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The Augmented Tonoscope

Towards a Deeper Understanding of the Interplay between Sound and Image in Visual Music

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Abstract

This thesis presents the theoretical, technical and aesthetic concerns in realising a harmonic *complementarity* and more intimate perceptual connection between music and moving image. It explores the inspirations and various processes involved in creating a series of artistic works - attached as a portfolio and produced as the research. This includes the *Cymatic Adufe* (v1.1) - a sound-responsive, audiovisual installation; *Stravinsky Rose* (v2.0) - an audiovisual short in Dome format; and the live performance works of *Whitney Triptych* (v1.2), *Moiré Modes* (v1.1) and *Stravinsky Rose* (v3.0).

The thesis outlines an approach towards realising a deeper understanding of the interplay between sound and image in *Visual Music* - through applying: the *Differential Dynamics* of pioneering, computer-aided, experimental animator John Whitney Sr.; alternate musical tunings based on harmonic consonance and the Pythagorean laws of harmony; and sound's ability to induce physical form and flow via Cymatics - the study of wave phenomena and vibration - a term coined by Dr. Hans Jenny for his seminal research into these effects in the 1960s and 70s, using a device of his own design - the 'tonoscope'.

The thesis discusses the key method for this artistic investigation through the design, fabrication and crafting of a hybrid analogue/digital audiovisual instrument - a contemporary version of Jenny's sound visualisation tool - *The Augmented Tonoscope*. It details the developmental process which has realised a modular performance system integrating sound making, sound analysis, analogue outputs, virtual systems, musical interface and recording and sequencing.

Finally, the thesis details the impact of this system on creating audiovisualisation of a distinct quality through: a formalist, minimal, decluttered aesthetic; a direct, elemental and real-time correspondence between sound and image; a mirroring of music's innate movement and transition within the visual domain; and an underlying concord or harmony between music and moving image.

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Dedication

To my father, Brian Sykes, for teaching me that 'being' is as important as 'doing'.

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Preface

This thesis accompanies the hybrid DVD entitled *The Augmented Tonoscope*. It presents the theoretical, practical, technical and aesthetic perspectives which inspired and guided the research. Despite its analysis and reflection, it shouldn't just be read as a critical review of the works, but rather as a complementary volume that explores the underlying paradigms on which the research is based.

The thesis has two main foci - theory and practice - which it attempts to weave together as praxis - practice imbricated with theory (arranged so that they overlap like roof tiles). The earlier chapters establish a theoretical and practical basis for the study's central proposition - of a harmonic *complementarity* and more intimate perceptual connection between music and moving image. They provide the foundations for the project overall, including discussions of: employing cymatic effects as a means to create a visible or visual music; the influence of musical consonance via the Pythagorean laws of harmony on visual music praxis and the artistic lineage of the form - particularly the *Differential Dynamics* of pioneering, computer-aided animator, John Whitney Sr.; and insights from contemporary cognitive neuroscience, sensory-centric philosophy and audiovisual composition praxis that suggest alternate understandings of the senses, perception and audiovisual relationships. It also introduces the key method employed within the research - the design, fabrication and crafting of a hybrid analogue/digital audiovisual instrument, *The Augmented Tonoscope* - as a means to investigate and test this proposition. The later chapters discuss the practical strategy of realising the instrument as a modular performance system and of producing a series of artworks through this process. While this emphasises technical realisation, it also weaves in aesthetic concerns and a more detailed analysis of the associated artworks. Finally, it draws theory and practice together into a synthesis of the research findings revealing the fresh insights and new knowledge that contribute towards a deeper understanding of the interplay between sound and image within *Visual Music*.

Despite a shift in emphasis within chapters, overall the intent is to create an equilibrium between the theoretical, practical, technological and aesthetic aspects of the work. This is predicated by a concern with the formal structuring of audiovisualisation exploring a strong harmonic correlation and intimate perceptual connection between sound and image. Both the thesis and the works have been produced through a convergence of transdisciplinary theory and practice, as well as an understanding of the close relationship between form and content. Accordingly, the associated artworks should be viewed in their own right - but also as part of a larger argument towards the development of a distinct approach to audiovisual composition.

The thesis uses a standard format of description, context, technical realisation and critical reflection to introduce and discuss the associated artworks. Still, it is important that the reader has a familiarity with the works in order to fully appreciate the arguments within the written material. The accompanying hybrid DVD provides standard DVD format documentation of the associated artworks and supplemental video illustrating their development. However, high definition versions of these videos are also provided within a 'The Augmented Tonoscope DVD-ROM Contents' folder on the disk accessible through the 'Finder' of OS X. This folder also contains software sketches and patches which have been realised in creating the works. They are not intended to be working examples, rather they provide additional evidence, akin to a storyboard or musical score, of the development of the associated works. A disk image of the hybrid DVD is available for download (http://phd.lewissykes.info/hybridDVD/).

The thesis makes occasional reference to development by Ben Lycett. His six-month placement between April-September 2013 as the {CODE Creatives} Coder-in-Residence, part of an AHRC funded Skills Development programme run by MIRIAD, the Research Institute of the Manchester School of Art and the academic context for this research, provided additional practical support for the project. He helped implement already well conceived and detailed creative coding outputs - specifically in the modules of *virtual systems* and *sequencing and recording*. His input was practical rather than conceptual and realised under the direction of this research. Although this working relationship facilitated and has since developed into a collaborative artistic practice any outputs so produced have been clearly indicated as being beyond the scope of this Ph.D.

In an attempt to make the communication of the research integral to its methodology, this research has implemented the PARIP model (as discussed in Section 3.2 Research Frameworks) in a more contemporary fashion - using it as the framework for an 'open' research journal via a:

- WordPress blog (http://www.augmentedtonoscope.net)

With documentation including:

- a digital sketchbook (http://augmentedtonoscope.tumblr.com);
- online photography (https://www.flickr.com/photos/lewissykes/sets/72157627089569359/);
- and video (https://vimeo.com/album/1454262).

This online documentation serves as an 'evidence box' of materials which helps make the research context manifest.

Finally, the use of the term 'this research' or 'this study' within the thesis refers exclusively to *The Augmented Tonoscope*.

1. Introduction

1.1 Outline

This investigation introduces key questions and concepts that lie at the heart of realising a more intimate perceptual connection and harmonic *complementarity* between music and moving image. This chapter doesn't aim to describe and explain each aspect in detail (these will be developed and expanded upon in later chapters), rather it acts as a brief survey in order to realise a more explicit understanding of the underpinning praxis[1] and general concerns.

Yet this hasn't been a conventional process within the research. Considering it a transdisciplinary study has meant drawing from disparate disciplines. By selecting theories and practices which seemed to resonate especially with the study, the research has matured into something more akin to an emergent system - a network of inter-relationships, connections and congruences. So this chapter aims to outline the narrative of an argument which has evolved and crystallised over the course of the study and in response to several key questions:

- What might sound look like?
- Are there visual equivalences to the auditory intricacies of rhythm, melody and harmony?
- Is it possible to characterise a visual music that is as subtle, supple and dynamic as auditory music?
- Can a combination of sound and moving image create audiovisual work which is somehow more than the sum of its parts?
- By what means, methods and mechanisms might this be realised?

Questions such as these have occupied the minds of artists, philosophers and art historians for centuries. Accordingly, they informed the premise on which this Practice as Research project is founded. That building a new, hybrid analogue/digital audiovisual instrument, *The Augmented Tonoscope*, would be an effective method for investigating this terrain; and that the slow, step-by-step, back-to-basics approach required by this strategy would facilitate looking deeper into the simple interplay and elemental relationships between sound and image - to what might be understood as essential building blocks of a visual music.

So this chapter:

- overviews the project in Section 1.2 A Personal Research Statement;
- establishes an artistic context for this work within *Visual Music*;
- introduces Cymatics - the study of modal wave phenomena and especially visible stationary wave patterns induced by sound;

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[1] Practice imbricated with theory - arranged so that they overlap like roof tiles.

- highlights artistic practice and research that explores Cymatics - particularly as a mechanism for generating a visual or visible music;
- summarises the Pythagorean laws of harmony and its implications;
- outlines an artistic lineage of visual art which applies these harmonic principles - through the legacy of pioneering, computer-aided, experimental animator, John Whitney Sr.;
- explores movement as a vital intermediary between sound and image - informed through research into musical gesture;
- defines a more intimate connection between vision and audition - through the innate perceptual effects of multi-sensory integration;
- introduces perspectives on the mutual relationship between sound and image in audiovisual perception - through approaches to audiovisual composition;
- and summarises how fresh insight and new understanding has informed this research.

1.2 A Personal Research Statement

Having both an artistic bent and an aptitude for science, led to an engagement in that area of transdisciplinary activity commonly termed Sci-Art where these practices intersect and interact. Especially an interest in exploring and revealing the patterns that surround us - those underlying, nonexplicit, innate motifs that underpin the natural world but are frequently hidden from our senses. So this research involves a close examination of a natural phenomenon - stationary waves. When physical matter is vibrated with sound it adopts geometric formations that are an analog of sound in visual form. While these effects have been noted for centuries they are best described through Cymatics (from the Greek: κῦμα "wave") - the study of wave phenomena and vibration. Dr. Hans Jenny (2001) coined this term for his seminal research in this area in the 1960s and 70s, using a device of his own design - the 'tonoscope'. So a key method in the research has been an attempt to design, fabricate and craft a contemporary version of Jenny's sound visualisation tool - a hybrid analogue/digital audiovisual instrument, *The Augmented Tonoscope*.

The artistic outputs of this research - sound responsive and interactive gallery installations, real-time visualisations of musical performances, short audiovisual films and live audiovisual performances - all attempt to show a deeper connection between what is heard and what is seen by making the audible visible. In fact the practice has a deeper interest in this approach of audiovisualisation than the inverse process of sonification - of making the visible audible. While a primary focus is on sound as medium, the aim is to create 'universal artwork' in the tradition of Trahndorff and Wagner's "Gesamtkunstwerk" (Moss, 2013). Yet since music is essentially an abstract art-form (Moritz, 1996:224) the process is relatively unconcerned with the literal depiction of objects from the real world - and so

creative outputs are typically abstract. (Or perhaps more accurately, even though the work reveals, depicts and is representational of natural phenomenon such as stationary wave patterns, since these are usually hidden from sight and so are unfamiliar to the viewer's eye, they may as well be considered abstract.)

The research has been leading towards fundamentals - to a reductionist, back-to-basics approach to exploring the real-time, elemental and harmonic correspondence between sound and image. The techniques of artistic media have been used to try and capture the essence of the audiovisual contract - its inner nature, its 'significant form'. The work has no subject per se, the focus is on the aesthetic experience of compositional elements - with a preference for pure tones and solo instrumentation, a minimalist greyscale palette and a Euclidian geometry of line and pattern. The artistic value of the work is determined by its form - the way it is made, its purely sonic and visual aspects and its medium. So the artworks produced, as described above, are essentially formalist in nature[2].

The study has pursued an interest in sensory multimodality and in creating artistic experiences that engage with more than one sense simultaneously - although the current emphasis is on audition and vision. Reflecting on the oscillatory and periodic nature of the vibrations that generate sound suggested that a search for similar qualities in the visual domain might create an amalgam of the audio and visual where there is a more literal harmony between what is heard and seen. So the work is predominantly concerned with the phenomenal - that which can be experienced through the senses - rather with the noumenal - that which resides in the imagination and 'inner visions'[3]. In fact the research argues for an aesthetics of vibration, a perceptual blending of the senses and a harmonic *complementarity* between sound and moving image.

The study responds to a fascination with how the interplay between sound and moving image might affect us perceptually. So with an artistic intent, it explores aspects of sensory-integration - the 'blurring' of the senses where each impacts upon the others to create a combined perceptual whole. While referencing aspects of Op art, also known as optical art, there's no overt attempt to create perceptual illusion though the work. The emphasis is on looking for something more subtle and fleeting, trying to find those particular conditions under which an audiovisual percept - a combined sonic and visual object of perception - is not just seen and heard but is instead *seenheard*. In this way the research is focused on the perceptual as opposed to the cognitive - in how we perceive the world around us rather than how we interpret, contextualise and make sense of it.

2 At least in an early 20th century definition of formalism proposed by the Post-impressionist painter Maurice Denis in his 1890 article *Definition of Neo-Traditionism* and by the Bloomsbury writer Clive Bell in his 1928 book, *Art*.

3 In the images, colours, shapes and textures of the 'mind's eye' and of the imagination; day-dreams, dreams and nightmares; delirium and hallucination.

The research attempts to apply an understanding of the philosophical nature of sonic objects - as individuals located in space but with uniquely auditory characteristics that change over time (O'Callaghan, 2013) - to look deeper into sound's relationship with image. Particularly an interest in how sound can interplay with the qualities of visual objects (and moving image in particular) with their characteristics of or relating to space. Key to developing thinking here has been the concept of the 'musical gesture' (Godøy & Leman, 2010) - of a shape created over time through music - either through the physical act of playing an instrument, or in the listener's imagination through the structure of the music, or implied through a musical metaphor. Shifting to this perspective has realised a more significant interest in movement, dynamic and transition than form, pattern and resolution - in short with the temporal rather than with the spatial.

