the user. The first four sonification techniques have shed light on what aspects from each of them may feature within multi-modal interactive installations. However, all four of them do not provide a complete foundation for the analysis. The last technique within the data sonification realm known as Model-based sonification has this advantage. Model-based sonification is a core technique and it is therefore explored in more detail in the next section.

Model-based Sonification

Model-based sonification (MBS) is based on an experience a user has when interacting with objects in their environment and receiving an auditory response. In real-world acoustics when a physical object such as a drum is struck with a mallet (energy excitation) the sound resonates acoustically and is decoded by the human ear. In MBS, the object is replaced with a virtual data object in a "model space" (area of interaction) that is influenced by the data set. The energy added by excitation to this model space then formulates a digital rendering of sound, which is then pushed through a loudspeaker into the acoustic environment for the human ear to decode (Hermann 401). MBS as a sonification technique looks at how real-world acoustic feedback is generated according to user interactions and aims to incorporate them into accurate and insightful data sonifications (Hermann 399).

Figure 2 set out below is a dynamic model of MBS as presented by Thomas Hermann in *The Sonification Handbook*:

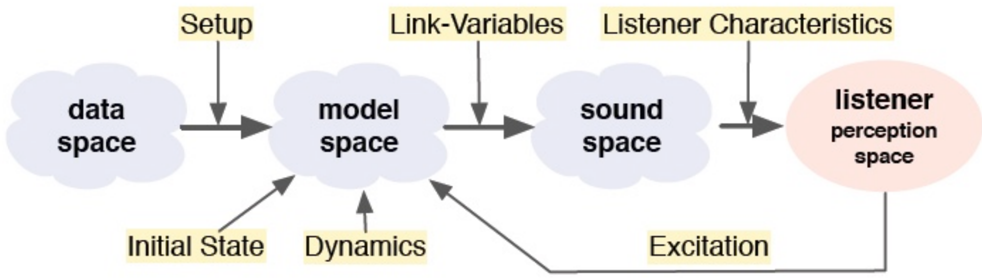

Figure 2: Dynamic Model for Model-based Sonifications.

The *Model Setup* that lies between the data space and the model space forms a bridge between the configuration of the abstract high-dimensional data and the tangible or gestural dynamics of the model space. The *Initial State* of the dynamic system is the beginning of the working system before user interaction is initiated. The *Model Dynamics* deal with sonifying the data parameters through various interactions that accurately represent the data under analysis. *Excitation* defines how the user interacts with the model. This can be in the form of tangible objects or gestural movements by the user. The *Link Variables* provide the “glue” for allowing the interactions within the model space to be portrayed within the sound space as a real-world acoustic system that responds instantaneously. Lastly, the location, orientation and distance between the sound space and the listener define the *Listener characteristics* of the MBS as perceived by the listener. Dependant on the design of the MBS these sounds can either be experienced as single sound sources such as the beating of a drum or they can be perceived as a soundscape such as the sound of rustling trees in a forest (Hermann 404-408). It is important to note that the experience will be different for every user because every user will listen, excite and perceive the dynamic model in there own distinct way.

Hermann categorizes listening into three modes: Everyday listening, Musical listening and Analytical listening (Hermann 400). Model-based Sonification (MBS) addresses two of these three listening modes. The first is Everyday listening and the second is Analytical listening. Everyday listening deals with source-identification. This is the knowledge that humans naturally develop when learning to identify the source (e.g. human) of a particular sound (e.g. cough) and the action that produced it (e.g. throat). Analytical listening is used to diagnose objects under investigation. For example, a matchbox is shaken in order to analyze and attempt to distinguish how many matches are contained within the box. This type of listening can compose attractive sonifications (Hermann 400). Analytical listening is also used when trying to identify what musical instrument is being played.

Conclusion

Having presented and explained all five data sonification techniques, I will later show how multi-modal and sound-driven interactive installations could easily follow this dynamic system of MBS since it has been developed based on the idea that interaction with objects results in real-world acoustics. In Chapter Two real-world acoustics are again addressed in conjunction with musical instruments to showcase the differences of acoustic sound production versus sound through an audio interface. MBS provides a basis for the analyses of the case studies because its basic outline can be mapped onto these types of interactive installations. I then show the use and importance of MBS inline with the case studies in Chapter Five. Both modes of listening i.e. everyday and analytical listening are useful in understanding the data that is relayed through a complex model-based sonification and these types of listening techniques are discussed in relation to the design process of the case studies presented in Chapter Five.

Chapter Two: Interaction and Musical Instruments

In *The Discipline of Interactive Sonification* Hermann and Hunt sprint through history from cavemen to modern man describing the sonification and interaction with interactive tools. They engage with the history and quality of interactive tools from the past, for example, a sharp stone that was used to cut meat. They note that the sonic feedback caused by this simple tool can determine the properties of the stone and guide the user's co-ordination and interaction with the tool. Through this development and interaction with tools, humans progressed in the world. This progression has resulted in many different creations, one of which is the development and evolution of musical instruments. Hermann and Hunt state that musical instruments are sophisticated and good examples of interactive devices that involve real-time physical interaction and sonic feedback (3).

This chapter outlines the history of musical instruments, their origin, categorization, design and development in line with the notion of interaction and sound-producing properties. I discuss the sound production aspects of the different types of instruments in question and show how the physical construction and physical aspects of interacting with each category of instrument can result in many different acoustic displays. I briefly look at electronic and digital instruments to describe the differences of these types of instruments. The topic of interaction with an object is discussed in more detail towards the end, as it is important to understand the relationship as analogous to that of a human player to his/her instrument.

Organology

Organology can be defined as “the study of musical instruments in terms of their history and social function, design, construction and relation to performance” (Libin 1). The flow chart below (Figure 3) maps current ideas of musical instruments and places the design and construction of these instruments at the centre as the link between organography and organology (Wachsmann et al. 1). The rectangles to the left, i.e. beliefs/symbolism, sociology and history/development, refer to contextual aspects and the ones on the right, i.e. performance, corporeal determinants and music, refer to the musical aspects. This research report begins by focussing on the history and development and then deals with the topic of corporeal determinants.

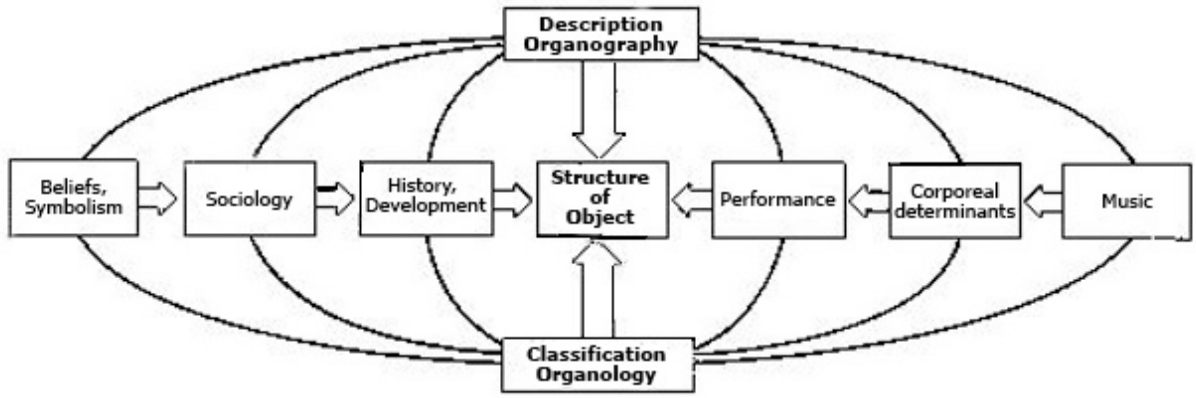

Figure 3: Scope of the Study of Instruments as Objects
and as Aspects of Biological and Social Musical Activity

Firstly the historical categorization of musical instruments, their construction and design is investigated.

Hellenic Greece classified instruments into two groups known as the ‘animate’ and the ‘inanimate’. Animate referred to the human voice whereas inanimate referred to string and wind instruments only[2]. It was only during the late second century CE that Pollux, a rhetorician, distinguished the category of percussion instruments. Boethius was the first, however, to present a three-category model that included strings, winds and percussion instruments. This classification system held out from the late Roman through the medieval and Renaissance period into the 20th century (Wachsmann et al. 1). This three-category model is able to encompass many of the modern western instruments but it is unable to accurately incorporate instruments from the East and/or many African cultures.

During 1880, the curator of the Brussels conservatory's instrument museum, Victor-Charles Mahillon, catalogued a collection of instruments[3] that became the first classification of musical instruments suitable for worldwide use. This formed the basis of many new systems with the most notable system being that of E.M. von Hornbostel and Curt Sachs in their *Systematik der Musikinstrumente: ein Versuch*, published in 1914. Hornbostel and Sachs categorized instruments according to their function and how they produce sound. This became the first model to rival Boethius's three-category model (Wachsmann et al. 1).

The Hornbostel and Sachs classification of musical instruments is divided into four main categories according to the way in which the sound is produced:

- Aerophones
- Idiophones
- Chordophones
- Membranophones

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[2] This research report will not deal with the 'animate' instruments, as they provide no viable link to the case studies featured in Chapter Five.

[3] Mahillon's work *Les Éléments d'acoustique musicale et instrumentale* (1874) may be further consulted.

Aerophones produce sound by setting up a vibration of air through the body of the instrument. These instruments can be further divided into free aerophones and proper wind instruments. Free aerophones send vibrations through unconfined air with the instrument in hand, for example a bullroarer[4]. Proper wind instruments enclose the air in a tube or vessel, for example, a flute or trumpet (Brown and Palmer "Aerophone" 1). When the player blows air through the tube, measured at different lengths, a different musical pitch can be achieved each time. In some cases, when doubling the speed of blown air through the tube, the frequency is doubled resulting in a musical pitch that is one octave higher even though the tube length has remained the same.

Idiophones create sound vibrations when the instruments are either struck, plucked, shaken, or subjected to friction. Instruments such as bells, rattles, cymbals and xylophones fall within this category (Brown and Palmer "Idiophone" 1). The player can shake a rattle, hit a bell or play the xylophones using various mallets. The sound resonates directly from the instrument. A wooden-key xylophone would produce a slightly gentler sound than a metallic-key xylophone. Various mallets also contribute to different sonic responses from the instruments. The construction and material from which idiophones are made play an important part towards the acoustic result.

Chordophones produce sound by sending vibrations over a stretched string. This section is further divided into 'simple' chordophones, for example, a piano or harpsichord, and 'composite' chordophones where the structure includes a neck, yoke or other component that acts like a string holder, for example, a harp (Brown and Palmer "Chordophone" 1). When the keys of a piano are played, a sound is instantaneously heard, however there is

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[4] An ancient ritual device initially used for communicating over long distances; emits a low vibrato sound.

much more to the mechanical workings of this than meets the eye. The strings of a piano are struck when the player presses a key, but hidden behind this key is a mechanical action. This mechanical action is similar to a hammer hitting a string. The string vibrates as a direct response to this action and creates sound. Once the key is no longer depressed a damper replaces itself over the string and the strings vibration stops, thus discontinuing the sound.

String instruments such as the violin also fall within this category. The bow of a string instrument is made up of long fine horsehair grouped together to form a long stick-like object. When this hair of the bow is dragged across the string/s of a violin, the friction creates a sound. These sounds can flow from one into another as long as the player keeps the bow gliding across the strings. With all string instruments the length of the string determines the pitch of the sound: the longer the string, the lower the pitch; the shorter the string, the higher the pitch. The players left fingers can further control the string's length. String instruments can also be plucked. This is a technique whereby the fingers of the player gently pluck the string upwards creating what is known as a pizzicato. The sound emitted is short and detached.

Membranophones are instruments that produce sound using a stretched-out membrane. All types of drums are placed in this category, but this section too has sub-divisions as membranophones may be struck, plucked, rubbed (i.e. subjected to friction) or sung, like a kazoo[5] (Brown and Palmer "Membranophone" 1). Drums come in all shapes and sizes thus many different pitches can be achieved: the bigger the drum and its membrane, the lower the pitch; the smaller the drum and its membrane, the higher the pitch. These

[5] This instrument has a buzzing timbral quality that resonates in sympathy with surrounding sounds.

percussive instruments can be struck using the human hand or by using soft, medium and hard mallets, thus producing different timbral qualities of the instrument.