Hans Jenny favoured practical experimentation over development of a mathematical model - an approach particularly relevant for a Practice as Research project. Yet this research is actually more interested than Jenny in the scientific nature of stationary waves. So it draws on derivations and formulas from physics and mathematics along with key aspects of Music Theory and particularly the Pythagorean laws of harmony, to code virtual models of a variety of oscillating and harmonic systems. The real-time computer animations generated from these models are used to visualise music. The intent was to superimpose these animations on top of the cymatic patterns generated from the analogue tonoscope device that is part of the instrument, allowing the physical patterns of 'visible' sound that appear on the surface of its vibrating drum skin diaphragm to be augmented with forms based on similar physical laws, but which could be extrapolated and manipulated in ways that the analogue never could.

Searching for prior attempts to find a visual equivalence to auditory intricacies has revealed the artistic lineage of this research. It is not surprising then, that its main influences lie with creators of early abstract film and somewhat later computer-aided abstract animation. Of particular interest is Oskar Fischinger's synthetic sound production experiments in the 1920s and 30s (Fischinger, 1932 & Moritz, 1976). Using a technique of 'direct sound', of printing regularly repeating geometric patterns directly into the optical soundtrack of the film, Fischinger used the photoreceptor of the projector to turn visual forms directly into music and so explored a direct visual correspondence to sound. From the 1940s onwards, John Whitney Sr. "created a series of remarkable 16mm films of abstract animation that used [customised analogue computation devices and] early computers to create a harmony - not of colour, space, or musical intervals - but of motion" (Alves, 2005:46). He championed an approach in which animation wasn't a direct representation of music, but instead expressed a "complementarity" - a visual equivalence to the attractive and repulsive forces of consonant/dissonant patterns found within music (Whitney, 1980). Exploring Whitney's legacy has become central to this research.

Finally, in building an instrument to visualise sound, this research is following in a rich tradition of instrument making (Hankins & Silverman, 1995) whose primary intent was to extend our senses to be able to consider that of which we were previously unaware - to 'reveal the hidden'. This process is reflected in the praxis by attempting to be more systematic about searching for the 'unfound' through artistic process. Trying to find that small, (possibly) unnoticed detail or 'never quite configured in this particular way before' set of circumstances that open up new lines of enquiry and may lead to fresh thinking. Courting serendipity - trying to master "the art of making the unsought finding" (Van Andel, 1994:abstract) - not just in the hope of the 'happy accident' but to be open to the latent potentialities within the practice's creative code and DIY electronic devices.

1.3 Visual Music

An obvious starting point is to define a clear and apposite context for this research - to describe and clarify its artistic terrain and locate it within a lineage of practice. First coined by the art critic Roger Fry when he wrote about the work of Pablo Picasso in 1912 (he re-used the term a year later to describe the works of both Pablo Picasso & Vasilly Kadinsky) (Rekveld, 2013:online), *Visual Music* now commonly describes that area of artistic practice concerned with the interplay between sound and image. The International Call for the Understanding Visual Music 2013 Colloquium offers an up-to-date definition[4]:

> The term "Visual Music" is a loose term that describes a wide array of creative approaches to working with sound and image. It's generally used in a field of art where the intimate relationship between sound and image is combined through a diversity of creative approaches typical of the electronic arts. It may refer to "visualized music" in which the visual aspect follows the sound's amplitude, spectrum, pitch, or rhythm, often in the form of light shows or computer animation. It may also refer to "image sonification" in which the audio is drawn - in some way - from the image. Sometimes visual music describes a non-hierarchical correlation between sound and image, in which both are generated from the same algorithmic process, while in other instances, they are layered without hierarchy or correlation altogether. Sound and image may be presented live, on a fixed support or as part of an interactive multimedia installation.

So *Visual Music* can be understood as a hybrid art form which explores blending (and lending) the characteristic qualities of the aural and the visual within an audiovisual contract - typically the abstraction, temporality and tonal harmony present within music, with the representation, spatialisation and colour harmony present within visual art. As John Whitney Sr. succinctly summarises, "of an art that should look like music sounds" (Whitney, 1980:front flap dust jacket).

[4] There are numerous alternative definitions - such as that by Keefer and Ox (2008) of the Center for Visual Music included in Appendix 7 - Glossary of Terms.

Despite the contemporary reference to 'the electronic arts' in the definition above, there is a long and rich tradition of attempts to realise a visual equivalence to music, as film historian William Moritz notes, "For centuries artists and philosophers theorized that there should be a visual art form as subtle, supple, and dynamic as auditory music—an abstract art form, since auditory music is basically an art of abstract sounds" (Moritz, 1996:224). Moritz acknowledges the lineage of the form beginning with Louis-Bertrand Castel's 'invention' of an *Ocular Harpsichord* in 1734, in which he proposed taking an ordinary harpsichord, but changing the mechanism so that "the pressing of the keys would bring out the colours with their combinations and their chords" (Franssen, 1991:21). Whether Castel actually built his audiovisual instrument is questionable, but research suggests that the idea occupied the minds of many more people than just its inventor (Franssen, 1991). While Castel admitted that the analogy between tones and colours was not perfect, his unique insight for his day was in reimagining how the differing qualities of sound and light might be combined - it was impossible at that time to make tones permanent, but colours could be made transient. Castel's influence is formative in the many mechanical light-projection inventions that followed.

Betancourt (2006) contends that the implication of Moritz' history of *Visual Music* is that a desire to create a synaesthetic art motivated the invention of visual music instruments and led not just to its dominance within abstract film but also to the painterly 'synaesthetic abstraction' of the early 20th century. Yet despite this rich history of 'colour organs' as they've come to be collectively known, Moritz goes on to argue, "... none could capture the nuanced fluidity of auditory music, since light cannot be modulated as easily as 'air'. The best instrument for modulating light took the form of the motion picture projector" (Moritz, 1996:224). Here Moritz could be making a significantly different point to Betancourt - that *Visual Music* only became truly technically realisable with the birth of the motion picture projector in the mid-1890s.

Supporting this perspective, the *See This Sound* (2009) exhibition and its accompanying catalogue carefully traces the tradition of artists' fascination with the relationship between sound and image - but since the beginning of the 20th century. It accepts that there is a broader context of art that explores 'the aesthetic and theoretical relationships between music and painting, between colours and sounds from the 19th to the mid-20th century' but argues that there is an alternative and distinct artistic tradition of "acoustic and visual interplay as it has developed and been artistically analyzed and treated since the early 20th century" (Rollig, Daniels, Rainer & Ammer, 2009:12).

This subtle but significant shift in viewpoint - from a painterly tradition that attempts to represent and interpret the dynamic, temporal, emotional and communicative aspects of music though graphical structures, shapes, colours and textures - towards an artistic investigation, usually through technology, of the interplay between sound and image,

better reflects the nature of this research. Furthermore, Rollig & Daniels argue "the development of electronic and digital media has enabled a previously unimagined complexity in the coupling of images and sound" (Rollig, Daniels, Rainer & Ammer, 2009:13) suggesting an unprecedented potential to develop new work in this oeuvre.

So while this research is located within the broader context of *Visual Music* it has a clear focus in the interplay between sound and image, best contextualised within the contemporary art theory, research and curatorial agendas advocated and disseminated through *See This Sound: Promises in Sound and Vision* (2009).

1.4 Stationary Waves

This research has pursued a particularly direct and elemental interplay between sound and image through the naturally occurring phenomenon of stationary waves - essentially an analog of sound in visual form.

Yet the notion of a stationary wave seems an anathema. How can a wave possibly be stationary? It is simply out of character and against its nature. Still stationary waves do exist and what's more they surround us - in the air that fills our architectural spaces and on the surfaces of the materials and objects that inhabit them. Mostly hidden from sight, they're occasionally noticeable in the most mundane of situations - such as the ridges that appear on the surface of a cup of tea as a bus or lorry rumbles by. Sometimes we experience them through our other senses: the loud and quiet zones we encounter while moving about the room of a nightclub; the patterns of vibrations of a window pane or a table top we feel through our finger tips and skin when a neighbour has the volume of their sound system or TV cranked up.

The appeal of stationary waves is rooted in a demonstration of the extraordinary within the everyday, of a naturally occurring phenomenon which seems to defy the natural order and which, despite scientific explanation, retains a fascination and invokes a sense of awe and wonder in the world around us. Contemplating stationary waves - the apparent contradiction contained within the term itself and the simultaneous stasis and dynamic implied - has thought provoking ramifications and invokes evocative poetic imagery (see Appendix 8 - Stationary Wave). As such, this research considers them an ideal subject for artistic investigation - to explore their manifestation, behaviour and application not just from a scientific perspective, but with an artistic sensibility and intent. So through close observation, this project has attempted to discover how stationary waves can reveal fresh insights and develop new knowledge about the aesthetic nature of sound and vibration.

A cursory search for stationary waves (also known as standing waves) - "a wave that remains in a constant position" (Giancoli, 2012:online) - results in a plethora of Physics 101 descriptions and illustrations of the effect. It is not surprising, since

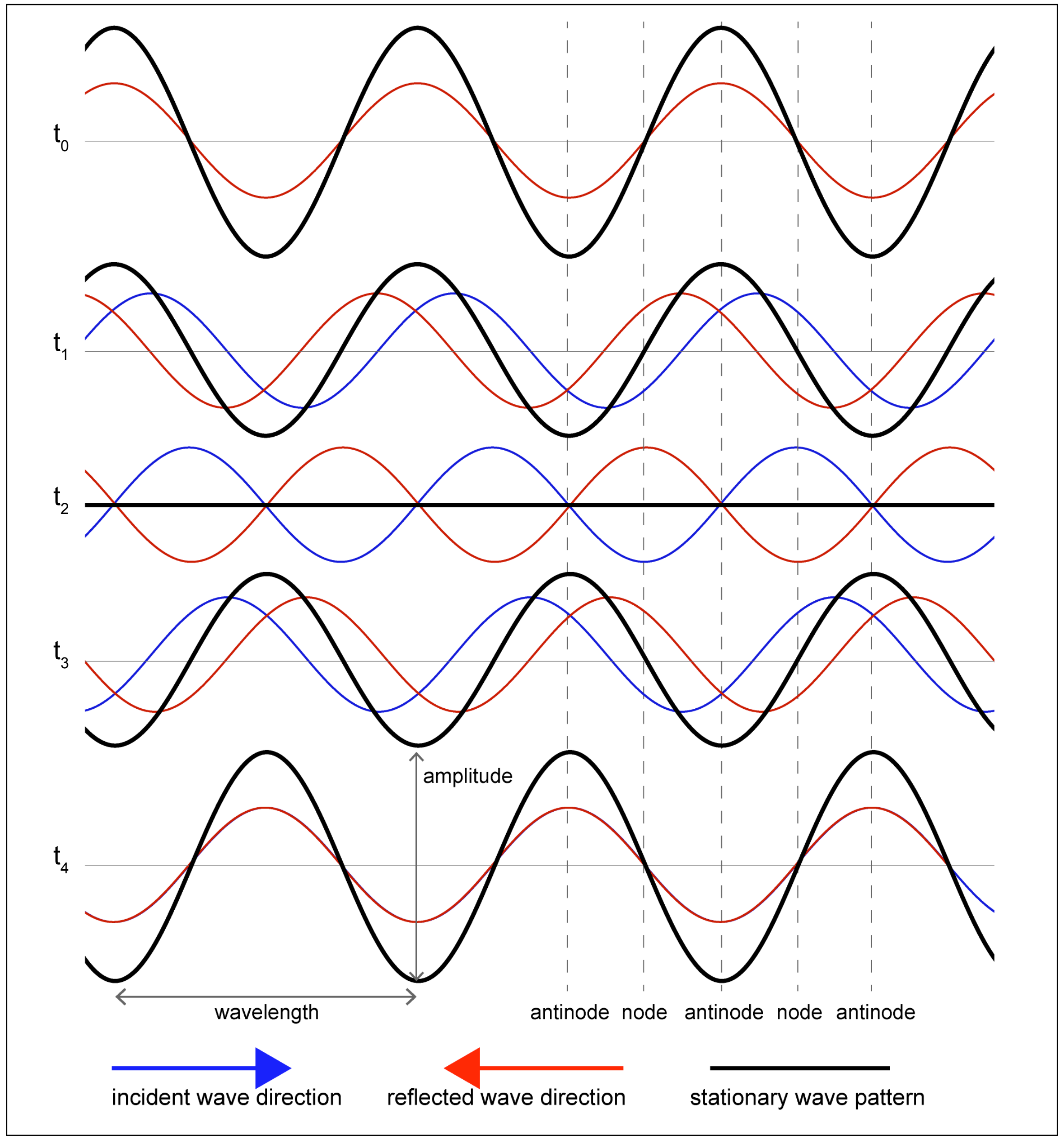


Figure 1 - Generating stationary wave patterns (Sykes, 2014)

The incident and reflected waves each progress 1/8 of a wavelength in their respective directions at times t_0 to t_4 illustrating half of the cycle of the resulting stationary wave pattern.