The four categories above are said to incorporate the majority of instruments across the world. And as noted, each category separates its instruments according to how they produce sound through a specific physical interaction. However, the construction, design and materials used when building all categories of instruments play an equally important role in their sound production.

The general acoustic properties of musical instruments are largely dependent on their construction and design. The timbre of the acoustic wave produced by each instrument is largely dependent on the material used for constructing the instrument. The different materials used provide a colourful display of sound even when producing the same perceived pitch from each instrument. Figure 4 below is an example of the acoustic pressure waveform, as recorded by a microphone, of four different instruments. They are all playing the frequency of 440Hz yet the result of the acoustic wave visually appears different. The pitch will be 440Hz, but the timbres of the instruments differ. The reason why the same pitch can be heard is that the wave-shape repeats regularly. This is known as a periodic waveform.

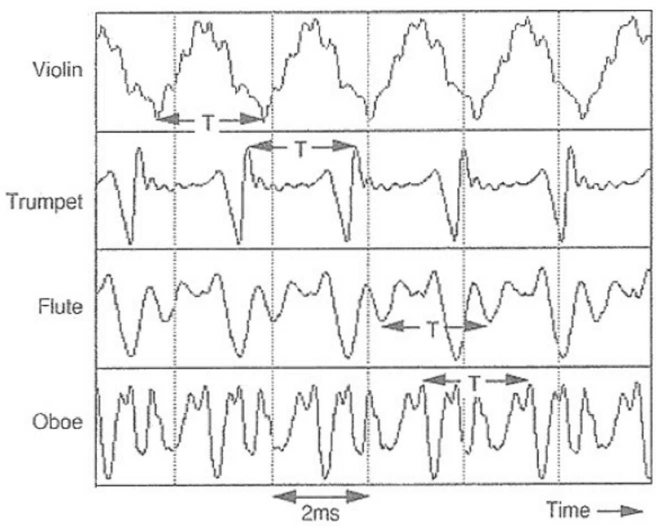

Figure 4: Acoustic Pressure Waveforms at 440Hz of a Violin, Trumpet, Flute and Oboe

Due to the design and construction of different acoustic musical instruments, the acoustic pressure waves present each instrument with its own unique sound quality. To provide more examples, the hollowed out wooden body of a guitar resonates when a string is struck, the metal tubes of a French horn present a specific timbre different to that of a trombone due to their size, length and metallic characteristics. It must be noted that the physical materials play an important role in the sound production of acoustic musical instruments, but what happens when the instrument does not rely on a resonant body? An instrument is inaudible unless it is connected to an audio speaker system. These instruments fall within a fairly new though broad category known as Electrophones.

Electrophones

The term Electrophones (or electronophones)

> is applied to instruments in which vibrations are created by acoustic means but which require amplification to make them audible (incorporating pickups, special microphones or other transducers) and to instruments in which the sound-generating system is based on electro-mechanical or electronic oscillators. (Davies 1)

Essentially these are instruments that produce sound electronically. This category of instruments is the fifth class of instruments devised later as an extension on von Hornbostel and Sachs' instrument classification system. As the invention of electronic instruments continued, the need for sub-categories within this category of electrophones arose.

In 1938 F.W. Gaplin proposed the three sub-categories that eventually prevailed:

- Electronic instruments

- Electromechanical instruments
- Electroacoustic instruments

Electronic instruments are dependant on the type of oscillator being employed, on the waveform generated by the oscillator or, lastly, on the relationship between the signal frequency generated and the sound heard (Davies 1). The Theremin is a good example of an electronic musical instrument. This instrument does not require any physical contact from the player; instead it uses two antennae, which judge the relative position of the player's hands when they are placed close by. One hand controls the oscillators for the frequency and the second hand controls the amplitude (volume). The sound is immediately sent to an amplifier and heard through a loudspeaker.

Electromechanical instruments produce sound by means of rotating 'tone-wheels'. These electric circuits can contain electromagnetic, electrostatic or photoelectric components (Davies 1). Elements of an electronic synthesizer instrument, for example, a Moog, fall within this category. The Moog is similar to a keyboard instrument, but it contains many more knobs and buttons that allow the player to manipulate and generate new sounds that have not been pre-programmed into the instrument. Most synthesizers do not have built-in amplifiers therefore require a separate audio system for the sound to be heard.

Electroacoustic instruments contain components that function exactly like acoustic instruments, except that the vibrations from these instruments are converted into volts within an electric circuit (Davies 1). Electric guitars and electric pianos fall within this group of electrophones. Often these electroacoustic instruments bare similarities to their acoustic ancestors; however, the sound production and how the instrument is heard differentiates them. They too require an amplifier and loudspeaker through which to play.

It is interesting to note that electrophones are still categorized as instruments even though they technically cannot produce their own sound without the aid of a separate audio system; however, the way in which these instruments generate the sound is uniquely dependant on the physical electronic and/or mechanical components that construct these instruments and how they are manipulated by the player in order to produce sound. Electrophones and more specifically electronic instruments have afforded musicians new and compelling modes of sound synthesis and control; however, they have been criticized in performance contexts for lacking in expression and for the continuous and organic feel found in acoustic musical instruments (Merrill and Raffle 213).

From the descriptions of aerophones, idiophones, chordophones, membranophones and electrophones, we note that they all require some form of interaction from the player in order to deliver a sound. As mentioned earlier, the second area this research report will observe are the corporeal determinants. Corporeal determinants refer to the player's body movements that provide interaction with the object by pushing, pulling, striking, lifting or exerting tension and distension of the muscles in order for the player to generate sound (Wachsmann et al. 1).

Most musical instruments require physical and a continuous energetic interaction from its player in order for sound to be produced. The type of interaction between the different groups of instruments is diverse. Percussive and plucked instruments do not rely on a continuous energetic input, as once the note is hit or plucked the impulse of energy is left to ring out, but then energetic input from the player is required again to produce the illusion of a continuation of that instrument's sound. Wind instruments and bowed string instruments require a continuous energetic input in order to sustain a sound, otherwise the sound will be cut off instantaneously. Electrophones generally do not require a continuous energetic input from the player as some of these instruments, for example, a synthesizer, require the simple flick of a switch or a pressed key featuring an acoustic orchestral sound that modulates. So the sound might be grand and fluctuate, but the physical interaction with the instrument is limited to one tiny interaction from the player. The combination of these many tiny interactions can, however, build up the intensity of the required interaction with a keyboard synthesizer.

Physical human actions that are exerted on the instrument in order for the instruments to produce a sound lead us to the topic of human-object interaction. It is necessary to understand this relationship as it is analogous to the relationship between human and their choice of musical instrument.

Human-Object Interaction

To interact means "….to act in such a way as to have an effect on each other" ("Interact"). This simple definition is significant because it illustrates that this action can be between two or more humans or perhaps between human and object. I focus on the latter. To interact with an object means to disturb it so that it reacts in a certain way. The way in which the object reacts informs the user/interactor and influences his/her next interaction with the object. There are a number of examples of humans functioning as players of instruments. A musical instrument is viewed as an object with which the user/interactor (i.e. the player) can interact. When a player interacts, in the correct manner, with any musical instrument, it produces an instantaneous acoustically pleasing result.

Hermann and Hunt further define different types of interaction. The first is a physical manipulation that is produced directly through the by-product of human activity. For example, a lady walking through a tunnel wearing stiletto shoes gives off a directly related acoustic sound that is an unintentional by-product of her walking style, the space she is walking through and the slimness of her heel. The second type of interaction is the intentional use of objects to create sound, for example, musical instruments (Hunt and Hermann 275). A simple rattle or shaker illustrates this type of interaction well. When the instrument is shaken, the sound heard can be rhythmical or irregular. The longer the player interacts with the instruments, the greater their understanding becomes of the instrument. The player starts to recognise and estimate how many beads may exist within the instrument. This understanding can define how fast or slowly the instrument must be shaken in order to achieve a desired result. The process of learning is also in progress.

Yehudi Menuhin and William Primrose authors of the book *Violin & Viola* describe the relationship between the player and his/her instrument. There is a delicate and platonic relationship between the violinist and his violin (7). Even though the contact between the violinist and his instrument is limited to the neck, the fingerboard and the bow, these three points of contact must be in perfect balance. The co-ordination and practice with this instrument is the only way to achieve acoustically pleasing results. Violinists can develop an awareness of space and sensation between themselves and the instrument if the strength of their performance, attack and incisiveness are derived from an understanding of and intimacy with their instrument (Menuhin and Primrose 12).

In order for the analysis of sound data to be better understood it makes sense that it should follow the first of these two types of interactions, whereby the sound is directly related to the interaction and the outcome of the sound is a natural by-product that is easily understood. However the analysis of sound data through various human-object interactions is not always this simple. The second type of interaction with an object involves constant unearthing and engagement with the object, until achieving familiarity with the object in order to fulfil its original use and perhaps go beyond and discover a new creative use with which to identify.

In other words, the interaction with and new creative use of an instrument is not only based on the acoustic sonic response. It is also based on the physical interaction or bodily performance with the instrument, as well as and the visual guidance provided either by a musical manuscript or by monitoring one's own playing motions. The performance and use of musical instruments includes three modes of interaction i.e. the physical, the visual and the acoustic elements. It is therefore possible to conclude that musical instruments are multi-modal.

It is important to consider both types of interactions with sound data and observe how they can be developed simultaneously. Over many years musical instruments have been tested and tried. The information learnt from this process should be used to inform and enlighten the direction of interactive installations that include multiple modes.

Conclusion

The categorization of instruments helps define and position musical instruments according to the type of corporeal determinants and interaction that is required for them to produce sound. We notice that the designs of acoustic instruments have resonant bodies that can generate the sound. Non-acoustic instruments require electrical means in order for the sound to be heard clearly. Both acoustic and non-acoustic instruments can represent sound in a musical or non-musical manner, depending on how they are manipulated and on how familiar the player is with them. All instruments within specific categories require different corporeal determinants from the player in order to initiate an interaction that results in sonic feedback. It is through these multi-modal human actions that the player is able to uncover new elements and develop a greater understanding and engagement with an instrument.

After many successful years of development and performing of musical instruments, it is necessary to question the knowledge gained about advanced interaction methods of these traditional interfaces in order to open up new avenues that can work towards the design and development of future interactive installations that incorporate multiple modes.

Chapter Three: Interactivity

In *The Discipline of Interactive Sonification,* Hermann and Hunt discuss how the electrification of the world followed by the industrial revolution brought about a major change as automated machines began to replace physical labour. However, the biggest change for human interaction with the world was due to the invention of the personal computer (Hermann and Hunt 3). Human-computer interaction has since expanded into many fields of study.

In this chapter I briefly outline the fundamentals of human-computer interaction in order to explain its role within the fields of sonification and interactive art. I then discuss interactivity as a general concept and its particular outcomes in order to fully understand the concept of interactivity within interactive installations. Interactive sonification is discussed as one area that explores the use of interactivity with sound. Lastly, multi-modal interaction is further explored as the case studies to be presented in Chapter Five incorporate multiple modes of interaction.

Human Computer Interaction: Physicality

Human-computer interaction (HCI) is originally derived from the field of computer science. Hewett et al. define human-computer interaction as

> a discipline concerned with design, evaluation and implementation of interactive computing systems for human use and with the study of major phenomena surrounding them. (5)

A typical and simple example of such an interaction would be a person using an interactive graphics software program at a personal computer. HCI incorporates the joint performance of tasks, and the communication and interface learnability between humans and machines. It also includes detailed programming, design and implementation for accurate functionality. All these aspects allow new interactive systems that can engage the users on numerous levels of interaction to exist.

Other disciplines have since adopted the HCI practice. The level of engagement with this practice is largely reliant on what type of computers are being used, the number of humans involved and how much interaction is required for the design of a system. HCI is an interdisciplinary field, therefore the implementation of human interaction with computers, allows for many positions and appointments within several disciplines such as digital arts, psychology, sociology, anthropology, engineering or industrial design, to name but a few (Hewett et al. 5). HCI studies the human side of interaction as well as the mechanical side of computers and how the two work together.