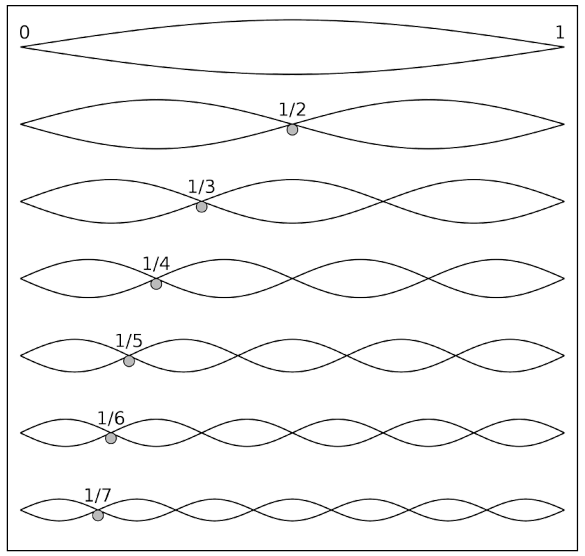


Figure 2 - Illustration of harmonic overtones

"... on the wave set up along a string when it is held steady in certain places, as when a guitar string is plucked while lightly held exactly half way along its length" (Richards, 2008).

standing waves in a stationary medium such as air, water or a stretched string, are a well known natural occurrence; relatively straightforward to describe through physical laws and mathematical formula; and with some very practical applications - such as the behaviour of musical string and wind instruments.

By means of illustration (Figure 1), consider waves on the surface of water in a wave tank[5]. A wave travelling in one direction will be reflected back when it reaches the boundary[6] of the end of the tank. This results in two waves, crucially of the same wavelength (and so frequency) and amplitude, but travelling in opposite directions. These then interfere with each other, superimposing themselves through an addition and subtraction of their relative amplitudes along the length of the tank, to create a stationary wave that is a product of both. This standing wave - an interference pattern rather a wave per se - has the same wavelength and double the amplitude of the incident and reflected waves - but since these are travelling at the same speed in opposite directions, effectively no movement of its own. It exhibits distinct nodes, points of zero vibration, at those positions along the tank where the relative amplitudes of the incident and reflected waves combine to cancel each other out - and antinodes, points of maximum vibration, where the relative amplitude of the incident and reflected waves combine to reinforce each other.

This effect is foundational to the harmonics of stringed musical instruments - a string fixed at each end - where the overtones or partials of the fundamental (or first harmonic) of the stretched string are also present and contribute to the overall timbre of the instrument (Figure 2). The nodes of these overtones are equally spaced according to small whole number multiples of the length of the string e.g. 1/2, 1/3 & 2/3, 1/4 & 2/4 & 3/4 etc. Accordingly, the frequencies of these harmonics are determined by the same, albeit inverted, small whole number denominator multiples of the fundamental frequency of the string e.g. if the string is tautened to a fundamental frequency of A4, 440 Hz, then the second harmonic with a node at 1/2 of its length will be 440x2 = 880 Hz, the third harmonic with nodes at 1/3 & 2/3 of its length will be at 440x3 = 1320 Hz etc. These are the harmonic vibrational states of a string - described through the Pythagorean laws of harmony.

Yet standing waves in a stationary medium also occur in higher dimensions - albeit with a proportionate increase in complexity. For example the two dimensional steady vibrational states of the surface of a bowl of water, or a thin metal plate, or the skin of a drum; as well as the three dimensional steady vibrational states of soap bubbles,

5 A laboratory setup for observing the behaviour of surface waves - typically a long rectangular box filled with liquid, usually water, left open or as an air-filled space on top. At one end of the tank an actuator generates waves; the other end usually has a wave-absorbing surface.

6 Boundary conditions are a prerequisite for generating the interference patterns of stationary waves. There has to be at least a single fixed point or edge in order to reflect a wave and so create the circumstances where an incident and reflected wave can interfere with each other.

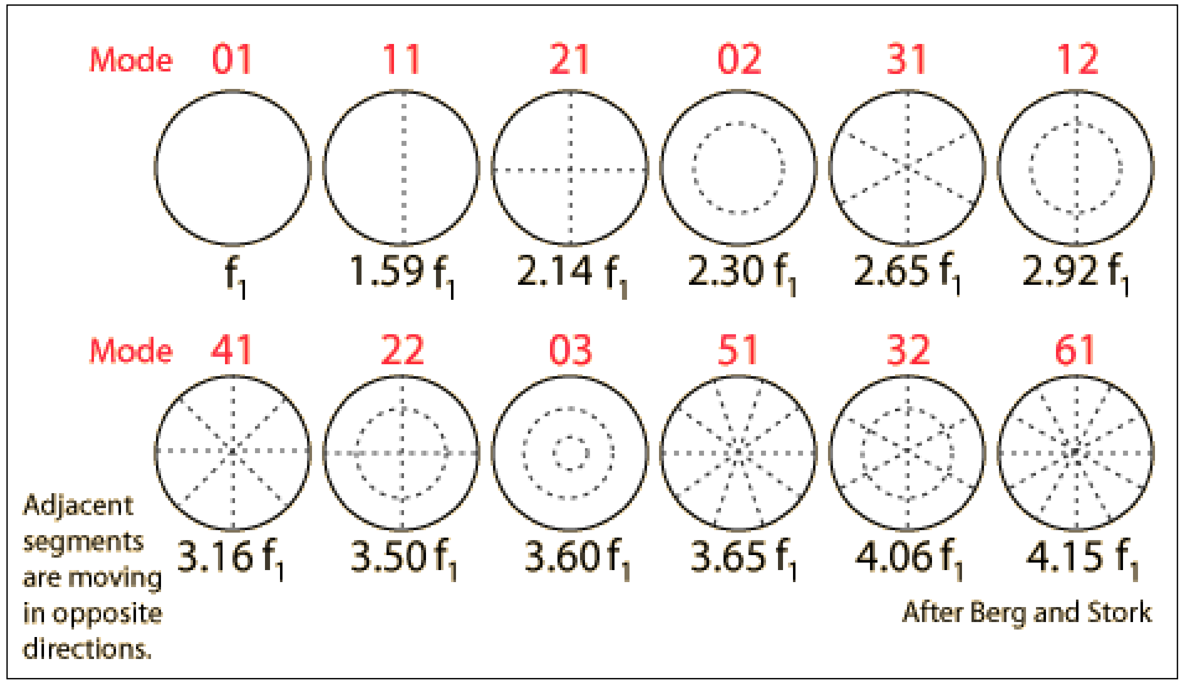


Figure 3 - Modes of vibration of a circular membrane, showing nodal lines (Figure from Livelybrooks, Univ. of Oregon)

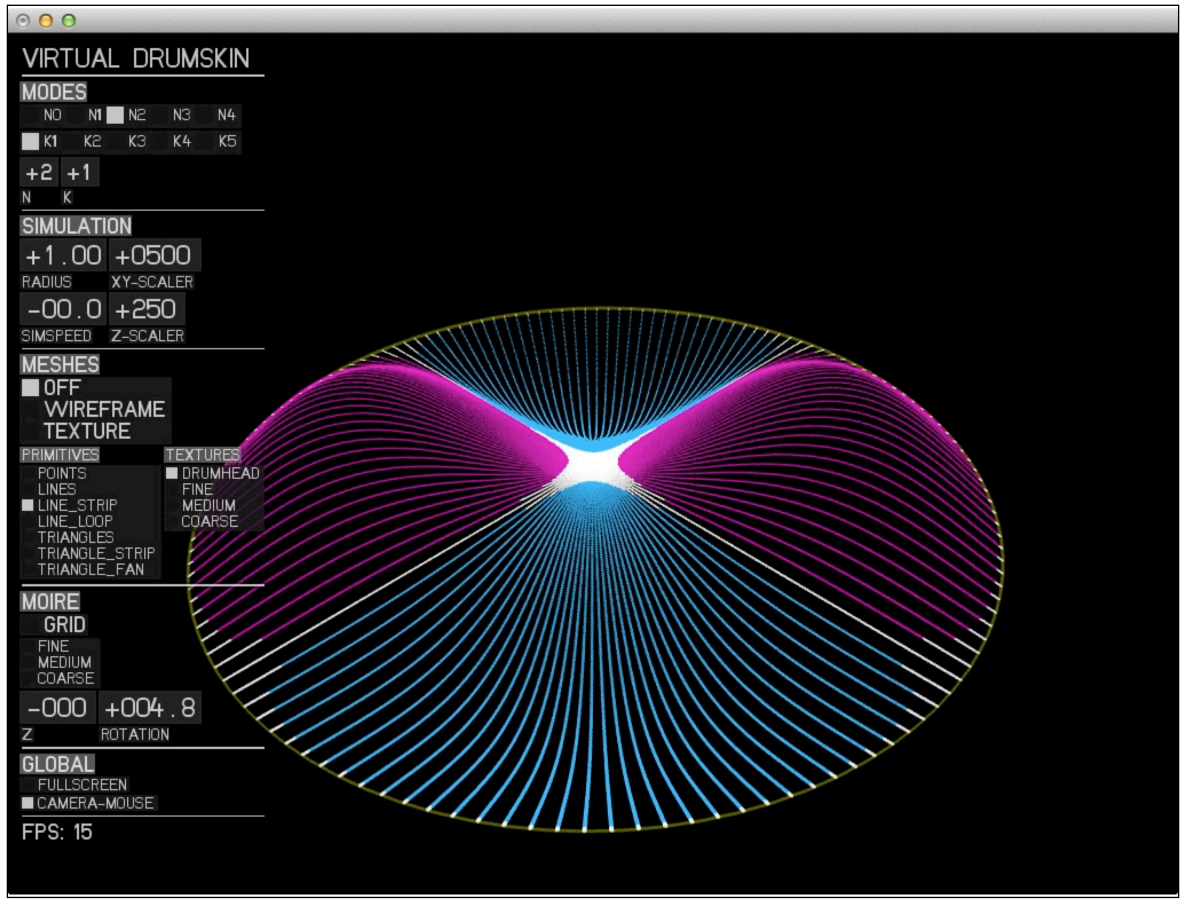


Figure 4 - The third mode (2,1) of a drum skin

Two diametric nodal lines and one radial nodal line (the drum boundary) - visualised through the *Virtual Drum Skin* model created in the open source C++ toolkit for creative coding, openFrameworks.

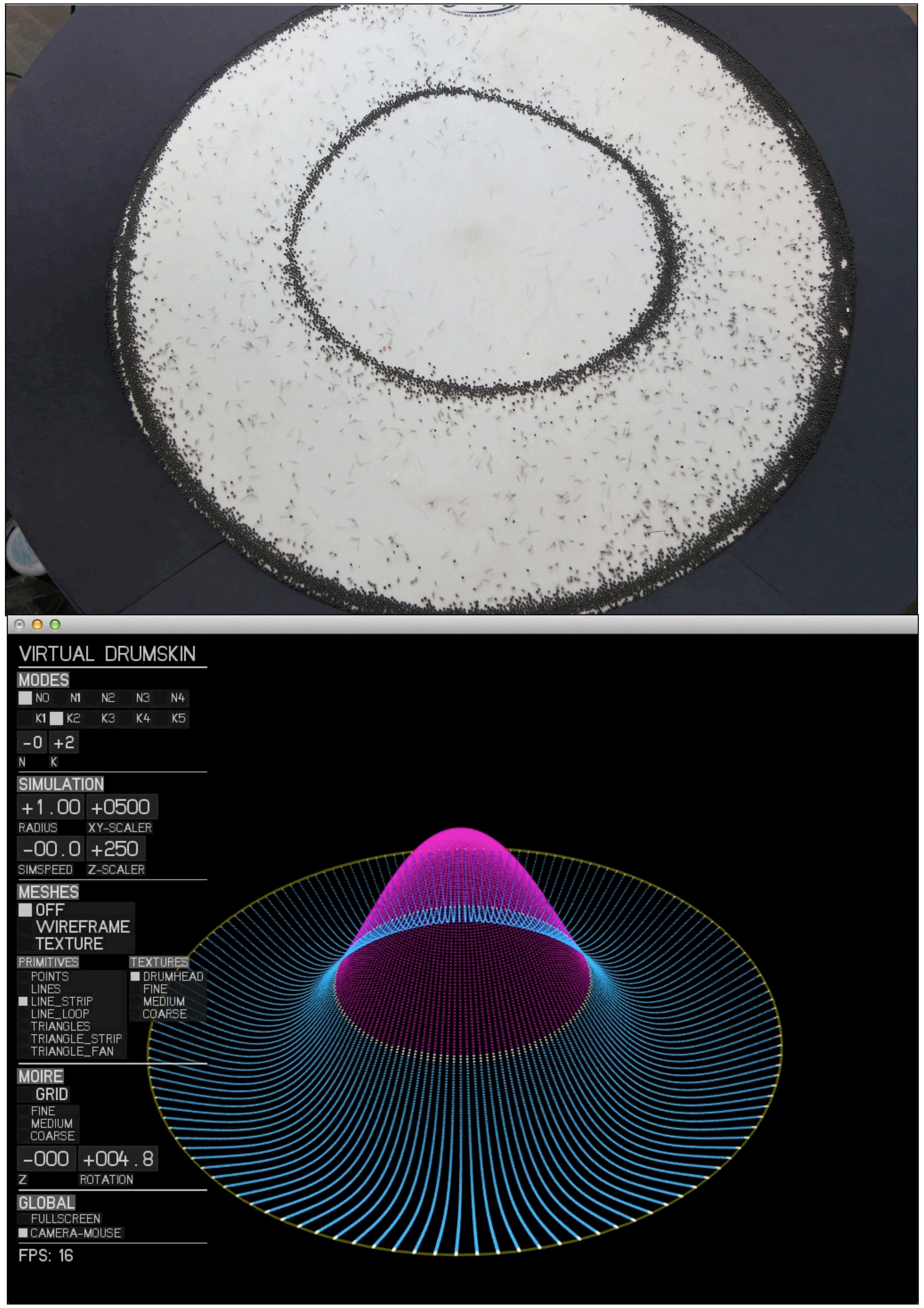
fixed volumes of air and even the electron within a hydrogen atom. This research has investigated stationary waves patterns induced by sound on the skin of a drum - where the nodal points along the one dimensional string are extended into nodal lines on the two dimensional circular drum head. In this case there are two types - diametric nodal lines which cross and divide the skin and radial nodal lines which mirror the circular boundary of the drum. Analogous to the harmonics of a one-dimensional string, the circular drum skin also exhibits a series of steady vibrational states (Figures 3 & 4) featuring various combinations of diametric and radial nodal lines at set theoretical ratios of the fundamental f_1 (Berg & Stork, 2004) and where adjacent sections are moving in opposite directions.