In the context of the first generation of electronic computer systems that utilized non-continuous and minimal input methods (i.e. only a keyboard and mouse) for user interaction, Hermann and Hunt propose that electronic computer systems fail to engage their users as they rely on language and/or symbolic processing only, as opposed to humans playing an acoustic musical instrument which requires a continuous, visual, auditory, and energetic physical interaction (3). In my opinion, new electronic computer systems should try to simulate similar types of continuous interaction similar to the learned style of playing a musical instrument. Even the simplest form of visual, physical and sonic feedback interaction can enhance a human-user's experience if it can relate to something inherent to their physical human bodies, allowing the experience to be as natural as possible. Playing an acoustic musical instrument provides the user with real-time physical interaction, visual guidance and instantaneous acoustic feedback. These multiple modes of interaction in line with computer interaction and musical instrumentation are discussed later in this chapter.

Hermann and Hunt declare that the computer has altered human interaction by hiding the subjective mode (i.e. data) of interaction with its tools and maximised the objective result. They suggest a move back towards subjective methods as they state, "…it is our interaction with the world that increases our understanding, and not just a head-knowledge of the resulting measurements" (4). Since Hermann and Hunt's 2004 article, there has definitely been a move towards subjective methods, as sound artists, musicians, artists and designers aim to contribute projects and installations that are highly dependant on the processing power of computers but aim to encompass a natural extension of human elements. Through clever craftsmanship and artistic measures, the mechanical side of computing systems is becoming invisible as the programmed software invites more interactivity.

Interactivity and Artistic Outcomes

There are many viewpoints surrounding the kind of interaction that exists between a human user and a computer. This kind of interaction is generally called interactivity and specifically refers to the meeting between humans and computers. I utilized the *Oxford Dictionary* to define the term interaction earlier and I shall also use it to define the term interactive in order to provide a clear understanding of the differences between the two terms. The term **interactive** means, "…allowing a two-way flow of information between a computer and a computer-user; responding to a user's input" ("Interactive"). The most common and basic thought, as noted in *The Handbook of Human-Machine Interaction* edited by Guy Andre Boy, is that interactivity means interacting with software via a computer screen, keyboard and some form of pointing device (8). However, these hardware components are the bare minimum with which humans physically interact with a system. New hardware components such as joysticks, microphones, data gloves, and metaphorical objects are all extensions that allow for different levels of interactivity. The hardware components have grown incrementally with the design of new systems but at the same time so have the software components. Constant modification and programming of software is required in order to develop the ability of hardware components to control the performance of appropriate functions that enable clear and meaningful interaction with the human user (Boy, 9). Therefore properly understood "interactivity refers to the combination of the procedural and participatory properties of the digital medium: the structures by which we script computers with behaviours that accommodate and respond to the actions of human beings" (Murray 12).

Margaret Morse in *The Poetics of Interactivity* identifies interactivity initially as "...a mode of engagement between machines and ourselves" (17). Throughout her chapter she clarifies that depending on which area of the sciences and/or arts one is pursuing, the interactivity can exhibit different processes and user experiences. Morse states that the type of interaction carried out by a human-user can be a physical, gestural, verbal or signalled in some manner, for the computer to read, translate or transform into a meaningful response, thus making the experience 'interactive' (17).

The notion of interactivity is not limited to a human user and their computer hardware and software components. These components are the basic structures that provide a starting point for the design of interactive systems. A designer's initial idea for an interactive system should also determine the type of outcome. The outcome is dependent on which field of research is under exploration. This research report aims to explore the interactive outcomes of artworks, more specifically interactive installation artworks. Therefore, I present a number of ways of thinking about interactivity from various digital artists, and sound artists.

Morse describes a model developed in the 1980s that demonstrates the three degrees of interactivity associated with the laser-disk player and computer interaction, providing an example of how the model's first degree of interactivity uses minimal interaction similar to the use of a television remote control (21). If the 'on' button of the remote control is pressed, the television will turn on by displaying an image and producing sound (provided the audio system is on as well). I can provide another example that features a simple digital drum instrument. If this instrument is sent an 'on' message and five milliseconds later an 'off' message[6] through an audio interface, the audio sound system will produce a single electro acoustic drumbeat sound and then five milliseconds later it will stop. Both Morse's example and my own show how the interaction follows a linear approach. This first degree of interactivity follows one direct route towards a final outcome.

The second degree of interactivity allows the user a choice of interactions resulting in pre-established outcomes. I can provide two examples for this second degree of interactivity. Firstly, the DSTV[7] decoder that allows the user to scroll through an entire television guide with their remote control in order to locate a specific channel. Once the channel has been found the user expects the channel's pre-established outcome. The second example demonstrates how digital music instruments with an audio interface can provide many technique-based options of how a digital drum can be sonified in terms of pitch, length, tone

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[6] The 'on' and 'off' messages refers to a digital binary numbers that is sent via a MIDI (Musical Instrument Digital Interface) cable to the system. This is a signal similar to that of a light switch with only two options of either on or off. (See "IMA" reference in the works cited section for more information on MIDI)

[7] DSTV stands for Digital Satellite Television. It was launched in 1995 as Multichoice's digital satellite TV service in Africa.

and timbre to name a few. Once the tone of the digital drum is selected again we are presented with a known, pre-established outcome. This second degree of interactivity also provides a linear and direct approach with predictable outcomes.

The third degree of interactivity allows the user to alter the final form of the artwork and/or create an individual experience with an installation with which they are interacting. I will provide a musical example of an advanced keyboard synthesizer. This instrument is capable of allowing its player to choose pre-loaded sounds and manipulate them into something completely new. This new sound can then be saved as a new pre-set therefore allowing the user to essentially design a new sound for the keyboard. The user has added to the sound banks of the instrument thus making a personal alteration to the instrument. The user can alter the final form of the instrument and create new experiences while interacting with the instrument. The design of the interactive element allows for changing sonic outcomes.

The first two degrees of interactivity provide a linear interaction approach with pre-established outcomes. The interactive input is directly related to the output and the user can follow only one direction. The input method is prescriptive rather than creative and the outcome is predictable. The third degree provides the means for a non-linear interaction and changing outcomes. Morse provides the following example of the Internet and World Wide Web. It is known that both the Internet and World Wide Web are designed to provide closed bodies of information; however, web readers can search these pages in a non-linear order. These web pages are also open-ended and subject to change by their creators (Morse 21). The visual interaction with these web pages from the readers' perspective thus becomes constantly interactive through its changing outcomes. The physical interaction with these web pages for the computer-user might be limited but the knowledge learnt and information provided is continually changing and expanding geometrically. I provide another example involving sound. Sound editing software e.g. Pro tools[8], can provide numerous options for acoustically recorded music to be mixed in unimaginable ways until the acquired sound is finally attained. The manner in which this is done is again non-linear and the outcome is open-ended and dependant on the mixing engineer, i.e. the user. The last two examples provided show the non-linear approach of the third degree of interactivity whereby the interaction is limited physically, but the brainpower and mental capacity required from the user is principal. In Chapter Five, I show the relationship and resemblance that the case studies share with this third degree of interactivity in terms of their non-linear interaction approach and varying outcomes. I believe the non-linear approach to be superior as it relates to the way in which humans naturally interact with one another.

Fujihata provides us with an interesting analogy known as the "grammar of interactivity" (319). He compares the field of interactivity to the construction of sentences. The grammar of interactivity tells one how to use the system whereas the grammar for writing sentences shows how to join words into well-constructed sentences. Once the grammar of the dynamic system's interactivity is understood, the user is able to engage with the system on many different levels. Similarly, once the meaning of a grammatical sentence is understood it is no longer about each individual word but rather the understanding of the full statement (Fujihata 319). Fujihata suggests that reading and writing becomes simultaneous. Interactivity within sound driven interactive installations should become as fluent as reading and writing. These systems and their users must become one unit since "it is the ultimate place/field for the self emerging in real-time, a place where the user's spirit is

[8] Pro Tools is a Digital Audio Workstation (DAW) providing the world with an application for music and post-production of sound. For more information visit http://www.avid.com

alive, where the user can be emotional enough to feel alive" (Fujihata 319). The system Fujihata refers to is an interactive artwork that is based on the functionality and design of computer systems. The interaction between an acoustic musical instrument and its player also fulfils this feeling of emotion and connecting with one's spirit, so through a process of deduction, it is possible to contemplate that the interaction with an interactive installation through a computer system can be analogous to that of a musical instrument. This "new" kind of instrument i.e. the interactive installation can provide a meaningful experience that enhances the process of attaining knowledge by feeling connected to the information gained via sensory forms of interaction.

The examples provided above by Morse and Fujihata sketch a brief picture regarding the outcomes and effects of interactivity. The outcomes of an interactive installation should provide non-linear approaches of interactivity, meaningful experiences that engage the user on an emotional level, and lastly, feedback that is directly related to the user's specific interactions. These aspects can simulate and present a sense of creative freedom and promote memory recollection of the installation for continual and progressive use. I believe these outcomes exist within successful interactive installations and acoustic musical instruments.

I now take a closer look at interactive sonifications as this introduces another framework that I believe is relevant to the exploration of interactive installations. This area is important to this research because it showcases how the sonic feedback of the exploration of data can emerge through interactivity.

Interactive Sonification

Hunt and Hermann contend that "Interactive sonification is the discipline of data exploration by interactively manipulating the data's transformation into sound" (274). This means that the human user is able to interact with a system that outputs sonic responses specifically and which is directly related to the data under exploration. Interactive sonification overlaps with topics in the field of sonification and human computer interaction as can be seen in Figure 5 below.

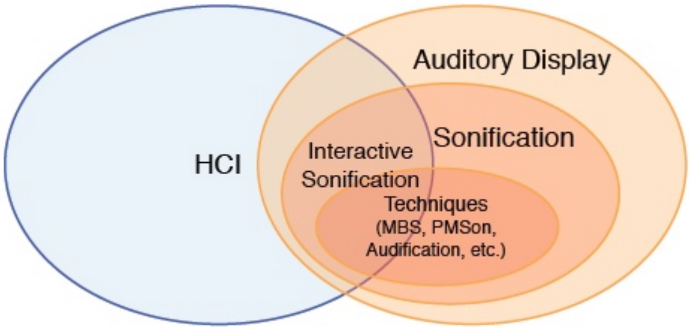

Figure 5: Topic Web of Interactive Sonification

It also provides an overlap with model-based sonification; hence it is necessary to identify with this area. It has been mentioned earlier that the sound made by a human tool can assist with understanding the mechanics of that tool. For example, if we hear the sounds emitted by a pair of scissors cutting paper, we automatically deduce how the scissors work due to prior experience with the tool. So it would be intuitive of sonifications to represent sounds in a similar manner that assists with the interpretation of the data under analysis and that present sonic feedback that is naturally and directly related to the data.

> The art of interactive sonification concerns the design of computer systems that enable human listeners to understand and interpret data by interacting with the data in a natural and effective manner (Hunt and Hermann 276).

An attractive aspect that interactive sonification provides is 'the human-user'. A programmed computer system will crunch data values that it is given and deliver an accurate result according to a specific question. The human mind however can translate the data and formulate patterns that were once unfamiliar into new innovative findings.

Interactive sonification models incorporate physical human interactions that exist within a physical space or a specific interaction parameter set out by the designer, whereby the human-user can explore the data. Whether it is a space for playing with an object that explores the data under analysis or a square space mapped out on the floor with sensors pointed at it for gestural interaction to occur, these areas allow for new explorations to exist between space and time. In a chapter by Brandon LaBelle entitled *Auditory Relations*, in *The Sound Studies Reader*, LaBelle discusses the relationship between sound and the space in which it is heard. He describes sound art "as a field that may engage levels of sociality through understanding not only the harmonies but also the dissonances between place, self and their interaction" (474). Interactive sonification installations must have the ability to acknowledge the human user interacting within the physical space. Within this space, the software programming of the installation should be able to provide the user with a sense of freedom through physical or gestural interaction. The sonic feedback should be an ultimate and accurate representation of the users interaction that makes the experience of sonic dissonances acceptable.

Hunt and Hermann (275) mention that there are six characteristics required for an interaction within an interactive sonification to exist:

- the user i.e. the interactor
- the user's needs

- the user's actions in response to perceived sounds
- the modes and means for controlling the sonification system
- how the user and sonification system form a closed loop
- how this loop impacts the ease of use, the ergonomics and creates a fun performance and experience for the user

These design characteristics presented by Hunt and Hermann above can definitely be aligned and utilized when dealing with interactive installations. It places the user at the centre of the installation and the data under analysis can be easily further decoded and experienced by the user through a sonic mode of interaction. These six characteristics required for an interaction to occur in an interactive sonification system are analogous to the type of interaction characteristics of acoustic musical instruments. The user is the performer of the instrument; the instrument provides the performer with a medium to translate data (i.e. the musical score) into musical expression; the performer's physical actions control and adjust the tone of the instrument. This constant interaction between the physical, visual and sonic modes allows the performer to generate a closed and continuous loop of musical expression thus creating a fun experience for the performer. Besides sonification, Interactive sonifications also incorporate other modes.

The modes I am referring to are the physical/gestural, visual and auditory type of interactions. In the likeness of acoustic musical instrument, interactive sonifications can also be utilized as additional input or output methods to consider when developing multi-modal interactive installations. It is necessary to discuss multi-modal interaction for two reasons: it provides more options for interactive installations to explore; and the case studies to be discussed in Chapter Five all contain multi-modal elements.

Multi-modal Interaction

The advent of the digital age has presented the world with an accumulation of data. This data has become impossible to perceive and comprehend all at once. The constant advancements in computing technology have provided new platforms for the growth and accumulation of data but these overwhelming amounts of data necessitate innovative methods to assist with its comprehension into valuable information (Coronel et al. 6). Interactive installations that involve elaborate sonic and visual displays have benefitted from these technological advancements in computing systems, opening many doorways for interactive digital artists. The techniques for decoding data are constantly expanding as has been observed in Chapter One of this research report with regard to the five different techniques within the field of data sonification. Yet sonification is only one mode in which to comprehend different types of data. Hermann and Hunt believe "interaction combined with sonification has the potential to bring computing to a new level of naturalness and depth of experience for the user " (1). The user of interactive installations would therefore have a similar experience to that of the use of acoustic musical instruments. Other modes that can be incorporated come from a visualisation, physical/tactile interaction or olfactory (sense of smell) practice. Adding and utilizing multiple modes can revolutionise the design of interactive systems. I now present each mode as it has been used in other contexts to show its individual importance.

The physical, tactile and/or gestural experiences of an interaction have been acknowledged as an important aspect of musical instruments throughout the historical progression of mankind. Humans learn through action. This type of interaction is not a new concept, but its use within interactive sonifications is sometimes limited due to the design of the instrument or interactive installation (Boy 8). This mode is important because any interaction with an object requires an initialization process and it is usually activated via this modal action. Visualization of data has been at the forefront of computer design for many years, and it is an obvious mode to include within interactive installations as it provides a sense of comfort for most users. As further developments and research on sonification occur, creators taking note of the value gained through the sonification of data. The advancements in sonification regarding computing systems are now comparable to visualization techniques. The olfactory experience is, however, a relatively new mode of exploration. At this stage I only acknowledge its existence as it falls outside the scope of this research report and does not feature in the case studies that are presented in Chapter Five.

Hermann and Hunt outline certain concerns that arise when using multiple modes for interaction, for instance: which modality should be more important? Or should the information be distributed equally among the modalities in order to obtain the best usability? Several modalities will offer the highest bandwidth but the distribution may be too complex and confuse the user; however, fewer modalities with uneven distribution may appear redundant (Hermann and Hunt 8). In Chapter Five, I address these questions by analyzing the various modes utilized within each case study.

As humans we expect our human brain and sensory system to perceive certain situations and cope with a certain mixture of information; it may seem therefore an obvious direction for interactive installations to include multiple modes. Hermann and Hunt, however, believe the area of research pertaining to sonification and interaction has not as yet been adequately addressed (8). In a chapter entitled *Designing Interactive Sound For Motor Rehabilitation Tasks*, Avanzini et al. begin to engage in this kind of research and have already noted that multimodal feedback can be used to improve performance in complex human motor tasks (271). They deal specifically within the area of technology-assisted motor rehabilitation tasks which "is designed to facilitate the reintegration of patients into social and domestic life by helping them regain the ability to autonomously perform activities of daily living", known as ADLs, for example, eating and walking. The ADLs involve visual, kinaesthetic, haptic and auditory cues, which are integrated in order to motivate the patients. This study shows that the addition of auditory feedback attained optimal arousal during the patients' physical activity; it reduced the perceived physical effort and improved the mood of the environment during training (Avanzini et al. 274).

This case study done by Avanzini et al. demonstrates that in the medical field multi-modal interactive designs are being utilized and are proving to be successful. This is no surprise as humans experience multi-modal interactivity in there everyday lives. It is only once the simple task of walking is taken away that one realises how many sensory modes are required for this task to be achieved. Through the case studies in Chapter Five, I explore the multi-modality of interactive installations and compare them to the multi-modality of acoustic musical instruments.

Conclusion

This chapter has defined and described aspects of human-computer interaction, interactivity and its outcomes, interactive sonifications, and multi-modal interaction. The types of interactivity that have been discussed in this chapter present significant challenges for the artist in terms of the interaction design process. It is therefore necessary to explore the design, implementation and programming of interactive systems.

Chapter Four: Design for Digital Interactive Works

This chapter focuses on the design aspects of digital interactive works and formulates comparisons with musical instruments. The chapter begins with a discussion around interaction design, its different approaches and elements. A section on the design aspects of the violin is included to illustrate how its attributes are similar to interaction design features. This section presents interface design alongside interaction design and discusses the key differences between them.

Interaction Design

The field of interaction design is understood primarily through Dan Saffer's book *Designing for Interaction*. Descriptions of interaction design suggest that it is an interdisciplinary field (see Figure 6 below) drawing together aspects of industrial design, information architecture and human-computer interaction, to name but a few.

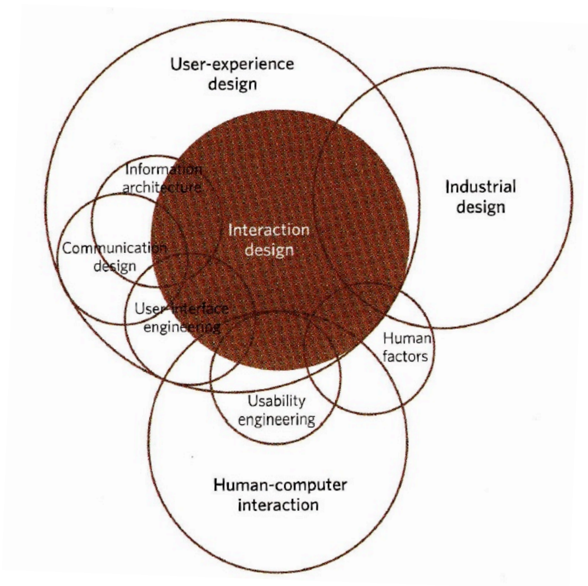

Figure 6: The Overlapping Disciplines of Interactive Design

Saffer states that “interaction design is the art of facilitating interactions between humans through products and services” (4), and that it aims to make connections between people through a product. It is also concerned with the behaviour of products and how they service people (Saffer 5). A Windows browser from 1995 is a product. This product was contextually designed according to the requirements of the time. Now, in 2014, this version of the product is outdated and the interactive elements would appear primitive to the current-day user. Interaction design is constantly dealing with an evolving medium, as products become outdated due to the rapidly changing technologies. Interaction design must ensure that these products and services remain suited to the time by continually upgrading products or by developing new products. Hence, interaction design does not and cannot align itself to any one technology, but can be considered an applied art, as declared by Saffer (4).

The products that this research focuses on are interactive installations, specifically multi-modal interactive installations.

According to Saffer, once a designer has envisioned and examined all angles of a core idea for an interactive installation, there are four ways in which to approach the interaction design:

- User-centred design
- Activity-centred design
- Systems design
- Genius design

I discuss all four approaches with the intent of drawing on this information for the analyses of the case studies presented in Chapter Five. When discussing artists and the design of their multi-modal interactive installations, I consider the artist and the designer to be the same person.

Saffer explains that a designer working on a project with a user-centred design approach aims to interpret what the user needs and his/her projected goals. This is managed by ensuring that the users guide the design process at every stage of the project. Therefore it is important that both the designer and the user conduct sufficient research. Users can become centrally involved and therefore can be viewed as co-creators (Saffer 31-32). Donald A. Norman in *The Design of Everyday Things* emphasises the importance of this by indicating that if users at any point need to ask themselves how they will remember an instruction, then the design has failed. The user must be able to figure out what to do and understand how to engage with the design (Norman 188). Artists designing multi-modal interactive installations should consider a user-centred design approach, as the incorporation of user-feedback can identify and rectify any unnatural interactions during the design process. This is useful if the artist is concerned with user satisfaction, however, this is not always the case.

The second approach to interaction design proposed by Saffer is known as an activity-centred approach. The purposeful actions and decisions of this design approach are key to the outcomes of this design model. These actions and decisions known as "tasks" can be as simple as making a sandwich or as complex as learning a foreign language. They have direct and intended outcomes based on specific activities. For example, musical instruments are products designed for one specific activity: making music. In this case, the activity not the user guides the design process. Therefore it is important that the designer researches the behavioural aspects of users, allowing for the creation of the correct tools to ensure that the users perform the necessary activities (Saffer 33-35). So in order for multi-modal interactive installations to portray similar design characteristics to those of acoustic musical instruments, they must be designed with a specific task that produces a direct and intended outcome.

The logical and analytical approach to interaction design presented by Saffer is known as systems design. The goals and needs of this approach are set according to the system. Users are de-emphasized in favour of context; however, the users goals are still considered. Designers focus on the structured and rigorous design of the system's components in order to eliminate any errors in a system. Errors in a system are seen as disturbances and are not welcome in a system design (Saffer 36-40). Although these disturbances can provide new access points for users' expression, the emotions and passions of users (i.e. disturbances) are not welcome in a systems design environment, hence its somewhat dehumanizing approach. If the intention is to create multi-modal interactive installations that are similar to acoustic musical instruments then a system design approach is not the best solution based on the fact that artists should engage with their users and humanize the interaction process. On a more positive note, this approach provides a holistic view of a product by focussing on the broad context of use, enabling designers and users to better understand the environment surrounding their product (Saffer 36-40). The analysis and specific parameters of data sonification would best suit this systems design approach, as it requires accurate methods of implementation associated with parameter-mapping sonifications (Berger and Grond 363).

According to Saffer, experienced designers are the focus of genius design. The designer in this approach is the source of inspiration. Genius design relies on the better judgement, wisdom, experience and decision-making of the designer. User-involvement usually occurs at the end of the process to decipher whether the design works as initially predicted by the designer. Many designers, including those who are inexperienced, utilize this approach for various reasons. However, genius design can either result in impressive designs or impressive failures (Saffer 41-42). The continual design enhancements and constant improvements to acoustic musical instruments show over a period of time that experienced designers can implement genius design. For multi-modal interactive installations the improvements to these installations usually occur at the software programming stage.

The best designers of products and artists of interactive installations are able to move between all four different approaches, but usually each situation warrants a particular approach. Works may be commissioned with tight budgets to function a certain way and often user involvement is impossible to implement due to the expense. Sometimes artists are unaware of the different approaches and often their ideas take priority before the decision of design approach. Either way, the eventual design approach decided by the artists should attempt to find a solution to the initial problem and reason for their design. In Chapter Five, I consider each case study individually and discuss the design approach on which each was based.

Once the artist has chosen an approach for his/her design, there are a number of elemental resources that can be manipulated. The powerful elements that should be incorporated into the design process are motion, space, time, appearance, texture, and sound. Here I discuss each element as expressed by Saffer and in Chapter Five I expand on how the implementation of each individual element has been utilized and observed in each case study.