1.5 Cymatics

So utilising these principles, *The Augmented Tonoscope* makes sound visible using little more than a speaker, an adapted drum and a powder of fine glass beads. Unlike much sonic work which aims to minimise the sympathetic vibrations of objects within the sound field seeing these as 'unwanted', the device actively employs the sound waves from the speaker to reciprocally vibrate its drum skin diaphragm. Sprinkling powder on the surface of the skin helps discern the nature of these vibrations - as the beads try to avoid those areas that are vibrating most (the antinodes) and collect in those areas that are vibrating least (the nodes) - like water always seeking the lowest point it can find - the place of least energy. The research looks for those particular conditions - the type and tautness of the drum skin; the timbre, pitch and volume of the musical tone - that produce distinct patterns. These forms (Figures 5.1 & 5.2) are the result of stationery or standing waves - steady vibrational states in which the waves travelling out radially from the centre of the drum, interfere with those reflected back from its edge to create combined wave patterns that are in dynamic yet simultaneously stationary.

The study of steady vibrational states such as these, formally described as modal wave phenomena, has a long and rich history dating back to Leonardo Da Vinci and a significant body of empirical evidence, theory and practical application, most notably:

- Robert Hooke's observation in 1680 of nodal patterns associated with the modes of vibration of glass plates (Daintith & Gjertsen, 1999);
- Ernst Chladni's development in the 1780s of a technique of drawing a bow along the edge of a thin metal plate sprinkled with sand and his documentation of the patterns that emerged - from which he developed Chladni's Law, a simple algebraic relation for approximating the modal frequencies of the free oscillations of plates and other bodies (Chladni,1787);



Figures 5.1 & 5.2 - The fourth mode (0,2) of a drum skin

As realised at 153 Hz on the skin of a 16” floor tom, visualised using small decorative beads and through the *Virtual Drum Skin* model.

- John William Strutt a.k.a. Baron Rayleigh’s two-volume, major treatise on sound and vibration in the late 1870s, still considered a classic and including a chapter on the vibrations of plates (Strutt, 1945);
- and Margaret Watts-Hughes, inventor of the Eidophone in 1885, which she describes in an article about her work *“... the extreme sensitiveness of the eidophone as a test for musical sounds detecting and revealing to the eye ... what the ear fails to perceive”* (Watts-Hughes, 1891:39).

Absolutely central to any discussion on the study of modal wave phenomena is Dr. Hans Jenny - the Swiss medical doctor turned sonic researcher. His two volumes - *Cymatics: A Study of Wave Phenomena and Vibration Vol. 1* (1967) & *Vol. 2* (1972) - are commonly accepted as the defining works in the field. In fact, Cymatics is a term coined by Jenny himself - to kyma, the wave; ta kymatika, matters pertaining to waves, wave matters. His work has no prior or subsequent match in terms of a detailed empirical investigation into the effect and manifestations of sound and vibration on physical matter - of sound’s ability to induce form and flow. The phenomena he investigated, documented and contemplated therein has been a source of inspiration for many, including artists, ever since.

The body of research outlined above has inspired contemporary scientific research into Cymatics as a means to reveal a deeper understanding into areas such as acoustics and phonology - notably John Stuart Reed, coinventor of the patented Cymascope (a scientific instrument that makes sound visible) and arguably the current world leader in scientific Cymatic research into areas such as the interpretation of dolphin communication (Reed, 2008).

Yet Jenny had a more exploratory and less applied agenda. He studied visual forms of the human voice using a device of his own design - the ‘tonoscope’. This was little more than a tube with sand sprinkled on to a rubber membrane stretched over one end which he then sang down. Yet the direct and responsive link between sound and image he produced, revealed through *Cymatics - Bringing Matter To Life With Sound* (Jenny, 1986), a documentary film he made of his own research, is a source of inspiration. If Jenny could achieve such demonstrable effects through such simple means almost 50 years ago - what could be realised with the computational power, fabrication facilities and access to a global network of knowledge, approaches and techniques available today?

So an objective for the study has been to develop this line of research by exploring the aesthetics of cymatic patterns and forms. Can the inherent geometries within stationary wave patterns provide a meaningful basis for a visual music? Will augmenting these physical effects with virtual simulations realise a real time correlation between the visual and the musical?

1.6 Cymatic Art, Architecture & Music

Inspiration and insight has been gleaned from the processes and methods of a range of contemporary art practice exploring Cymatics, as well as open-source creative coding modelling its effects and manifestations. Yet despite acknowledging the numerous artists who employ Cymatics within their work, with only very few exceptions can their outputs can be described as instruments. One notable exception is Suguru Goto's current interactive sound installation, *Cymatics* - a contemporary work most akin to *The Augmented Tonoscope*. While it potentially replicates this research, there are marked differences as discussed in Chapter 2. Literature Review.

More significantly, Cymatics has inspired and informed comparable artistic research in the associated disciplines of architecture and musicology - specifically in the study of spatial form and harmonicism.

Benlloyd Goldstein's (2009) *Cymatica* architectural thesis investigation into the synthesis of spatial proportion and form generated from sound, formalises his approach "In Search of Cymatic Architecture". Goldstein's exploration of cymatic motion and use of code to realise images, animations and 3D printed cymatic forms presents an interesting crossover with this research.

However, John Telfer's (2010) study into *Cymatic Music*, *"*an audiovisual science and music project that investigates the possibilities of creating a system of visual, or rather visible music*"* (Telfer, 2010:online) is particularly relevant and provides much food for thought. He also asks if cymatic patterns can be interpreted musically:

> Does a particular sonic frequency correspond with a particular vibrational form and by extension, does the architecture of sound which we call harmony in any way correlate with the structural classification of cymatic forms? While we can certainly see what we hear, can a creative bridge be built between them through systematic concordance? (Telfer, 2010:online)

Telfer conducted a series of thorough, empirical experiments in which he observed and analysed the discreet, symmetrical forms produced by sound on the surface of a bowl of water. While his mapping of these symmetries to frequency hinted at a harmonicity - those frequencies which produced the steady vibrational states of patterns with the same multifold symmetries, adhered to some extent to the harmonic series - he could not explain how the different symmetries interconnected from a harmonic point of view. However, he also conducted experiments (following Hans Jenny's lead) into the behaviour of vibrating soap bubbles - and concluded that spheres do in fact vibrate harmonically. There is a harmonic correspondence between bubble diameter and the frequency of the tone which induces a given bubble symmetry - all vibrational states are clearly proportionally related.

Aspects of Telfer's theorising have also been influential. He argues that the 12-tone Equal Temperament or 12-ET musical tuning system which has dominated Western Music since the C18th - the twelve equal intervals of a keyboard octave embedded in the piano and fretted string instruments - obscures the fact that this system has harmonic inconsistencies. Accordingly, he suggests that a cymatic equivalence to musical harmony will be difficult to find in music based on the Equal Temperament.

This perspective opened the possibility of exploring alternative musical traditions, particularly those which use perfect intervals or Just Intonation - that is musical tunings underpinned by small whole number ratios as defined by the Pythagorean laws of harmony. Despite the contemporary dominance of the Equal Temperament within Western Music, there is still a rich history and tradition centred on Just Intonation - from the Pythagorean tuned music of ancient Greece; through plainsong - the body of chants used in the liturgies of the early Catholic Church; the subtle harmony through inference rather than full chordal structures conveyed through the counterpoint of the Baroque; to the likes of Harry Partch, an American, 20th century composer and instrument creator who explored micro-tonal composition developed from sophisticated Just Intonation scales. There's also several other non-Western musical traditions, such as South Asian art music and the Arabic Maqam scales, which while not wholly based on Just Intonation do rely heavily on perfect intervals within their organisation.

So a key issue for the research has been how the principles of Just Intonation might impact on *The Augmented Tonoscope*. How might it shape its development? What existing instruments will it be most akin to? Which musical traditions might best support the search for an equivalence between musical tone, analogue cymatic pattern and digital motion graphics?

1.7 The Pythagorean Laws of Harmony

The emerging centrality of the Pythagorean laws of harmony to this research, justifies an overview of its essentials through a reduction of select sources (Achilles, no date; Mathieu, 1997; Maor, 2007).

Pythagoras is commonly held to be the first individual to study the relationship between music and mathematics, though the principles were previously utilised by the Mesopotamians and Indians centuries earlier. He established that the perfect consonances of music were simple, whole-number ratios - octave (1:2), perfect fifth (2:3) and perfect fourth (3:4) - and that significant musical relationships, such as the tonal pitches of a given scale and the string lengths used to produce them, could be described mathematically. Maor concurs *"*Pythagoras concluded that numerical ratios rule the laws of musical harmony - and by extension the entire universe. It was to become an Idée fixe with the Pythagoreans and the cornerstone of their world picture" (Maor, 2007:17). Aristotle claimed that Pythagorean ideas exercised a marked influence on Plato - and so through him as a consequence, all of Western philosophy.

Harmony - derived from the Greek ἁρμονία (harmonía), meaning "joint, agreement, concord", from the verb ἁρμόζω (harmozo) "to fit together, to join" - is a central tenant in the Pythagorean view of the universe. The term was often used for the whole field of music, while "music" referred to the arts in general. Musical harmony is the use of simultaneous notes or chords, which permit harmoniousness (sounds that please), by conforming to certain preestablished compositional principles such as consonance. Harmony is often said to refer to the 'vertical' aspect of music, as distinguished from melodic line, or the 'horizontal' aspect.

Musical tunings based on Pythagorean perfect consonances, in which the frequencies of notes are related by ratios of small whole numbers, is known as pure intonation or Just Intonation (sometimes abbreviated as JI). Any interval tuned in this way is called a pure, perfect or just interval and the two notes in any perfect interval are members of the same harmonic series. Harmonic intervals come naturally to horns and vibrating strings. As such there are several conventionally used instruments which, while not associated specifically with Just Intonation, can handle it quite well, including the trombone and the violin family. A cappella groups that depend on close harmonies, such as barbershop quartets, usually use Just Intonation by design.

A basic system of Just Intonation is Pythagorean tuning, perhaps the first musical tuning system to be theorised in the West, in which all the notes within its twelve-tone scale can be found using the ratios 3:2 & 2:3, the intervals of the ascending and descending perfect fifth (the next simplest after the ratios 2:1 which produces ascending octaves and 1:2 which produces descending octaves). Pythagorean tuning may be regarded as a '3-limit' tuning system, because all the ratios used in its determination are obtained by using small whole numbers never greater than 3.

So starting from D (an example of D-based Pythagorean tuning), six other notes are produced by moving six times a ratio 3:2 up (an ascending fifth - i.e. an increase in frequency by a perfect fifth) and the remaining notes by moving six times a ratio 2:3 down (a descending fifth - i.e. a decrease in frequency by a perfect fifth), giving the note sequence:

A♭ - E♭ - B♭ - F - C - G - **D** - A - E - B - F♯ - C♯ - G♯

This succession of twelve 3:2 and 2:3 intervals - each seven chromatic notes apart - spans a wide range of frequencies and so these notes are then adjusted

back into a single or base octave range by applying multiples of the ascending or descending octave ratios 1:2 or 2:1. To produce a twelve tone scale, one of the enharmonic (equivalent but differently named) notes at each end of this sequence is arbitrarily discarded - usually the A♭. Yet this system of perfect fifths doesn't quite fit into an octave range, so there is a small difference in pitch between the A♭ and G♯, known as the Pythagorean comma - about a quarter of a modern semitone of 100 cents. This means that one of the fifths, the 'wolf fifth' (in D-based tuning specifically from G♯ to E♭) is badly out of tune.

So a drawback of Pythagorean tuning is that the wolf fifth in this scale is unusable (though overall the tuning system is manageable when the music isn't particularly harmonically challenging) which in turn leads to the more significant limitation - that it is not possible to change key without retuning the instrument. Attempts to overcome these inconsistencies and limitations led to a series of alternative tuning systems and ultimately to the adoption by Western Music in the 18th century of the 12-tone Equal Temperament - a system of tuning, in which the octave is divided into a series of 12 equal steps with identical frequency ratios between successive notes.

However, there have also been efforts to extend the basic system of Just Intonation in more sophisticated ways to create more flexible 12-tone and multi-tonal scales - including 5-limit, 7-limit, 17-limit - as well as specific JI tuning systems employed by the likes of Harry Partch - one of the first composers to work extensively and systematically with micro-tonal scales, writing much of his music for custom-made instruments that he built himself, tuned in 11-limit (43-tone) Just Intonation.

1.8 John Whitney Sr.

The Pythagorean laws of harmony and its perfect consonances has much significance beyond music - in areas such as philosophy, architecture, visual art and design - and most pertinently for this research, motion graphics.

John Whitney Sr. is considered by many to be the godfather of modern motion graphics. "Beginning in the 1960s, he created a series of remarkable films of abstract animation that used computers to create a harmony - not of colour, space, or musical intervals, but of motion" (Alves, 2005:46). He championed an approach in which animation wasn't a direct representation of music, but instead expressed a "complementarity" - a visual equivalence to the attractive and repulsive forces of consonant/dissonant patterns found within music.

Whitney generated motion graphic patterns through programs of simple algorithms run on early computers, output step-by-step to a cathode ray tube (CRT) monitor and then captured frame-by-frame on a film camera. These figures, often reminiscent of naturalistic forms such as flowers and traditional geometric Islamic art, would resolve periodically from apparent disorder - points of dissonance - into distinct alignments - points of consonance. He then applied his mastery of experimental filmmaking to select, optically print, colour, overlay and edit these sequences into his completed works. Later in his career he experimented with early computer-based audiovisual composition systems - though he never quite managed to recapture the impact of his formative earlier works.

In *Digital Harmony: On the Complementarity of Music and Visual Art* (1980), Whitney argues that harmony's function within music could be matched in visual art and particularly within computer generated animation - proposing his ideas of a visual harmonic correspondence or *Differential Dynamics*:

> This hypothesis assumes the existence of a new foundation for a new art… a broader context in which Pythagorean laws of harmony operate… that the attractive and repulsive forces of harmony's consonant/dissonant patterns function outside the dominion of music. (Whitney, 1980:5)

He recognised that his work represented the infancy of an art form, but suggested *"*Composers will discover a congruence of aural-visual partnership ... grounded on valid harmonic interrelationships equally applicable to sound and image*"* (Whitney, 1980:18). Whitney's legacy is evident in the many artists influenced by his work - a notable example being composer, writer and video artist Bill Alves - one of Whitney's last collaborators before his death in 1995. Alves built upon the principles he outlined, extending his *Differential Dynamics* into three-dimensions and exploring new interpretations of dynamic Just Intonation.

Accordingly, this research has found a deep pedagogic connection in the creative outputs and writing of John Whitney Sr. His exploration of visual harmonic relationships is crucial to the development of 20th century computational arts and emblematic of our fascination with audiovisual experience. However, Whitney's creation of a system of audiovisual forms has no concrete auditory counterpart. In addition, music and sound is often more refined and complex than a simple exploration of perfect forms. So the artistic outputs of this research include a series of real-time, code-based audiovisual works inspired by, interpreting and extending Whitney's animated films. Building on his aesthetic of simple dot and line and dynamic geometric form they re-imagine his intricate two-dimensional patterns as complex three-dimensional shapes. More significantly, they also take the next step of integrating music and its inherent harmonic structure as the driving force for those visual forms, something that Whitney - despite his ideas on how to apply concepts of the Pythagorean musical laws of harmony to the visual art of motion - never fully realised.

1.9 Movement in Music - Musical Gestures

The harmony of motion explored within Whitney's work may be sufficient, in and of itself, to suggest a viable connection between music and moving image - an amalgam of the audio and visual where there is a more literal harmony between what is heard and what is seen. Yet this research has sought additional evidence to support a hypothesis that movement itself should be considered a vital intermediary between music and visuals - an effective mechanism for creating a more intimate perceptual connection between sound and image.

In *Musical Gestures*, Godøy & Leman (2010) present compelling evidence that our experience of music is intimately linked to movement. In this edited collection of papers spanning more than a decade of research sponsored by the European Science Foundation and addressing the fundamental issues of gesture in relation to music its editors argue, *"*We conceive of musical gestures as an expression of a profound engagement with music, and as an expression of a fundamental connection that exists between music and movement*"* (Godøy & Leman, 2010:X). They go so far as to claim music is an art of sound and movement and that music means something to us because of this combination.

So whether it be in the physicality of the musician performing music or in the responsive bodily motions of the listener experiencing it; suggested in the imagination through the dynamic of the music or implied through a musical metaphor - musical gesture is pervasive within music. The significance of these musical gestures - of shapes created over time through music - is that this process routinely encodes information which imparts meaning. A commonplace illustration would be to compare the outwardly similar gestures of waving goodbye and cleaning a window - the former communicates meaning, the later does not. These effects are described under the label of embodied cognition - that area of cognitive psychology research that tries to *"*better understand the integration of gesture with perception and with thinking in general, including insights on how body movement is both a response to whatever we perceive and an active contribution to our perception of the world*"* (Godøy & Leman, 2010:4).

So does this perspective on movement and its intimate connection to music have a significance for *Visual Music* too? Are visual representations of music which are dynamic and in movement, more likely to create a close correspondence between sound and image? Can audiovisual techniques that reinforce innate musical gestures (shapes created over time through music) with dynamic visuals (forms created over time through motion graphics) generate work of a different perceptual quality?

1.10 The Senses and Perception - Sensory Integration versus Synaesthesia

Considering whether it might be possible to link the senses together more closely, required a better understanding of the processes involved in vision and audition. This has effected a distinctly perceptual focus to this research not fully appreciated at the outset. However, it became evident that most work on perception by cognitive scientists and philosophers is visuocentric - with the inference that what has been learnt about vision and its objects can be neatly extrapolated to the other sense modalities.

Casey O'Callaghan is amongst the few contemporary sensory-centric philosophers that challenge this endemic view. He argues, *"*Nothing guarantees that what holds of seeing holds generally of perceiving*"* (O'Callaghan, 2013:1) and that to discover what there is still to learn about perception demands thinking seriously about our other senses, the natures of their objects and their similarities and differences. Furthermore, O'Callaghan contends that investigation into the senses remains decidedly unimodal. Even when researchers have avoided the visuocentric and turned to the other senses, their investigations are generally still in isolation to the others, and this is problematic in his view:

> … investigating the senses in isolation from each other leaves out what is perhaps most important to understanding perception's capacity to furnish awareness of a complex but nonetheless unified world. The elaborate patterns of interaction, communication, and recalibration among perceptual modalities must be accommodated by any future philosophical theory of perception and perceptual experience. (O'Callaghan, no date:2)

In fact, he argues that our senses continually interact and cooperate with each other, *"*Perceiving is *richly* multimodal*"* (O'Callaghan, 2013:2). When O'Callaghan talks of sensory multimodality he means instances where our perceptual processes are multimodal - where information from multiple senses is assembled and knit together to produce a unified or integrated perceptual experience - *"*We may see and hear, but what we see depends upon what we hear*"* (O'Callaghan, 2013:3). This he argues, isn't an occasional occurrence, it is pervasive.

There is a growing body of cognitive neuroscience research (e.g. Macdonald & McGurk, 1978; Shams, Kamitani & Shimojo, 2000) that confirms that our senses aren't distinct - they connect with and influence one another all the time. Evolution has designed this innate multi-sensory integration to take advantage of situations where the primary sense for a given situation is in some way *'*interrupted*'* - information on the same object but from different senses is used to *'*recalibrate*'* the primary sensory data. A commonplace example would be trying to follow a conversation in a noisy bar - audition is dramatically improved by studying the speakers lips and facial expressions. More generally within the audio-visual experience and inherent within *Visual Music*, when we perceive images and sounds occurring coincidentally, either in space or in time, they are frequently bound together to form a multimodal percept - a multi-sensory object of perception.

Moreover, this is distinctly different from the experience of synaesthesia - when stimulation in one sensory system impacts experience ordinarily associated with another - and which for O'Callaghan, is robustly illusory: *"*The processes responsible for synaesthesia ... nearly always produce illusions. Synaesthetes do not literally hear colors or taste roughness. There is no regular connection between the colors of things and the colors synaesthetes experience as a result of hearing sounds*"* (O'Callaghan, 2013:8). So despite Bentancourt's (2006) assertion that our understanding of 20th century abstraction may be reordered by considering synaesthesia as a primary motivation for *Visual Music* - and through it abstract film and early painterly "synaesthetic abstraction", this research favours the exploration of the innate and universal effect of sensory integration.

This raises intriguing questions about whether it is possible to link the senses together more closely by exploiting the way in which sensory integration happens innately. Can an understanding of multi-sensory integration be applied in such a way so as to produce creative outputs that exploit this phenomenon for artistic purposes? Is it possible, with artistic intent, to manipulate a *'*multi-sensory object of perception*'*? If so, what will it be and how will it behave?

1.11 Audiovisual Composition

In *Audio-Vision: Sound of Screen*, Michel Chion (1990) provides a rare theoretical framework for studying the mutual relationship between sound and image in audiovisual perception, albeit that he has a specific focus on the process of adding sound to image and a particular perspective on the "re-association" of image and sound as a fundamental upon which sound film is built. Chion argues that sound film qualitatively produces a new form of perception: we don't see images and hear sounds as separate channels, we "audio-view" a trans-sensory whole. Here Chion agrees with O'Callaghan, *"*Visual and auditory perception are of much more disparate natures than one might think. The reason we are only dimly aware of this is that these two perceptions mutually influence each other in the audiovisual contract, lending each other their respective properties by contamination and projection*"* (Chion, 1990:9). He suggests "new effects" are evident in this combining of sound with image, proposing "synchresis" - the spontaneous and irresistible mental fusion, completely free of any logic, that happens between a sound and a visual when these occur at exactly the same time - but more significantly, also introducing the concept of "added value" - a technique of combining sounds and images in order to generate a third audiovisual form, a type of experience which is distinct from the experience of images or the experience of sounds in isolation from one another.

In his 2005 Ph.D. thesis and 2007 article, Mick Grierson makes the case for promoting the interdisciplinary study of audiovisual composition - the interpretation of the relationship between audio and visual material - as neither Art/Film studies nor

Music/Sonic arts but as a metadiscipline in its own right. He argues that the effects of sound and image in isolation are complex enough, more so when combined and further complicated still by the apparent “new effects” proposed by Chion and recent discoveries by cognitive neuroscience research into sensory-integration.

Lipscomb (2004, cited in Grierson, 2007:1) has shown that audiences perceive closely synchronised material as being more effective. Work at the Shimojo Psychophysics Laboratory (Kamitani & Shimojo, 2002, cited in Grierson, 2005:2) has proven that audiovisual material is processed in combination, and that this alters the perception of the material with definite effects. Sekuler & Blake (1985, cited in Grierson, 2005:2) have discovered that multi-sensory cells in the brain respond more strongly when visual and sonic events occur simultaneously and only respond to sound when it comes from the same vicinity as the visual source. Grierson concludes that this research supports Chion’s notion of “added value” - *“strongly synchronised material is effective in producing a type of experience which is distinct from the experience of images or the experience of sounds in isolation from one another”* (Grierson, 2005:2).

Yet Lipscomb argues that despite a proliferation of audiovisual information in our everyday lives - including the aesthetic audiovisual identities utilised by modern corporations, advertisers and media companies - very little research is being carried out to analyse the dynamics of the material. In fact there is a scepticism and even resistance to acknowledging this possible contribution to the field amongst the decidedly unimodal and conceivably *‘purist’* perspectives that dominate. Audiovisual works which exhibit strong structural links are sometimes referred to as being guilty of “Mickey Mousing” - the exact, and as a consequence, simplistic synchronisation of visual and sonic events - *“… because of the implication that exact illustration is a rather tedious and silly way to relate music and image”* (Curtis, S *in* Altman, R, 1992, cited in Grierson, 2007:1), “Mickey Mousing is poor practice. It is considered unsubtle, unnecessary and creates humour when none is required …*”* (Birtwistle, 2002, cited in Grierson, 2007:1). In *Analysing Musical Multimedia*, Nicholas Cook (cited in Grierson, 2007:1) argues that multimedia is “predicated by difference”, and the “duplication of information across sensory modes” cannot be described as multimedia.