Saffer states that "without motion, there can be no interaction" (45). Objects that do not move are static. There can be no movement of objects if there are no interactive forces surrounding it. Interaction design is concerned with the behaviour and motion of people and products interacting simultaneously. Saffer presents an example whereby a finger clicks a button of a computer mouse and this action triggers visual motion on the computer screen

(45). I offer a simple musical example of a piano that remains static and soundless until a single key is pressed. In both examples the physical interaction with an object triggers visual and/or sonic motion.

Saffer observes that “all interaction takes place in a space” (46). He elaborates on this, explaining that the space can be a physical space, a virtual space or both as it becomes a home for all interaction to take place and context for motion (45). I present the example of the placement of pianos within a space because new meanings can be created when pianos are positioned in different locations. If the piano is placed in an auditorium, it is expected that great masters will perform on the instrument in front of many audiences. If the same piano is placed inside a small room, it can be assumed that this piano is utilized as a practice instrument. Hence, the space provided for any instrument or any interactive installation reveals a context for its utilization and suggests how it will be treated.

Saffer suggests that “movement through space takes time to accomplish” (47). He confirms that all interactions happen over time and designers create this rhythmical timing. Because users are accustomed to instantaneous feedback, it is important to deliberate the rhythmical design of timing in interaction design (47). Saffer presents an example, stating that if a simple mouse-click took a single second delay before anything appeared on a computer screen, the user would eventually become frustrated. I suggest that this delay is only frustrating if it is unexpected as part of the design, for example, a professional pipe organist knows that the distance between the keyboard controller and the physical pipes of the instrument can cause the sound to be delayed as a key is pressed, therefore the organist will adapt his/her playing style in order to accomplish the rhythmical timing of his/her fingers in accordance with the desired sonic response of the instrument. If a delayed reaction is not expected from an instrument or installation, it is generally important that feedback is instantaneous as it instils a sense of control in the user. Another more physically interactive example presented by Erkut et al. shows the outcomes of rhythmic sound interaction in fitness centres when the music playing over an audio system directs the user's pace on a treadmill (341).

Another element presented by Saffer that goes hand-in-hand with the contextual space provided for interaction design is that of "appearance". Saffer states that appearance also provides an indication of how to interact with the design of an installation. The variables to consider are proportion, structure, size, shape, colour (hue, value, saturation) and weight (Saffer 49). He also points out that appearances can convey emotional and meaningful content, which encourages a particular physical or gestural interaction with a design (Saffer 49). For example Saffer suggests that a saturated blue box on a computer screen will attract the eye more quickly than a pale yellow box (131). This could force the user towards a specific area of interaction whether intended or not. Artists should therefore be attentive towards the appearance of there installations. Closely linked to appearance is texture. Texture can also convey how to interact with the design. For this reason, texture is often a good substitute for appearance when designing for the visually impaired (Saffer 50).

The last element of an interaction design presented by Saffer is sound. The designer of an interactive installation can adjust the pitch, volume or timbre (tone quality) of sound in order to achieve the desired effect (50). The player of a musical instrument can also make these adjustments to pitch, volume and timbre, but there is a significant difference between the sounds produced by acoustic musical instruments and the sound production of interactive installations. The sound produced by an acoustic instrument is directly linked with the physicality and material of the instrument. For example, idiophones are instruments where the body material itself is the resonator of sound, and membranophones have a membrane attached to the body of the instrument, which is the resonator. There is a direct and tangible relationship between the material of the instrument and the quality of sound produced through interaction. With interactive installations, sound is produced and heard through an audio interface when the computer sensor captures the interaction of the physical gestures made by a user with the tangible material of an installation. This interaction triggers the sonification that has already been pre-conceived by the designer through MIDI sequences or pre-recorded sound samples. The users can interact with the installations and perhaps even manipulate the sound expressively, but the physical material of these interactive installations does not create any natural acoustic resonance. This is a clear and distinct difference between the sound production of acoustic musical instruments and multi-modal interactive installations.

Interaction design requires the assembly of all the elements of interaction mentioned above in varying degrees according to the needs of the product. I now provide an example by discussing the elements of interaction and the interaction design approach according to Saffer, with regards to a musical instrument. More specifically, I consider the violin as the product and the human as the user.

Yehudi Menuhin and William Primrose, authors of the book *Violin & Viola*, describe the relationship between the performer and his/her instrument. They discuss the platonic relationship between the violinist and his violin as well as the space and sensation between the violinist and his body (7). I outline these relationships using the interaction design perspective laid out by Saffer. The question whether or not a similar or comparable relationship between users engaging with an interactive installation can be observed will be discussed in Chapter Five.

The Violin and Design

This brief account of the violin aims to consider musical instruments in relation to interactive design techniques. Most modern musical instruments from all categories of instrumentation have undergone years of development and improvements. I have chosen the violin specifically because it has been recorded that due to its chin requirement only Homo sapiens are capable of playing the instrument (Menuhin and Primrose 10). Anatomically, the ape has no chin therefore he can only play the piano, blow a flute or beat a drum. I thought this concept interesting as it portrays the violin as superior to other instruments and highlights the fact that the violin was developed using a human user-centred design approach, much like some multi-modal interactive installations.

This is by no means a complete account of the history and development of the violin, but establishes the key changes and improvements of the instrument. The violin is proposed as a direct descendant of the Viol family of instruments. By 1550 the full four-string instrument and its family (the viola and cello) had emerged as the string instruments that we still use today. Over the next 100 years the violin went through basic proportional changes, for example, the form and symmetry to enhance the sonic resonance of the instrument in order to meet the demands of soloists, the larger concert halls and the new musical compositions that challenged the physical boundaries of the violin. The modern violin we know today was fully developed by the 19th century (Gunzenhauser 1). This development included changes to the bow, the invention of the chin rest, the lengthening of the neck and fingerboard, the heightened bridge, the thickened soundpost as well as the thinned-down soundboard. All these changes contributed towards achieving greater volume and brilliance of tone with the instrument thus allowing for advanced playing techniques for the virtuoso violin repertoire of composers such as Niccolo Paganini and Fritz Kreisler (Wade-Matthews 103).

The historical account above shows that the violin has undergone many years of development in order to achieve perfect conditions for usage and virtuosic performance. Based on the definitions of interaction design processes from Saffer, the interaction design approach for the violin can be described as predominantly an activity-based design process – the main task and activity being for the instrument to make music. However, the changes made during the 19th century could be seen to incorporate a user-centred design approach because the users of the violin were also the co-creators of the instruments as much testing was done throughout the development of the instrument. Based on the history of the instrument's development, the aim was to refine the violin so that it could produce a better tonal quality, a more comfortable playing position and push the sonic capabilities of the instrument as far as possible. Because this instrument has had many years of development, it is possible to consider that the later violin-makers, i.e. the designers of the instrument, incorporated their extensive experience and knowledge of the instrument into the design process. As mentioned earlier in the text Genius design relies on the better judgement, wisdom, experience and decision-making of the designer. The later years of the design of the violin have definitely been approached from this design perspective since the instrument has passed through the hands of many famous violinists and highly experienced violin-makers i.e. designers such as Andrea Guarneri, Francesco Rugeri and Antonio Stradivari (Gunzenhauser 1).

As mentioned above, three of the four interaction design approaches outlined by Saffer can be observed in the history of the violin's development with a slight predominance of the user-centred design due to the violin-makers being violinists themselves. Humans designed an instrument specifically adapted to the human body. The violin is held under the chin but close to the ear, with the left-hand controlling the pitch and the right hand controlling the sonorous tones created through the directed movement of the bow over the strings. A full commitment from the player and consistent practice time with the violin can achieve expressive interactions and enjoyable experiences for the user. Artists should aim to facilitate these expressive interactions and create similar enjoyable experiences for their users with their own artworks. The notion of usability of the violin has been discussed thus far; therefore, I invite researchers to further investigate the notions of learnabililty that has not been adequately covered in this text.

The elements of interaction design are also analysed with reference to the violin. Menuhin and Primrose describe the appearance of the violin as representative of a woman's body as every line is curved or bent (7). This is purposefully for acoustic reasons; however, this representation of the violin suggests how the elements of interaction design are portrayed by Menuhin and Primrose:

> The handling and playing of a violin is a process of caress and evocation, of drawing out a sound, which awaits the hands of the master. It is enticing and fascinating, passive if you wish, but ready to respond at the slightest touch. A beautiful violin contains that infinite potential – of sound, flexibility, colour, intonation, pitch and volume – which awaits the music and the musician. (9)

The motion of the bow in the users hand and the strings of the violin create a platonic relationship whereby the one cannot sound or express itself without the other. The proportions and size of the violin allows the instrument an abundance and variety of "spaces" in which the instrument can perform, for example, sidewalks, practice rooms or great auditoriums. The time it takes to master the instrument is certainly extended, but the structure, size and appearance of the instrument is specifically designed to guide the user via a somewhat comfortable physical, visual and sonic interaction in order to attain the correct sound. Even though only one person can play a violin at a given time, there is also the possibility of interaction between two or more violinists. The interaction design of the violin is not limited to one instrument and one user but a group of violinists each playing their own instruments together can present further human-human interaction on a physical, visual and sonic level.

Interface Design

The interface design of a digital product or system aims to represent a visual, audible or physical aspect that inspires the user's input and guides the system's or product's output (Saffer 150). Interface design is often seen as synonymous with interaction design; however, the two are different. Interface design sits between the machine and the user as a means of hiding the functional but unsightly back end of the digital product or system (Murray 10). Interaction Design is the art of facilitating the users' connections between themselves and the product or system (Saffer 5).

A musical instrument is a physical object with which humans directly engage in order to make music. I suggest that the body of the violin is therefore an interface that contains and hides its vibrations and acoustic resonances until interaction occurs. As the bow is drawn across the strings of a violin, sound vibrations are produced. But the violin's functionality and therefore its interaction design are visually noticeable to the user. The user will eventually understand how the sound is produced; therefore the interaction design and the interface design are so closely tied that they are believed to be the same. This is not entirely true for digital products though; with digital products the interaction design is the invisible functionality that is made somewhat visible and usable through an interface (Saffer 122). The user may not know how the inner workings of a digital product are created or function, but the interface will provide a tangible and understandable space for the user to access and engage with the product.

In the book *Inventing the Medium* by Janet Murray, she has a chapter entitled *The Tool Model: Augmenting the Expressive Power of the Hand.* In this chapter she discusses the usefulness of a tool that is able to perform an action controlled by the hand. The tool becomes an extension of the hand and is manufactured to suit the task. These tools can be used for pointing, grabbing and expressive gestures (Murray 291). Most musical instruments are physical interfaces and tools through which a human touch and interaction is required. In digital environments, sometimes the physical interface is also a tool for physical engagement. Murray states that “a tool is a simple device, customized to a single purpose, operating under our control and responsive to our direction, whose effects are immediately visible to us” (321).

Murray explains that the tool model is used to focus on key design goals, for example, efficiency, learnability and transparency, and by being efficient can help avoid unnecessary intermediate steps and delayed results (302). What she is suggesting is that if artists design interfaces that provide some form of physical interaction with the user through a tool then the learnability of a simple task can be easily demonstrated or a complex one can be achieved with practice. The transparency of a tool can allow the user to focus on the task and not the functioning of the tool (Murray 302). If the interface design is successful, the tool can distract the user’s attention, thus allowing the user to focus on fostering expressivity and virtuosity with the artwork. Acoustic musical instruments shadow this notion of Murray’s tool model.

> The model of the musical instrument is expressive by virtue of its physical affordances and the learned mastery of the performer. By fitting the kinetic

> ability of the performer to the affordances of the instrument, great skill can be attained" (Murray 308).

Through further research efforts, it is possible to predict that computer input systems for multi-modal interactive installations will one day allow the same level of practice required (in musical instruments) in order to offer comparable expressiveness and transparency for its user. But very few people are prepared to invest years of practice in order to learn how to use a tool or a new interface. Ideally, Vissel et al. suggest new interfaces should slowly accommodate increasing skill levels by exposing additional functionality as users master the interface (91).

The tool model has been a useful concept for interaction and interface design, but there are also those tools that do not require physical contact in order to support the design process. The Theremin is an instrument that does not require any physical contact from the player like many electronic and digital products/interfaces that are moving towards a future of what is known as 'faceless interfaces' (Saffer 147). Saffer provides examples of faceless interfaces such as voice-controlled phones, global positioning systems, and motion sensors, which are all controlled by the voices and gestural movements of the human body (147). These interfaces can respond to a person's mere presence.