Yet according to Grierson, audiovisual composition which exploits structural relationships - a synchronisation of visual and sonic events - by its nature rises out of a desire to understand these combined audiovisual effects - and *“*audiovisual composition, in fact, may rely on an understanding of this ‘effectiveness’ and the complexity of its operation*”* (Grierson, 2007:2). Here Grierson isn’t arguing for Mickey Mousing, he acknowledges the process of composition may shift to and from heavily synchronised material, he simply highlights the perceptual possibility of audiovisual construction and urges us not to dismiss it.

However, Birtwistle (2002, cited in Grierson, 2007:1) goes on to contend that Mickey Mousing has radical potential since it:

> ... punctures the bubble in which western music has placed itself, forcing an acknowledgement of an ‘outside’, an other: in this case, the visual. Not only does Mickey Mousing destroy the notion of an isolated specificity, of an abstraction from all else, but it also introduces ideas of other kinds of structuration, other ways of considering structure, other ways of thinking music, and other ways of thinking about music.

1.12 An Examination of the Senses

We are enmeshed in a world of audiovisual information vying for our attention. Some of the unique properties of the combined audiovisual form are already being empirically exploited for profit. So what are the practical benefits of all this theorising? How might it impact on practice? How might the visual musician bring these perspectives to bear to create work of a different quality?

This research has attempted to find an alternative, perhaps deeper connection between the aural and visual that is not solely dependent on a synchronisation of visual and sonic events. By creating an amalgam of music and moving image in which there is a more literal harmony between what is heard and seen; engaging the viewer in a subtlety shifted way - a (kinetic) synchronisation between the senses of hearing and sight that results in a “co-sensing” of a “co-expressiveness” - where the mind is not doing two separate things, it is doing the same thing in two ways (MacNeil, 1992); and in searching for those subtle and fleeting conditions under which an audiovisual percept - a combined visual and sonic object of perception - is not just seen and heard but is instead *seenheard*.

In this way the research is concerned with the phenomenal - that which can be experienced through the senses - rather than the noumenal - that which resides in the imagination and *‘inner visions’*; and is focused on the perceptual - in how we perceive the world around us - as opposed to the cognitive - how we interpret, contextualise and make sense of it. This is also reflected in a focus within the research on the lineage of artistic exploration into the interplay between sight and sound, especially through a blending of the senses, which contributed to the development of *Visual Music*, abstract cinema and arguably abstract art.

Yet this research also proposes that a more meaningful connection between music and visuals begins, as Morritz suggests, with the motion picture projector. It is essentially in the movement of abstract film that the stirrings of a deeper equivalence between sound and moving image can be found - and not as Betancourt (2006) would have us, in the lineage of colour organs that explored the synaesthetic notion of mapping qualities of sound to light - and most commonly pitch to hue.

Accordingly, this research argues that striving for a more profound perception - of seeing things as they actually are, their simple being - is an essential condition for creating meaningful audiovisual artwork, as suggested in a personal *A Visual Music Manifesto* (see Appendix 1 - A Visual Music Manifesto):

> What we deserve is thoughtful and inventive exploration of the interplay between sound and image.
>
> A re-capturing of the imagination, a re-inspiring of awe and wonder and a re-engagement in deep and significant ways.
>
> We should strive to make *Visual Music* that transcends the background noise and offers unique and profound insights into the relationship between things and the nature of the world around us.

Akin to that by which Moritz critiques Oskar Fischinger's synthetic sound production experiments, *"*Ah, but those visuals contain formulas and gestures that communicate with us subconsciously, directly, without being appreciated or evaluated*"* (Moritz, 1976:online).

So the ambition has been to outline an approach towards realising audiovisualisation of a distinct quality, of creating works which integrate:

- a direct, elemental and real-time correspondence between sound and image;
- an underlying concord or harmony between music and moving image;
- a mirroring of music's innate movement and transition within the visual domain;
- and a more intimate perceptual connection between the aural and visual.

The key method for achieving this - of designing, fabricating and crafting a hybrid analogue/digital audiovisual instrument, *The Augmented Tonoscope* - will be detailed in subsequent chapters.

2. Literature Review

2.1 Introduction

This chapter develops the line of argument introduced in Chapter 1. Introduction with additional evidence uncovered through select literature. It aims to: extend the critical discussion; show insight into differing arguments, theories and approaches; and reveal a deeper synthesis and analysis of key published work - linked to this research's purpose and rationale. It shows that relevant work in the field has been read and understood and used to: avoid duplication of research; develop a framework for the enquiry; raise questions for further practice; and suggest further research. It also attempts to define and limit the research; place it in a historical perspective and artistic lineage; and relate personal findings to previous knowledge.

Overall it serves to contextualise the study and provide the frame of reference from which it operates - identifying those contributions from the literature that are consequential to this research and which guided its course and direction. Most importantly, it endeavours to highlight the need for this research through a description of the literature and existing artwork in the field, indicating how this praxis builds on past theory and practice and fills an *'*absence*'*.

Still, the research has attempted to find innovation, not through a pursuit of the novel, but by searching for connections between seemingly dissociated disciplines to find out whether these linkages might reveal fresh insight.

So the approach has been to break down the key research question (see Section 7.3 Key Research Question):

- How far can artistic investigation into Cymatics - the study of wave phenomenon and vibration - contribute towards a deeper understanding of the interplay between sound and image in *Visual Music*?

Into a series of component parts:

- What insights have been gleaned about Cymatics - the study of wave phenomenon and vibration?
- What constitutes artistic investigation into Cymatics?
- How has the research developed a deeper understanding into the interplay between sound and image?
- How can this work be contextualised within *Visual Music* and wider audiovisual culture?

Then use inductive[7] and abductive[8] reasoning to search for hermeneutic[9] connections between them. This approach is informed by the concept of "systems thinking"[10] proposed by Gregory Bateson and his notion of an "ecology of the mind" - of discovering "the pattern that connects" within a hermeneutic system of perspectives.

Insights into Cymatics

2.2 Hans Jenny's Cymatics

- Jenny, H. (2001) *Cymatics: A Study of Wave Phenomena and Vibration*. New Hampshire: Volk, J. (first printed as Vol. 1 1967, Vol. 2 1972)

The study of modal phenomena has a long and rich history and a significant body of empirical evidence, theory and practical application. Yet absolutely central to any discussion of the study of modal wave phenomena is Dr. Hans Jenny - the Swiss medical doctor turned sonic researcher. His two volumes - *Cymatics: A Study of Wave Phenomena and Vibration* Vol. 1 (1967) & Vol. 2 (1972) - are commonly accepted as the defining works in the field.

Key to Jenny's analysis of Cymatic effects are notions of an underpinning periodicity in nature expressed through common rhythmicity, oscillation and seriality. Jenny himself hoped that his research into Cymatics would open the eyes of others to these underlying periodic natural phenomena. As a long-standing visual musician there is an intrinsic temporal linearity to the practice - a focus on shaping the progress of a work from start to finish. Jenny's emphasis on periodicity encouraged a more cyclical and repetitive approach, reflected in development within the associated artworks.

7 In inductive reasoning the premises seek to supply strong evidence for (not absolute proof of) the truth of the conclusion - which would be probable, based upon the evidence given. In an inductive argument, the premises are intended only to be so strong that, if they were true, then it would be unlikely that the conclusion is false (Internet Encyclopaedia of Philosophy (IEP), no date).

8 Abductive reasoning is a form of logical inference that goes from observation to a hypothesis that accounts for the reliable data and seeks to explain relevant evidence. Although the premises do not guarantee the conclusion, if true, they best explain the facts. Abduction is often called "Inference to the Best Explanation" (Stanford Encyclopedia of Philosophy (SEP), 2014).

9 Hermeneutics is the theory of the interpretation of written, verbal, and nonverbal communication to derive understanding. Although its traditional focus is on the interpretation of biblical texts, wisdom literature and philosophical texts, modern hermeneutics finds application in fields of study ranging from psychology to architecture and computer science - *"… perceiving a moving horizon, engaging a strand of dialogue that is an on-going re-articulation of the dynamically historical nature of all human thought"* (Stanford Encyclopedia of Philosophy (SEP), 2014:online).

10 As proposed by influential British anthropologist Gregory Bateson, the basic idea of a system theory in social science is to solve the classical problem of duality; mind-body, subject-object, form-content etc. System theory, therefore, suggests that instead of creating closed categories into binaries (subject-object), the system should stay open so as to allow free flow of process and interactions. In this way the binaries are dissolved (Bale, 1992).

Jenny saw vibrating plates and diaphragms as being environments of extraordinary complexity - stationary wave patterns were only one manifestation, alongside: currents which imparted flow to the patterns; centres of rotation and revolving heaps with influent streams and connecting flows; Lissajous figures formed with more or less clarity as areas of oscillation moved towards each other; eddying regions which pointed to turbulences; and occasional interference oscillations flitting across the field. He understood these as an expression of the movement within an energising process - a "creans/creatum" relationship. So Jenny considered the whole system in his analysis, taking account of the complex structures within the vibrational field and the shift from form to form, not just the discrete geometric patterns that emerged at certain frequencies, *"Hence it is possible not only to produce vibration patterns and investigate the laws to which they continuously conform, but also, and more especially, to make a close study of the transitions as one figure gives way to another"* (Jenny, 2001:22). Coming to appreciate this perspective prompted a shift of interest (relatively early in the research) to the transition between the discreet patterns of steady vibrational states rather than the patterns per se - reflected in attempts to automate portamento within the *sound making* module as detailed in Section 5.2.1 Sine Wave Generator (SWG).

Jenny emphasises the "triadic nature" of Cymatics - hear the sound, see the pattern, feel the vibration - highlighting three essential aspects and ways of viewing a unitary phenomenon. This suggested the potential for a multimodal sensory instrument and prompted efforts to link the senses together more closely.

Particularly relevant for a Practice as Research project he also favoured a practical experimentation over a mathematical model, *"What we are concerned to do then, is not to formulate hypotheses about backgrounds and final causes, but rather to press on step-by-step with our exploration into this field and to find methods of giving tangible expression to this phenomenology"* (Jenny, 2001:20). In contrast, this research is actually more interested than Jenny in the scientific nature of stationary wave patterns, drawing on mathematical derivations to code a virtual model of a circular drum skin and display its modal vibrational states - as detailed in Section 5.5.1 Virtual Drum Skin.

Artistic investigation into Cymatics

2.3 John Telfer's Cymatic Music

- Telfer, J. (2010) *Cymatic Music*. [Online] [Accessed on 1st March 2011] http://www.cymaticmusic.co.uk/

While there are numerous examples of creative work that deploy Cymatics, there are few that explore it as a means to create a form of visual or visible music - with the notable exception of John Telfer's *Cymatic Music*. An introduction to his audiovisual science and music project has been made in Section 1.6 Cymatic Music.

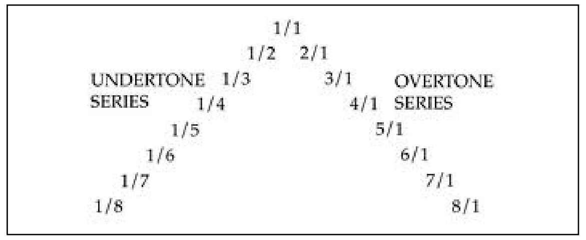


Figure 6 - The Pythagorean Lamdoid

Figure 13 *in* (Telfer, 2010:online)

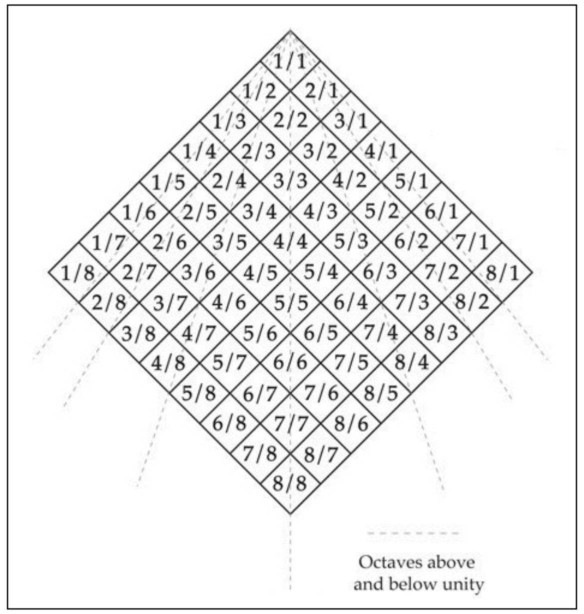


Figure 7 - Lamdoma - the Pythagorean Lambdoid in its completed form

Figure 15 *in* (Telfer, 2010:online)

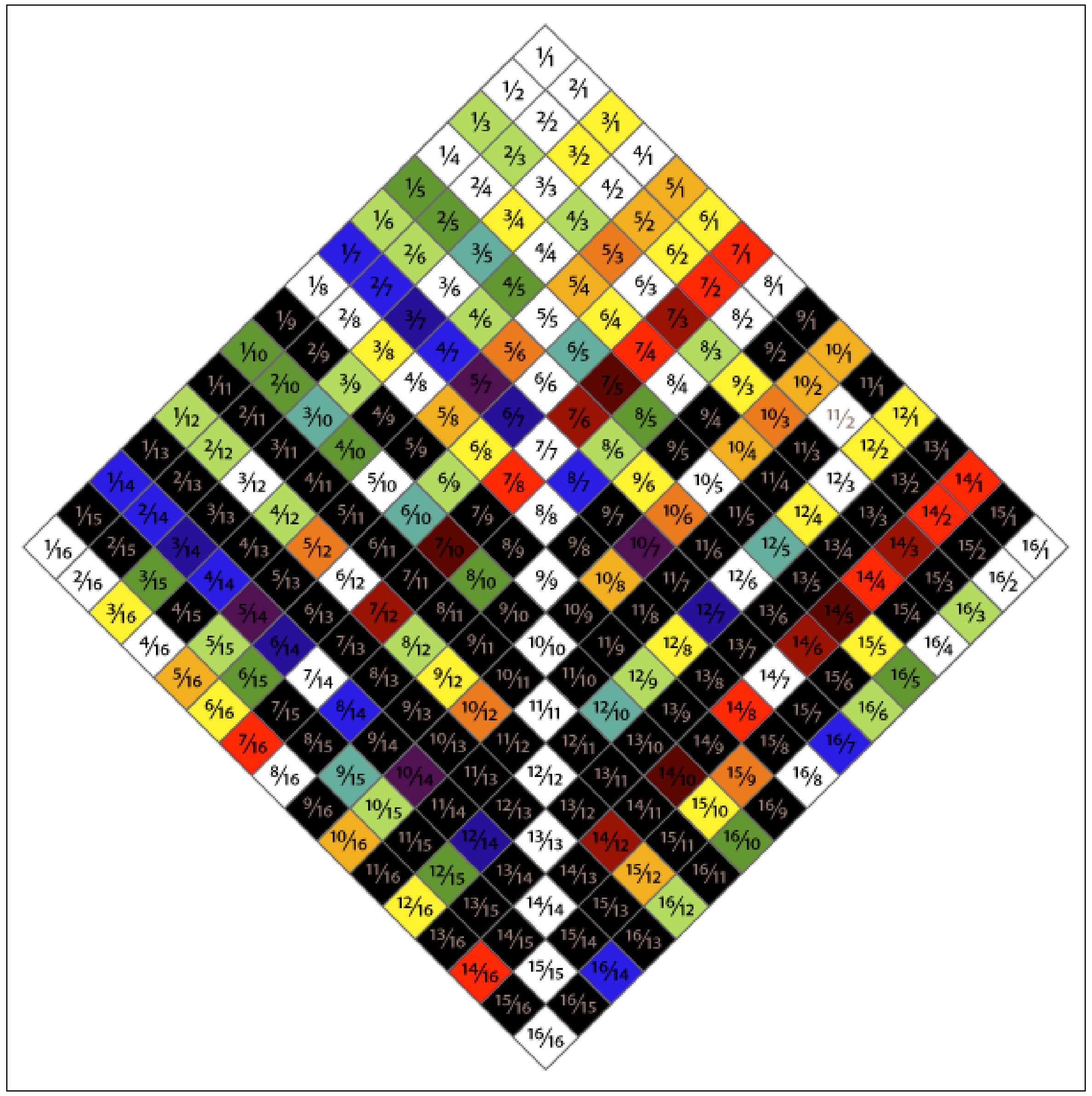


Figure 8 - Telfer's 16-limit *Lamdoma Matrix* - Figure 20 *in* (Telfer, 2010:online)

Telfer also asks if cymatic patterns can be interpreted musically but argues that a correspondence between musical tone and cymatic pattern and form will most likely not be found within the 12-tone Equal Temperament of Western Music. He suggests *"it is worthwhile developing a music system with firm acoustic foundations, particularly if this system is to be used as a tool for cymatic enquiry"* (Telfer, 2010:online) and responds with his theory of harmonicism, a mathematically and musically consonant framework of proportional Just Intonation - where the spans between notes are calculated based on small whole number ratios.

Telfer revisits the ancient Pythagorean Lamdoid (Figure 6) - a construct which integrates the well-established harmonic progression of overtones or harmonics - perfect intervals based on the whole number ratio sequence of 1/1, 2/1, 3/1 etc. - with the more unorthodox arithmetic progression of undertones or subharmonics - perfect intervals based on the whole number ratio sequence of 1/1, 1/2, 1/3 etc.

This re-emerged in the late 19th century in its completed form as the Lamdoma (Figure 7) - making these two progressions the axis of a 2D grid. Each cell represents a ratio defined by its position in the grid i.e. a cell in the third column (harmonic series) and fourth row (subharmonic series) has a ratio of 3/4 or 0.75 of the unity, 1/1, base frequency - 330 Hz if the base frequency is 440 Hz.

Telfer's version, the *Lamdoma Matrix* (Figure 8), includes a detailed analysis of the grid looking for patterns in the duplicated ratios e.g. 5/3, 10/6, 15/9 and the harmonic relationships between cells - settling on a functional colour coding to map those ratios on the matrix that are more or less consonant with each other. Cells of the same colour are equivalent or highly consonant, of similar brightness generally consonant, of dissimilar brightness increasingly dissonant and of a marked difference in brightness, decidedly dissonant. This mapping of relative consonances and dissonances helps reveal the matrix's underlying symmetry, general structure and lines of octaves above and below unity which fan out from the 1/1 cell.

Telfer's research is compelling, particularly if it does indeed *"take advantage of the creative cross-fertilisation between musical harmony and physical patterning"* (Telfer, 2010:online). Accordingly, he advocates that the Lambdoma should be seen as a practical creative resource for music - and this research has adopted and adapted it within the *musical interface* module of *The Augmented Tonoscope*, the application and analysis of which is discussed in later chapters and appendices. However, Telfer favours manufacturing acoustic musical instruments to interpret the harmonicism within the Lambdoma, although he recognises and points to the possibility of an electronic (and digital) approach which this research has adopted.

2.4 Suguru Goto's Cymatics

- Goto, S. (2013) *Suguru Goto*. [Online] [Accessed on 12th April 2012] http://suguru.goto.free.fr/Contents/SuguruGoto-e.html
- Piemonte Share. (2011) *Cymatics - Production*. [Online] [Accessed on 12th April 2012] http://vimeo.com/32333689
- Imperica. (2011) *This fluid world*. [Online] [Accessed on 12th April 2012] http://www.imperica.com/features/this-fluid-world

Suguru Goto's current interactive sound installation is a contemporary artistic investigation into Cymatics that is most akin to *The Augmented Tonoscope*. While not seen in person, online research via its website, press materials and associated video documentation has enabled an understanding of its conceptual frameworks, technological underpinnings and production values.

Cymatics (Goto, 2011) is realised as two discrete but allied works, each housed in the gallery space within its own approximately 3m^3 box - one black the other white - each with a single door. Within the black box is a ~1m^2 metal tray mounted into the top of a waist high plinth. Water in the tray is vibrated by an arrangement of transducers fixed underneath which playback a sequenced musical composition, resulting in shifting vibrational patterns across the surface of the liquid. This is simultaneously projected on one wall of the room. Within the white box is a waist high ~1m^2 plinth with four ~10" speakers mounted in the top. Non-Newtonian fluid is vibrated within each of the vinyl covered cones producing dynamic, globular forms that rise and fall out of the material. Custom applications on an iPad allow interaction with the works through what appears to be control of the audio and so the resulting cymatic forms.

In some ways this all sounds remarkably familiar. However there are marked differences between *Cymatics* (Goto, 2011) and *The Augmented Tonoscope*.

Cymatics (Goto, 2011) is a commissioned art work - supported and produced by Action Research, an initiative sponsored by the Turin Chamber of Commerce. The work employs a sophisticated combination of off-the-shelf, commercial transducers, speakers and amplifiers developed in a well equipped professional lab. A production video shows Goto overviewing the testing alongside a team of technicians responsible for the actual construction of the devices. Goto then created music compositions to drive both devices (and though the sound quality of the documentation isn't that clear) with a heavily sequenced score using mechanical and industrial sounds, perhaps influenced by his recent *RoboticMusic* works. While the overall aesthetics realise a reductionist, minimal, integrated audiovisual system, the materials chosen to demonstrate the cymatics effects - water and a non-Newtonian fluid (most likely corn starch in water) - are very conventional in Cymatics terms and the outputs of the works are analogue only. Input via an iPad control interface is certainly contemporary, yet they appear to be virtual control interfaces emulating traditional physical hardware of buttons, knobs and sliders. The language employed in describing the works is effusive: *"*Cymatics creates real spaces that are metaphysical and spiritual at the same time. A place where art is a bridge between the material and the spiritual, between technology and nature, and between the humanities and science*"* (Imperica, 2011:online). Finally, Cymatics seems to be a divergence from Goto's more contemporary practice of robotic musicians, technologically augmented performance and telematic presences in augmented realities, though it may mark a return to his earlier instrument based work such as *The Superpolm*, a virtual violin built in 1996.

In contrast, The Augmented Tonoscope is primarily intended as an audiovisual instrument - a live performance tool and means to produce short audiovisual films. While the associated artwork of the Cymatic Adufe produced through this study is also a sound-responsive installation, it is only one iteration of several outputs from this research. Moreover, this research explored the process of building an instrument from scratch, with minimal help and at own expense and with a distinct bias towards *technology misuse* - "when customers modify features or expand the usage of products and services in ways that were never intended" (Fisher, Abbott and Lyytinen, 2013) - including the use of unconventional mediums to visualise the physical cymatic effects. Early prototypes indicated an industrial/scientific aesthetic with a complex union of discreet modular components that collectively produced the functionality of the instrument.

A distinct focus has been the attempt to create a hybrid analogue/digital device - of integrating an emulated tonoscope with an analogue one - projecting the analogue cymatic patterns but superimposing them with digital forms derived from a virtual system, modelled according to real-world physics and mathematical laws and which behaves like the analogue device, yet has the ability to be extended, twisted and abstracted in ways the analogue never could. This close integration of analogue and digital in *The Augmented Tonoscope* differentiates it from the more limited digital control aspects of Goto's *Cymatics*. Finally, there's no spiritual dimension and only a passing nod to metaphysical contemplation in this research, the critical focus being the aesthetic, artistic and scientific aspects - an artistic exploitation of a natural physical phenomenon for creative purposes - to generate audiovisualisations in which there is a real-time, direct and elemental link between what you hear and what you see.

Accordingly, this research argues that it is this real-time, dynamic and aesthetic interplay between audio and augmented cymatic visual outputs that marks this research as unique and has the potential to provide new insights and understanding into the relationship between sound and image within *Visual Music*.

2.5 The Legacy of John Whitney Sr.

- Whitney, J. (1980) *Digital Harmony: On the Complementarity of Music and Visual Art*. Peterborough, N. H.: McGraw-Hill

John Whitney Sr. is considered by many to be the godfather of modern motion graphics. *"*Beginning in the 1960s, he created a series of remarkable films of abstract animation that used computers to create a harmony - not of colour, space, or musical intervals, but of motion*"* (Alves, 2005:46). He championed an approach in which animation wasn't a direct representation of music, but instead expressed a "complementarity" - a visual equivalence to the attractive and repulsive forces of consonant/dissonant patterns found within music. The sleeve notes from *Digital Harmony*, outline his modus operandi,

> John Whitney's … computer graphics and visual art centred upon the centuries-old idea (impossible before computer graphics) of "an art that should look like music sounds" … His … films demonstrate … that dissonance resolves to consonant patterns of motion. The crucial function in music of harmony's charge and discharge of tension or forces in chordal and tonal sequences is now matched … in the visual world (Whitney, 1980:front flap dust jacket).

John Whitney Sr.'s praxis offers a figurative model for the "harmonic motion" of patterns - *Differential Dynamics*. Based on the trigonometry of Euclidian geometry, Whitney used simple mathematical equations and early computers to generate elementary animated figures - making dots or other shapes move around in: circles; parametric curves - as in *Matrix* I and III (1970 and 1972); various rose curves (sine functions in polar coordinates) - commonly known as the "Whitney Rose"; and in *Arabesque* (1973) making dots initially arranged in a circle move linearly but wrap around at the edge of the screen. In all of these examples the same points of resonance, of striking symmetry within the pattern, occur at the same points of harmonic proportions. Dr. Mick Grierson (2005) summarises the underlying principles:

> Whitney's Differential Dynamics successfully models the behaviour of sound and our appreciation of it as music in three main ways. First, it takes as a basis the idea of harmonic resonance and relates it to the idea of visual symmetry. Secondly, it takes the idea of the harmonic series and applies it to a series of nodes in a visual pattern. Thirdly, it takes the idea of tension and release, and applies it to the process of moving towards and away from symmetrical forms in a system of patterns. As such it is a system for creating visual composition from a framework based on our experience of music. This means that it is highly compatible with the desire to develop a system for composition whereby both the sound and the image generation process are calibrated on the same plane with a similar degree of temporal relation. This particular technique demonstrates significant similarity to our general experience of music (Grierson, 2005:82).