David Rokeby's *Very Nervous System* is a good example of an interactive sound installation that uses sensors to respond to a person's presence. Rokeby describes this interface as invisible and diffuse but still offering a vital and strong texture through time and space (Rokeby 1). See Figure 7 below, which shows Rokeby himself interacting with his work. The movements of his body detected by motion sensors in this specific space, on a street in Potsdam, create sound and/or music (Rokeby 1).

Figure 7: Very Nervous System

Conclusion

The design processes and the inclusion of human user-centred design are good starting points from which to draw information in order to create multi-modal interactive installations that function in a similar manner to acoustic musical instruments. A good combination of interaction design and interface design can result in remarkable products that last generations as the design of acoustic musical instruments has done. Murray states that "design decisions can affect the way we think, act, understand the world and communicate with one another" (2). At the end of the day, the artists and designers choose and define how their artwork or interface must function within society. Even though the tool for sound production of an acoustic musical instrument and a multi-modal interactive installation are distinctly different both can communicate to their users as long as experienced designers pursue consistent efforts to define and refine their tools.

Chapter Five: Case Studies

Chapter Five provides a critical and comparative analysis of the three case studies, namely: Firewall (2012) by Aaron Sherwood and Michael Allison, The Manual Input Workstation (2004) by Golan Levin and Zach Liebermann, and Model Hat Digiphony (2012) by Constantina Caldis[9]. All three case studies are interactive installations. The first two case studies are the primary case studies pertinent to this research report whereas the third case study is presented as a secondary and more reflective case study.

The analysis of each case study investigates the musical and design attributes focussing on the following points:

- A description of each case study is presented in order to outline the basic configuration of each work.
- The sonification method known as Model-based sonification is analysed as a main framework in order to align each case study to this structured model and reflect on the relationship between the input (interaction with the system) and the output (resultant knowledge gained).
- The outcomes of the interaction and interface design are discussed according to the approaches and elements mentioned by Saffer; they are then compared to musical instruments in terms of their usability and learnability; lastly the evolution

[9] I, Constantina Caldis am both the author of this research report and the creator of the piece *Model Hat Digiphony.* This piece is being used as a comparative and reflective case study in this research report rather than a practical component or a primary case.

and re-design of technology and techniques of the case study in relation to musical instruments are considered.

- An examination of the multi-modal attributes contained within the work and how they function together.
- The last aspect of analysis attempts to categorize the case study within the mould of a musical instrument category in an effort to answer the initial question pertaining to this research.

To conclude I provide a short comparative analysis of these criteria across the three case studies and reflect on what has been learnt and discovered.

Firewall

The first of the two primary case studies of this research report is *Firewall (2012)* by Aaron Sherwood and Michael Allison. Based on the video content and literary documentation that I have viewed online, I describe and explain how this installation functions from the user and designer's perspective in order to analyze this work according to the criteria outlined at the beginning of this chapter. I am assessing this particular work through the concepts presented by Hermann and Hunt's 2004 article in order to address their validity in a current artwork from 2012.

Firewall is described by Sherwood as a haptic instrument whereby fire-like visuals and acoustic feedback are directly affected by the tactile interaction on a stretched-out spandex membrane (Sherwood 1).

The website explains that *Firewall* is structurally supported by a metal frame, whereby a piece of spandex is setup in a vertical manner approximately two meters in height and one meter in width; projected onto this tactile membrane are orange visuals that can be seen in Figures 8.1 and 8.2 below (Sherwood 1).

Figure 8.1: Firewall Soft Curves

Figure 8.2: Firewall Sharp Angular

The two different visual displays seen in Figures 8.1 and 8.2 are different projections that produce slightly different auditory results. The online video shows how a user can switch between these two independent and different versions of the same product and is then able to interact directly with the membrane. If the membrane is left untouched, no audio will be heard and the installation will remain silent (Sherwood 1).

In chapter Two I presented the sonification technique of Model-based Sonification (MBS) as presented by Thomas Hermann in *The Sonification Handbook* (404-408) and further described this model through the aid of Figure 2. I now align and describe the workings of *Firewall* according to this structure, following a sequence according to the Initial State, the Excitation, the Model dynamics and the Listener characteristics of MBS.

The *initial state* of *Firewall* is when the orange visuals can be seen but not heard. The installation is silence. The physical interaction and *Excitation* of the installation occur when the user slides his/her hand across the membrane and/or presses into the membrane. The visual directly responds to the position of the hand. As this tactile interaction occurs, an auditory event transpires simultaneously. Sherwood explains that the varying pressure of the interaction with the membrane allows the audio to be manipulated in an expressive manner (Sherwood 1).

The online video content demonstrates that when tactile interaction occurs with the graphic display of Figure 8.1, the audio heard is a solo piano piece. If the membrane is touched a gentle piano piece will fade in and will continue to play as the user's hand glides across the membrane. The audio heard becomes more interesting as the hand presses into the membrane because then the user is able to control the volume and speed of the piano piece being heard. Hence the user is given the ability to alter the piano piece expressively according to volume and speed parameters. Once physical and tactile interaction with the membrane ceases then the solo piano piece stops (Sherwood 1) and the installation falls back into its Initial state. I now provide a direct comparison of a musical instrument regarding these two parameters of volume and speed. The control of volume and speed for the performer playing an acoustic piano is produced usually through a quick horizontal motion (for speed) and vertical motion (for volume) of the hands and fingers working together and these motions can also be noticed in *Firewall* as it uses a similar process whereby the hand can quickly brush horizontally across the membrane which speeds up the piano piece and the volume is increased when the hand pushes the membrane inwards. In Figure 8.2, the functionality of the *Firewall* is identical to Figure 8.1; however, the audio heard is an electronic sound that has an incisive melodic sound.

See Figure 8.3 which shows the depth of engagement with the membrane. The interaction with the vertical depth of pressure to the membrane can create expressive auditory results affecting the volume, and the interaction with the horizontal Cartesian space data affects the speed at which the audio is played back.

Figure 8.3 Firewall Depth

In both versions of differing visual and aural displays of the installation, the volume and intensity of the auditory events represent the outcome of the auditory and visual data under scrutiny. According to MBS this is the *Model dynamic* of the installation (404-408). This data is manipulated via physical and tactile interaction in order for the user to feel as if they are expressively generating the audio themselves. The *listener characteristics* (as described in MBS) allow the user's perception of what is heard to guide the location and orientation of the interaction and experiment with the two parameters (volume and speed) as seen in a musical event.

This installation is also multi-modal as it utilizes three modes, namely, a visual representation and a tactile interaction which result in an auditory event. The orange fire-like visual display acts initially as an attractive element but once the tactile interaction with the membrane occurs, the visual becomes the means through which users interact with the auditory feedback and thus a secondary mode. By listening analytically, the user can gain knowledge into how to control the volume and intensity of the audio and how best to utilize this function for expressive playing. *Firewall* uses the visual, physical and auditory modes and can therefore be considered a multi-modal interactive installation.

The technical design and programming of this installation uses the following components for its functionality: the Kinect, Processing software, Max/MSP software and Arduino hardware. Sherwood explains that once interaction occurs, the kinect measures the average depth of the membrane from the frame it is mounted on; this data information is then processed through algorithms in Max/MSP and represents the data information as volume changes or speed changes (Sherwood 1). The interaction design of this data is extremely well concealed behind the interface design thus allowing the user to play with the interface without considering the mathematics behind it. The membrane is the primary interaction hardware and the means for the user to directly connect with the programmatic artwork.

As there is no documentation provided, I speculate that the interaction design follows an activity-based approach, whereby the actions and task of the user is to expressively manipulate the audio via tactile interaction to expressively perform music. However, in order to achieve fluidity between the work and a user, I speculate again that the designer of the installation also focussed on a user-centred design, because the installation allows the user to alter two expressive musical parameters, which are experienced by users of acoustic musical instruments. The usability and learnability of the installation is easy to accomplish. There is no hidden data or interfacing requirements that need to be discovered and hence this work is a pleasing, easy-to-use multi-modal interactive installation. This suggests that the work employed a simple user-centred interaction design as well. When compared to the interaction design of acoustic musical instruments, it can be noted that in order to achieve the same sense of simplicity and comfort with an acoustic musical instrument, much practice is required.

Could this installation therefore represent a new kind of instrument? It definitely suggests similarities with the category of membranophones. A membrane is used as the tool with which to physically interact and manipulate the volume and speed parameters of the music. The physical, visual and auditory modes are utilized. The physical interaction with the membrane can be approached in a non-linear way, but eventually the changing outcomes will become obvious. As a stand-alone installation, *Firewall* can certainly fall within the parameters of musical instruments, but this installation has no degree of difficulty. Even a non-musician is able to play with *Firewall* because its design cannot render it musically more complex or more difficult. A non-musician can easily play a drum too, however there are escalating levels of difficulty that can be learnt on a drum. According to the design of *Firewall,* it cannot enable any further levels of virtuosity to be achieved as a stand-alone instrument; however, this is not *Firewall's* intended function and reason for development.

This work was originally developed for Purring Tiger as a performance piece titled *Mizaru*, which premiered in June 2013. The title of the work is one of the names of the three wise monkeys from Japanese culture. These monkeys are better known in English culture as *See no evil, Hear no evil* and *Speak no evil* (Sherwood 2). *Mizaru* explores society's relationship with death and in Sherwood's words, "by accepting our own mortality we actually become more alive, knowing we could die at any moment makes every moment special" (2).

During the performance of *Mizaru,* the interaction of the dancers with the firewall presents beautiful imagery with captivating sonic responses. The performance piece uses two *Firewalls* on either side of the stage. The choreography of the piece is designed so that the dancers perform in the centre of the stage and move around and towards the *Firewalls*, i.e. this is an interactive set. These *Firewalls* thus form part of an entire production and are no longer stand-alone installations. The *Firewalls* can be considered as structured interactive sets placed in a specific location on stage in order for the dancers to utilize them and perform with them. This can be compared to the percussion section of an orchestra whereby the percussive musical instruments are placed on the stage and await musicians who will utilize and perform with them. All musical instruments placed and brought onto the stage come together through the guidance of a conductor and produce the sounds of an orchestra. In *Mizaru* the orchestra is a combination of the interactive set and its dancers.

After viewing the online video content of *Mizaru*, I can say that the *Firewall* is initially used in a similar manner as if interacting with the stand-alone version. The only difference is that the dancers also utilize their bodies and heads against the spandex membrane in order to initialize and excite the installation as can be seen in Figures 8.4 and 8.5 below.

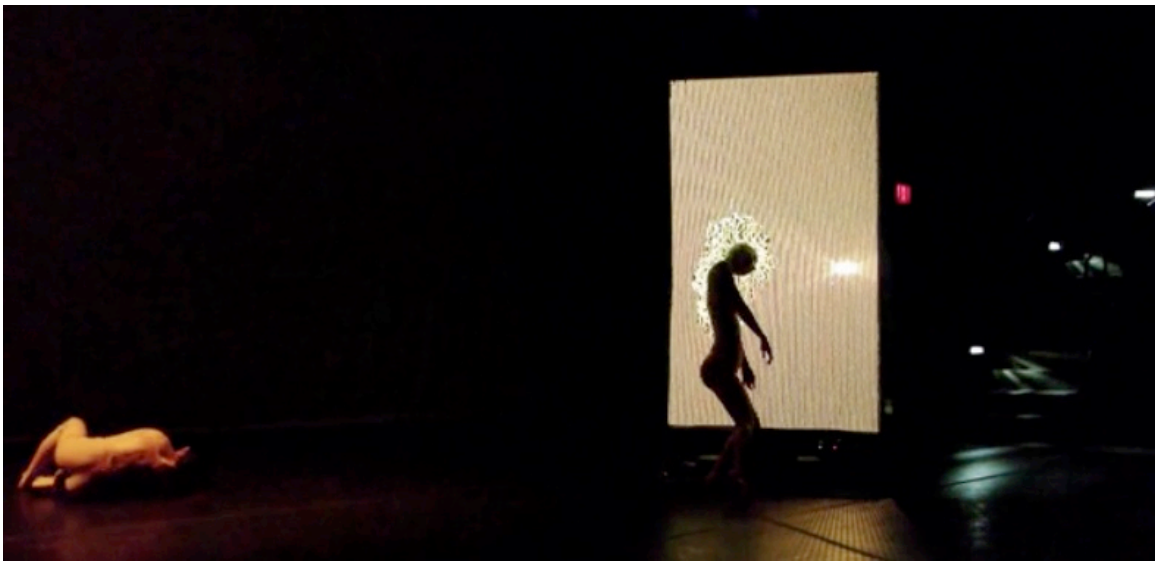

Figure 8.4: Mizaru Head Interaction

Figure 8.5: Mizaru Hand-to-Shoulder Interaction

At another point during the performance of *Mizaru* the *Firewall* is switched off. This programmatic interactive artwork is no longer utilized, but instead the screens are used for feedback projections, which map the dancers' movements. This feature can be seen in Figure 8.6 below and is purely a visual representation of the dancers, with no audio content.

Figure 8.6: Mizaru Visual Mapping

What is interesting to note is that even though the stand-alone installation performs minimal functions compared to a musical instrument, its utilization within *Mizaru* showcases its real purpose for development. This installation was initially designed to be adapted according to the needs of the performance piece *Mizaru* and can provide multi-modal levels of interaction for the dancers and the audience members as a pre-composed and choreographed installation piece. Musical instruments provide one main purpose and that is to make music. *Firewall* provides a few features of musical instruments but it can also be transformed into something new, something instrumental relating to more than just sound. As utilized in *Mizaru,* I can say that it has effectively transmitted its own spirit into the emotion of the users and its audiences.

The Manual Input Workstation

The Manual Input Workstation (2004) by Golan Levin and Zach Lieberman is the second primary case study to be presented. It is "a work of art that allows the interactor to use hand gestures and/or finger movements to present a series of audiovisual vignettes" (Levin and Lieberman 1). There are two modes for this artwork, the performed mode titled *The Manual Input Sessions* and the interactive installation mode *The Manual Input Workstation*. Even though the former presents itself as an instrument for the usage in performances, I analyse the latter for its interactive element, which allows users to explore the artwork.

The reason I chose the work by Golan Levin and Zach Liebermann is because they are both renowned artists and engineers in the field of interactive arts. Golan Levin's work tends to explore the design of creative systems that involve new modes of interactive expression, and Zach Liebermann's work explores the creative and human uses of technology. I am investigating this work because it was developed during the same year the Hermann and Hunt article was published, i.e. 2004. Another reason for using this project as a case study is its versatility as an installation. It has been developed in three different versions, thus also incorporating three different styles of interaction. The three versions are known as NegDrop instrument, InnerStamp instrument and Rotuni.

A paper presented at the Proceedings of NIME (New Instruments for Musical Expression) 2005 Vancouver, Canada titled *Sounds from Shapes: Audiovisual Performance with Hand Silhouette Contours in The Manual Input Sessions* by Golan Levin and Zach Liebermann provides a useful description documenting how the installation *The Manual Input Workstation* functions (Levin and Lieberman 1). I begin by describing this installation as one entity and then discuss the different interactions for each version.

I refer back to Chapter Two where I presented the sonification technique of Model-based Sonification (MBS) as proposed by Thomas Hermann in *The Sonification Handbook* (Hermann 404-408) and described this model with the aid of Figure 2. I will now align and describe the workings of *The Manual Input Workstation* according to the MBS structure that follows the sequence of the Initial State, the Excitation, the Model dynamics and the Listener characteristics.

The installation comprises an overhead projector, a video projector, a computer vision system and a dynamic lighting system. The *Initial State* of the installation is silent, with pink lighting projected within the outline of the overhead projector. This pink area represents the interactive space of the installation. The *Excitation* of all three versions of the installation begins when the participant's hands pass over the projector to create a silhouette of an object or by placing an object on the overhead projector. The objects and/or silhouette will then produce both visual display and auditory feedback. The audification of the object is directly related to the visual and experiential knowledge of how that object should sound and react. The sounds perceived by the user are known as the *Listener characteristics.* The *Model*

Dynamics of each version are slightly different and I discuss the differences between the *NegDrop Instrument*, *InnerStamp Instrument* and *Rotuni*, which are all different version of *The Manual Input Workstation* contained within the same installation.

According to Levin and Lieberman, I have paraphrased the functioning of the *NegDrop Instrument* and describe it as follows: The individual user's hands hover over the projector and create a shadow of a rectangular shape. Once the shape is created by drawing the boundary of the inside of the shape created by the user's hands, it drops down the screen and bounces for five seconds with a sonic resemblance of how heavy the shape is and then the sound stops (Levin and Lieberman 1). See Figures 9.1 and 9.2 below.

Figure 9.1: Negdrop High Frequencies

Figure 9.2: Negdrop Low Frequency

As explained by Levin and Liebermann, the audification of the 'weight' of the shape is determined as follows: smaller rectangular shapes produce higher frequencies and larger ones produce lower frequencies. Many different rectangular-sized shapes can be created simultaneously and produce a mixture of high and low frequency sounds; those then drop to the bottom of the screen and after approximately 5 seconds disappear visually and sonically (4). I have noticed that the sounds produced are directly related to the visual object and this concept is explored in the discussion on Auditory icons in Chapter One of this research report. The sound of the object dropping is so closely related to the image that if either one of these modes, i.e. the visual or auditory, were not present, the understanding of the sound of the object or the visual of the object would be obvious to the user. Even though the physical interaction with the installation is minimal and only the hand gestures are required to begin interacting with the work, the object-related sounds might entice the user to create different sizes and shapes in order to produce new sounds. This could become a musical game that plays around with object size and sonic frequency relationships.

Levin states that the *InnerStamp instrument* is similar in design to the *NegDrop Instrument* except that once a shape is created continuous sounds are heard (Levin 1). The sound can then be manipulated as the user ruptures the shape's contour by moving his/her finger in and out of the shape. See Figures 9.3 and 9.4 below.

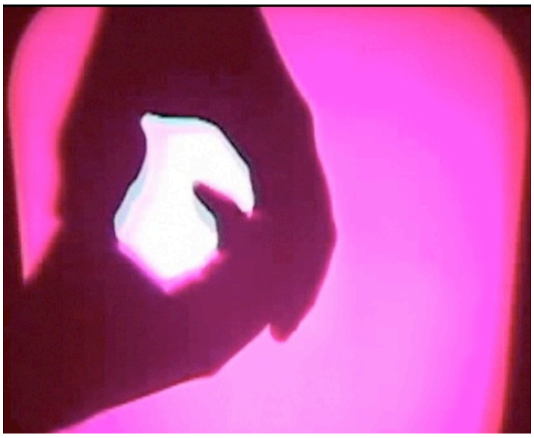

Figure 9.3 Innerstamp Creation

Figure 9.4 Innerstamp Continuation

Even though only one shape is depicted in the images above, more than one shape can be created at a time. And due to the continuation of the visual and auditory feedback, the interactive space can become quite visually and audibly crowded. Again, the size of the shape determines the sounding frequency of the shape. The *Negdrop* and *Innerstamp instruments* are quite similar. They both feature minimal physical interaction, but all shapes created through this interaction produce direct visual and audible relationships.

A third version known as the *Rotuni* allows the user to place a physical object, for example, a small ruler or a round glass, on top of the overhead projector. This object then lies stationary and produces a visual similar to a radar display moving around the boundaries of the object in a circular fashion, and also creating a sound which is directly related to the dimensions of the object (Levin 1). See Figure 9.5 below.

Figure 9.5: Rotuni Many Objects

Figure 9.6: Rotuni Hand with Spike

If the object has an unusual spike in it, as seen in Figure 9.6 above, the pitch of the sound will be higher every time it circulates towards that section of the object. Any spike in an object allows the melodic material to be controlled within a rhythmical context. When more objects are added, the sonic and visual environment builds up (Levin and Lieberman 3).

All three versions of the *Manual Input Workstation* can be used simultaneously and they each involve the utilization of three modes. The physical interaction mode is the primary source of input and the visual and auditory feedback is the output for this installation. This installation utilizes the physical, visual and auditory modes thus I consider this work to be multi-modal. It has already been said in Chapter One that humans naturally develop a method of learning how to identify the source of a particular sound and the action that produced it as explained in *The Sonification Handbook* as *Everyday Listening* (Hermann et al. 400). I deduce from the online video content of this work that the auditory feedback of *The Manual Input Workstation* is based on *Everyday listening* which relates to source-identification. Due to aspects of interactivity across three modes, I consider *The Manual Input Workstation* to be a multi-modal interactive installation.

I speculate that the interaction design follows an approach which is activity-centred, user-centred and utilizes genius design. The activity is to create sounds with objects and gestures. The responsiveness of the installation is based on a user-centred design, which makes the user feel like he/she is in control of creating a unique sonic environment. And lastly, genius design encompasses the experience and knowledge that the developers utilized in the creation of *The Manual Input Workstation*. By simply viewing the online video content of this work, I can deduce that the users become so comfortable with the work that they begin to experiment with its virtuosic properties almost immediately. Levin and Lieberman have obviously experimented and experienced a level of comfort and mastery with *The Manual Input Workstation* therefore allowing the performance mode *The Manual Input Sessions* to exist and be utilized on stage as a performable instrument by themselves and others.

The installation is easy to use and quick to learn and it functions in three unique ways that allow for different parameters of the installation's versions to be explored by the user. Could this installation be considered a musical instrument? Yes, but it falls within the category of electronic instruments. As explained in Chapter Two, electronic instruments are dependant on the type of oscillator being employed, on the waveform generated by the oscillator and/or on the relationship between the signal frequency generated and the sound heard (Davies 1). The Theremin is suggestive of this type of instrument since the instrument does not require any physical contact from the player and the sound is immediately sent to an amplifier and heard through a loudspeaker. *The Manual Input Workstation* too does not require any physical contact from its user as its means of engagement and its sonic component is also sent to an amplifier and heard through a loudspeaker, hence I deduce that *The Manual Input Workstation* can be categorized as belonging to the new generation of electronic instruments.

As mentioned earlier, this installation can also be utilized during a performance. The *Manual Input Sessions* is the performance aspect whereby Levin and Liebermann set up the installation and utilize it specifically as an instrument in which to create sounds and musical motifs. From a performance perspective, this installation becomes a new instrument that can be performed live in front of an audience, thus making it resemble a musical instrument that can be mastered.

Model Hat Digiphony

I, the author of this research report, designed and developed this case study, known as *Model Hat Digiphony (2012).* This work is over a year old and I decided to reassess the work from a more reflective viewpoint in comparison to the other two primary case studies; however, this is by no means a declaration on my part that the works are comparable in their research and development. All documentation and exhibition video recordings reside with me. The development and progress for this work can be found online at the following url: http://wiki.digitalarts.wits.ac.za/index.php/Tina_Caldis#MIDYEAR_EXAM_INSTALLATION_PROJECT. I describe this case study as an interactive installation whereby colour (RGB) data values are sonified through interaction with objects guided by physical movement (Caldis 10). I provide a full description of the work while considering the installation in terms of to the dynamic model structure of a model-based sonification. The layout of this interactive installation can be viewed in Figure 10.1 below.

Figure 10.1: Layout of *Model Hat Digiphony*

A 3x3 metre area was outlined on a blackened floor. The speakers and computer interface are hidden using black sheets to create a castle-like structure in front of the delineated area. Just behind the structure is a projected image on a vertical wall showing a bird's-eye-view of the outlined area. The projection of this area has a 16-block (4 by 4) grid superimposed over it. Hanging on the right-hand side of the outlined area are rectangular-shaped hats. An A2-sized (approximate size) painter's canvas board has been attached to a number of hard hats. The canvas boards have been painted red, green and blue and match the colour of the hard-hat to which they have been attached (Caldis 10). So, how does this installation work? I provide as objective a descriptive analysis as possible focussing on the piece's components with regard to the key aspects that have been addressed in the two primary case studies described above.

The white outlined area as seen in Figure 10.1 is referred to as the 'interactive space' where all the physical interaction with the installation takes place. The canvas hats are the 'interfacing objects' utilized by the user in order to present the required colour information to the sensor through which the computer executes the work, thus allowing for interaction with the installation. The floor of the interactive space is completely silent until the sensor captures colour information and this is known as the *Initial State* of the installation, as suggested by Hermann et al. in *The Sonification Handbook* on Model-based sonification. I will continue to describe this work within the confines of a model-based sonification as done with the previous two case studies. The user is required to choose the interface object colour of their liking, place it on their head and walk into the interactive space. This action begins the *Excitation* state of the installation as the interactive space now generates an instrumental sound due to the colour information observed by the sensor and sent to the computer. This information is then translated into auditory information and displayed through an audio interface or loudspeaker. The instrumental sound heard is a digital representation of a single musical instrument. If the sensor observes more colour information, then another musical instrument will be heard. The more colour information picked up by the sensor, the more instruments will play to form a musical symphony. The instruments for this work were chosen from a small orchestral setup which includes the violin, viola, cello, bassoon, xylophone, trombone, trumpet and flute, among others.

The *Model dynamics* of the installation recognises the colour of the hat and translates it into an instrumental sound. Hence this colour data is being sonified in a similar manner to how Earcons are sonified, as described in Chapter One. Only the interfacing objects affect the excitation of the installation. This is because the sensor must pick up a large quantity of colour within a specific quadrant, otherwise no sound will be heard. The human body is the medium with which to shift the interface object into the interactive space and bring about the interaction. See Figure 10.2 showing multiple users within the interactive space wearing the interfacing objects.

Figure 10.2: Multiple users wearing hats in the interactive space

The different colours represent different sections of an orchestra. The red objects represent the high frequency instruments such as the flute, oboe, violin and viola. The green objects represent the mid-range frequency instruments and some rhythmical instruments such as the cello, marimba, and xylophone. The blue objects represent the low-frequency instruments such as the bassoon, double bass, tuba and trombones (Caldis 10). However, these relationships between the instruments and the colours are indirect and must be learnt by the user.

The *Listener characteristics* of this model-based sonification are the sounds perceived by the user as they locate and orientate themselves within the interactive space. Analytical listening allows the user to identify the instruments heard. If the user interacts with the work alone, moves around the interactive space and experiments with the different coloured objects, he/she can identify the specific colour-data to instrument relationships. As the relationship between the auditory response and colour data is indirect, it would be easier if the user were placed alone within the interactive space in order to learn what sounds are emitted based on their position in a specific quadrant. The greater the number of users within the interactive space, the less obvious these relationships are, but new aspects unfold. As more users begin to enter the interactive space, more instrumental sounds are added to the sonic display.

The intention behind the design of this interaction was to create a musical activity between people and instruments. Through further analytical listening with multiple users, the changes in the melodic and rhythmic lines of multiple instruments can be noticed. The increase in instrumentation should cause greater melodic and rhythmic complexity (Caldis 10). However, there are some major shortcomings in this musical activity. The pre-recorded sound files do not allow for any manipulation of the melodies or rhythmical content; the sound is either 'fading in' or 'fading out', and no other musically specific parameters such as pitch, timbre, or rhythm can be altered by the user/s. In fact, the interaction with the sound is quite limited compared to the two primary case studies. The interactivity with this installation provides non-linear interaction but it does not provide enough changing outcomes; hence the auditory feedback can become mundane.

Besides the audible sound, the users are able to navigate within the interactive space by viewing a projection of a 16-block grid including the topside of the user's hats on the vertical wall laid out in front of them as seen in Figure 10.3 below.

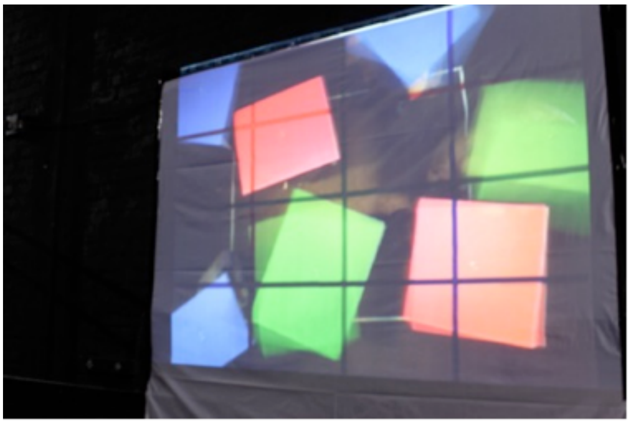

Figure 10.3: Visual Projection

I designed this visual component because the auditory feedback was not effective enough in demonstrating the colour information in relation to the type of instrument that was heard. If a user is within the interactive space, they can better orientate themselves according to the given visual and auditory information. Having many users wearing different coloured hats within the interactive space produces a much more colourful visual representation; however, the navigation and movement of each individual person does become restricted by overcrowding in the space, as can be seen in Figure 10.4 below. This was not the intention for the space, but rather a by-product that was miscalculated from a design perspective.

Figure 10.4: Interaction, Projection and Users

When reflecting on the multi-modality of this installation, it is clear that the physical object for the interaction mode is required as an input, while the auditory and visual modes produce the output. If the user analytically listens to the auditory response, this information can be utilized to guide the physical input and create a closed loop of continuous interaction. This work however is unresolved and even though it contains multiple modes, they have not been incorporated into the work as effectively as possible. I would consider *Model Hat*

Digiphony a first attempt towards becoming a multi-modal interactive installation, but it is still far from fully realizing this form.

With regards to the interaction design, I discuss two of the approaches: an activity-centred approach and a user-centred approach. As the creator of this work, I initially viewed this as extremely user-specific with the goal being that the users would be able to create their own unique musical symphony. Due to varying factors, this approach however did not reflect the final results of a user-centred design. In hindsight, the interaction design of the programming did not follow a typical user-centred approach but rather an activity-centred approach. It became an activity for multiple users rather than a passage of self-discovery for one user. The actions of the users and their movements within the space are meant to direct the music. As an activity-based design, one could say that the interactive installation was successful, but as a user-centred design it has not been entirely successful. I believe it is possible to re-programme the software to enhance the auditory responses with a higher level of user interaction so that more musical parameters can be displayed in order for *Model Hat Digiphony* to react and allow for interactions similar to those of playing an acoustic musical instrument.

In relation to the two primary case studies, I cannot categorize *Model Hat Digiphony* as a musical instrument. While it is worthwhile investigating how this can be achieved as the installation already poses some of the attributes of musical instruments (for example, it utilizes multiple modes and its final output is auditory), but the engagement and interaction with the installation need attention. At this stage this installation resembles the beginnings of a newly invented instrument that requires more time and perhaps a few more years of development and refinement.

Conclusion

To close, I will attempt to provide a solution to the initial question of this research report and discuss whether it is significant to acknowledge multi-modal interactive installations as new kinds of instruments.

The subject matter and analysis of the case studies discussed in this research report have presented many interesting arguments for and against the suggestion that multi-modal interactive installations could be considered a new kind of instrument. The arguments that support this statement can be seen through the incorporation of musical parameters and the multi-modal interactive engagement as presented in the case studies. The arguments that suggest otherwise are presented when the relationship between the interaction and the auditory feedback is limited or unrelated. What follows are a number of strengths and weaknesses that I put forward as the final thoughts of this research report.

As this is a music and design investigation, I begin by returning to one of the aims of this research report which was to investigate the characteristics of interaction and interface design observed in acoustic musical instruments and compare them to those observed in multi-modal interactive installations in order to present a series of similarities and/or differences between the two. Through this investigation I have shown that even though multi-modal interactive installations exhibit design features similar to those of acoustic musical instruments, I can only assume that these digital artworks are only considered instruments if the artist intended the design of his/her installation to take a musical path. It can be observed in *Firewall* that the intention was for dancers to interact, i.e. perform with the installation. In *The Manual Input Workstation* a performance component was experienced by individual users as was the version known as *The Manual Input Sessions*, as this created direct musical relationships between the sonic and visual responses created by the performers. Lastly, in *Model Hat Digiphony* the intention was to create a space for musical and creative performance with objects.

The players of acoustic musical instruments have all been subject to a performance module with their instrument at some point in their training. The virtuosic performance of acoustic musical instruments usually occurs after much time and practice; however, the novice can also experience this element. Often with multi-modal interactive installations the first performance with the installation is a learning curve until the user discovers how to best manipulate the interactive elements of the installation to suit there style. The performance with a multi-modal interactive installation is quite different to that of an acoustic musical instrument because of the time it takes a user and/or performer to experience levels of virtuosity.

All three case studies presented aspects of user-centred design and activity-centred design that resulted in the users ability to feel in control of the task they were required to address within each installation. The findings of these case studies have demonstrated how some interactive installations can exhibit musical performance aspects as seen in *The Manual Input Workstation*. Some can manipulate the sound through the various musical parameters, such as the volume and speed control of *Firewall*; and in both primary case studies they have shifted the focus of the inner workings of the computer interface by providing a tool or object similar to that of an instrument with which the user can directly interact with the installation, even if that tool is simply the human hand. As long as there is a continuous energetic interaction between the user and the installation, it can be noted that the multi-modal interactive installation is successfully functioning in a similar manner to acoustic musical instruments. And this can be seen when users are constantly engaging physically and consistently testing the boundaries of their musical instruments and/or a multi-modal interactive installations.

The design model of Model-based sonification exemplifies a structure that these installations adhere to. The results of this model typify how players learning to play an acoustic musical instrument engage and also contain themselves in a closed and continuous loop of interaction. I would like to think that most multi-modal and sound-driven interactive installations follow the dynamic system of Model-based Sonification because it has been developed based on the idea of interaction with objects resulting in real-world acoustics. Even though these real-world acoustics are represented through audio interfaces, the digital representation of these sounds have become so closely matched that the resultant audio is easily distinguishable to the user.

Many of the musical parameters, interactive elements and physical objects utilized by multi-modal interactive installations describe the capacity of acoustic musical instruments. I therefore consider multi-modal interactive installations to be a modern day extension of acoustic musical instruments with only one reservation in mind, the production of sound. As mentioned, the physical material is responsible for the natural resonance of an acoustic musical instrument sound production, whereas in a multi-modal interactive installation the sound production is only a digital representation of acoustic sound played through an audio interface. So how are multi-modal interactive installations and acoustic musical instruments sonically connected? I believe it is the element of interaction with sound that connects these two.

The physical interaction with the installation and the output of its sound response must be directly related to one another. The sonifications of multi-modal interactive installations are based on an experience a user has when interacting with objects in their environment and receiving a related auditory response. The same can be said for acoustic musical instruments, with the only exception being that the sound is not electronic. Even though the sonic representations of multi-modal interactive installations may not be acoustic, they have begun to resemble and operate in a similar manner to acoustic musical instruments. This has been demonstrated by the case studies as some of the installations possess similar interactive qualities of the instruments from categories such as the membranophones and electrophones.

The research revolving around data sonification in Chapter One outlined the different techniques according to which sound is being analysed and utilized as a tool for data analysis. Chapter One has shown that through years of research digital technologies have been developing in order to provide users with sounds that are directly related to their actions and movements, thus allowing the users to experience a natural interaction with the sound similar to that of real world acoustics. Even though the tools for sound production of an acoustic musical instrument and the tools for multi-modal interactive installation can be distinctly different, both can communicate with their users as long as experienced designers pursue consistent efforts to define and refine their tools to simulate real-world acoustics. Designers and artists should be encouraged to conceive of digital environments that constantly explore new technologies that depend on the interactive elements resulting in natural and understandable sounds that relate to real world acoustics and not its mathematical equations.

If the main purpose of a multi-modal interactive installation is to provide its user with sonic feedback through physical and visual interaction, then this type of installation may present a starting point for a new kind of instrument to be developed. Whether it can be directly associated with a particular category of musical instruments will be left up to the designers and artists of these works. Perhaps it is best to observe multi-modal interactive installations as a new category of musical instruments for digital artists to develop and expand upon. Only then, after years, decades or even centuries, can a category for these new entities be defined in the same manner that it took ages for musical instruments to be accurately categorized and catalogued. Interestingly enough, there are still contentious debates regarding the categorization of music instruments.

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