Whitney's approach holds particular resonance for this research because it exists at the interface between analogue and digital technologies - albeit at the infancy of this endeavour. Also as an artist, Whitney is particularly open about his methodology and approach - as he declares in *Digital Harmony*, *"*the purpose is to document my own approach and propose the seminal idea of making an approach*"* (Whitney, 1980:5). So Whitney is an inspiration in that he not only shared his attempts *"*to define, as much as I understand them, the principles of harmony as they apply to graphic manipulation of dynamic motion pattern by computer*"* (Whitney, 1980:6) but that despite embracing new technology he still applied his experience and expertise in the traditions of filmmaking to maintain the integrity of his creative outputs without succumbing to the lure of the novel. This is both a legacy and challenge.

What is particularly intriguing about Whitney's "complementarity" is the notion of a visual equivalence to the consonant and dissonant patterns found within music. Is there a parallel between Whitney's *Differential Dynamics* and the vital cymatic figures and forms induced by sound? Is it possible to match both the charge and the discharge of tensions within tonal and chordal sequences cymatically?

2.6 Musical Gestures

- Godøy R. I. & Leman M. (eds.) (2010) *Musical Gestures: Sound, Movement, and Meaning*. New York & London, Routledge.

The harmony of motion explored through Whitney's work suggested further investigation into movement as an intermediary between music and visuals. In *Musical Gestures: Sound, Movement, and Meaning* its editors argue that experiences of music are intimately linked with experiences of movements. They go so far as to claim music is an art of sound and movement and that music means something to us because of this combination. They also contend that musical gestures is an eminently interdisciplinary topic, drawing on ideas, theories and methods from disciplines such as musicology, music perception, human movement science, cognitive psychology and computer science - corroborating this research's approach of pursuing diverse lines of enquiry to build a network of inter-relationships, connections and congruences.

Notions such as "sound related gestures", understood as movements in sound that are sonically rather than physically gestural (such as pitches rising, rhythms that have a galloping character); and "sound as metaphor", movement implied through music - as described by Middleton: *"*How we feel and how we understand musical sounds is organised through processual shapes which seem to be analogous to physical gestures*"* (Middleton , 1993, cited in Godøy & Leman, 2010:17) - prompted experimental investigation into shaping portamento between tones. Thinking about musical gestures not only provided a deeper insight into the way movement is embedded within music, but in turn, also provided insight into how the actual physical movement of glass beads on a vibrating diaphragm or particle systems in a virtual model within *the Augmented Tonoscope* might serve to communicate additional layers of meaning encoded within the harmonic progressions of the music itself.

While not all the perspectives outlined in *Musical Gestures* were relevant to this research, there were particular areas of interest: the development of new digital instruments and multimodal interfaces with computers that try to make meaningful combinations of sound and movement; and the application of technologies (such as motion capture) to open up new views on the fleeting. More significantly, a consideration of music and gesture revealed a growing interest in human perception and cognition as a multimodal and embodied phenomena and research into the way the body affects perception and thinking: *"*Under the label of 'embodied cognition', we can now better understand the integration of gesture with perception and with thinking in general, including insights on how body movement is both a response to whatever we perceive and an active contribution to our perception of the world*"* (Godøy & Leman, 2010:4).

2.7 Sensory-Centric Philosophy

- O'Callaghan C., (no date) Research Statement. [Online] [Accessed on 29th May 2013] http://caseyocallaghan.com/research/Statement.pdf
- O'Callaghan C., (2011) 'Lessons from beyond vision (sounds and audition).' *Philosophical Studies*, 153(1):143-160. [Online] [Accessed on 29th May 2013] http://caseyocallaghan.com/research/papers/ocallaghan-2011-Lessons.pdf
- O'Callaghan C., (2013) 'Hearing, Philosophical Perspectives.' *In* H. Pashler (T. Crane) (eds.) (2013) *Encyclopedia of the Mind.* SAGE. [Online] [Accessed on 29th May 2013] http://caseyocallaghan.com/research/papers/ocallaghan-2013-Hearing.pdf

Musical Gestures revealed a pathway into perception and the senses - stimulating further enquiry into contemporary sensory-centric philosophy and cognitive neuroscience research in order to develop a deeper understanding of multimodal sensory perception in the hope of realising a more intimate perceptual connection between sound and image.

Casey O'Callaghan summarises his work as *"*providing an empirically-literate philosophical understanding of perception that is driven by thinking about non-visual modalities and the relationships among the senses*"* (O'Callaghan, no date:2). Through numerous articles, papers and monographs he develops accounts of the issues surrounding vision, audition, the chemical senses, and the bodily senses as well as more unconventional sensory phenomena such as synaesthesia and cross-modal illusions, drawing on empirical work in psychology and the neurosciences to

strengthen traditional philosophical methods and perspectives and argue for *"*the importance of the senses to casting and resolving central philosophical problems in metaphysics and epistemology*"* (O'Callaghan, no date:2).

His arguments broadens the debate by offering perspectives which are more nuanced and influenced by audition and the other senses. He asks *"*What is it to auditorily perceive an object?*"* (O'Callaghan, no date:1). He suggests that current theorising has been shaped by attempts to explain perception as providing an awareness of the sensible features of ordinary material objects. While this may be intuitive for vision and touch, it isn't for audition: *"*A sound is unlike a table or a brick, and sounds do not auditorily appear to be bound to ordinary objects, as are visible colors, shapes and textures; sounds are audibly independent from ordinary objects and their features*"* (O'Callaghan, no date:1). Still, sonic researchers talk increasingly of *'*auditory objects*'*. O'Callaghan responds by proposing an alternative account of audition in which *"*sounds are distally-located, perceptible individuals which instantiate audible qualities and take place over time*"* (O'Callaghan, no date:1). In proposing a nature of sounds that treats them as discrete temporal events he essentially suggests that time is to hearing what space is to seeing. In O'Callaghan's view auditory objects are also mereologically[11] complex individuals, but individuated and identified in virtue of temporal characteristics and pitch, unlike their visible counterparts, which use spatial characteristics, including boundedness, connectedness, and cohesion. This offers a perspective in which at least vision, touch and now also audition target perceptual objects understood as mereologically complex individuals, even though the objects in question are not all commonplace material objects.

O'Callaghan's writing does much to inform the search for a deeper understanding into the interplay between sound and image through a more perceptive insight into how we engage with the ocular and the auditory and particularly how they interact and cooperate with each other - corroborating contemporary cognitive psychology research exploring sensory modality - how we attain an awareness of the world around us by interpreting sensory information. Key papers by Macdonald & McGurk (1978) and Shams, Kamitani & Shimojo (2000) and their seminal studies into sensory illusions - now commonly termed the *'*McGurk Effect*'* and *'*Double Flash Effect*'* respectively - indicate that our senses aren't distinct - they interact with and influence one another all the time. While artists may seek much more explicit large scale behavioural rules than scientists can with confidence supply there are certainly markers and hints towards creative possibilities here.

[11] Mereology (from the Greek μερος, "part") is the theory of parthood relations: of the relations of part to whole and the relations of part to part within a whole (Stanford Encyclopedia of Philosophy (SEP), 2014:online).

3. Methodology

3.1 Introduction

Despite its populist appeal, there is limited academic research into the application of Cymatics within a *Visual Music* context. So this investigation has not taken the traditional approach of studying research in the field in order to reveal an absence and so define a research question. Rather, it has trusted implicit practitioner knowledge, gained through years of practice and curation, to identify the focus of the investigation and then steer the research through the surrounding terrain. Considering it a transdisciplinary topic has meant drawing from disparate disciplines - selecting theory and practice which seemed to resonate especially with the study to introduce alternative perspectives, inform understanding and spark new insights. As such, the research has drawn from acoustics, sensory-centric philosophy and critical art theory to musicology, cognitive neuroscience and computer science. It has also investigated the lineage of the practice through the ideas, approaches and techniques of inspirational artists.

So the research has advanced, not through the specialism of a single discipline, but through diverse and by contemporary standards at least, potentially conflicting lines of enquiry. It doesn't propose a hypothesis based on deductive rationalisation of established thinking within a discipline. Neither has it followed a conventional model of progressing through the discreet stages of analysis, synthesis, conceptualisation and epistemology applying deductive reasoning to form the argument. Instead, it has adopted an alternative strategy, breaking the overarching research question down into a series of component parts and then using inductive and abductive reasoning to search for hermeneutic connections. In doing so, it describes and defines the research as something more akin to an emergent system - as a network of inter-relationships, connections and congruences.

This approach is informed by the concept of "systems thinking" proposed by Gregory Bateson and his notion of an "ecology of the mind" - of discovering "the pattern that connects" within a hermeneutic system of perspectives. Yet it stems from a predisposition as a musician for pattern recognition - to naturally filter out the *'signal'* from the background *'noise'*, discern emerging forms and intuit their nature. Accordingly, the study has recognised repeating motifs within the varied perspectives of the disparate sources, which through the process of the research, have been formalised - resolved, reduced and oriented into a concentric alignment. This has crystallised the central argument to the thesis - of an aesthetics of vibration and a more intimate perceptual connection and harmonic *complementarity* between music and moving image.

This approach to the research is mirrored within the key method of designing, fabricating and crafting a hybrid, analogue/digital audiovisual instrument, *The Augmented Tonoscope*. Its evolution has resulted in a modular performance system comprising of discrete, specialised but interconnected components which collectively produce its functionality. It is also reflected in the formalist nature of the associated artworks.

This formalism persists within this thesis as a set of literary mechanisms which structure the writing and foster repeating patterns within the text. The emphasis here is on modularity - on discrete, specialised but interconnected units of writing which collectively communicate the new understanding and fresh insights realised through the research overall. This writing schema alternates focus through each of a set of perspectives - the theoretical, practical, technical and critical aspects of the research, as well as its philosophical implications and poetic potential. This allows the research to speak with different voices - to describe the study though a rationalisation of key research findings, details of technical realisations, reflection and evaluation of praxis, thought provoking ramifications and evocative imagery. Yet this strategy is something of a balancing act. The conventional academic idiom demands a regular structure of summation through synthesis and analysis. This thesis attempts to reflect the hermeneutic approach of the research through a schema which allows these patterns to emerge more gradually - in a way that only progressively reveals their congruence and interconnectedness, but ultimately makes them more understandable.

3.2 Research Frameworks

PARIP (2006) - Practice as Research in Performance - was a five-year project, funded by the Arts and Humanities Research Board, led by Professor Baz Kershaw and the Department of Drama: Theatre, Film, Television at the University of Bristol. Robin Nelson (then at the Department of Contemporary Arts, Manchester Metropolitan University) and who sat on the PARIP Advisory Group, consequently wrote several papers and edited a book *Practice as Research in the Arts: Principles, Protocols, Pedagogies, Resistances* (2013) which expressed, developed and refined the project's research outcomes.

> The PARIP project has directly and indirectly addressed the modes of knowledge PaR might develop. It has done this by illustrating a range of praxes (practices within which the potential to engender knowledge is imbricated) in its various symposia and conference events and through discussion of the issues at these, and related forums, regionally, nationally and internationally. The project has thus contributed specifically and generally to the evolution of PaR in the UK Academy. (Nelson, 2006:1)

This study draws from the model of research methods and critical approaches developed through the PARIP initiative and Nelson's subsequent writings. They propose a dynamic model for the process of cross-referring different sources of testimony, data and evidence in a multi-vocal approach to a dialogic process. The product of *Mixed-Mode Practices* sits at the centre of a triangle and at one of each of the apexes sits:

- *Practitioner Knowledge* - tacit knowledge, embodied knowledge, (phenomenological) experience, know-how. The suggestion that practitioners have "embodied within them", enculturated by their training and experience, the "know-how" to make work;
- *Critical Reflection* - practitioner "action research", explicit knowledge, location in a lineage. A conscious strategy to reflect upon established practice as well as to bring out "tacit knowledge";
- *Conceptual Framework* - traditional theoretical knowledge, cognitive-academic knowledge. Creative practice becomes innovative by being informed by theoretical perspectives, either new in themselves, or perhaps newly explored in a given medium.

Each corner of the triangle, each stage of the process of making and of research as well as the product itself, is seen as potentially knowledge-producing. Where one data-set might be insufficient to make the insight manifest, the research in its totality yields new understandings through the interplay of perspectives drawn from evidence produced in each element proposed. In sum, praxis (theory imbricated within practice) may thus better be articulated in both the product and related documentation.

Key to applying this approach was setting clear research objectives at the outset of the project:

- designing, fabricating and crafting a sonically and visually responsive hybrid analogue/digital instrument;
- producing a series of artistic works for installation, screening and live performance;
- writing an accompanying thesis and collecting an "evidence box" of materials.

Yet, in an attempt to make the communication of the research integral to its methodology, this project has implemented the PARIP model through more contemporary means - as the framework for an online research journal and its supporting online documentation including a digital sketchbook, video and photography. These show how the various aspects of the study inform one another through the clearly structured categories of:

- *artistic outputs* – demonstrating rigour in respect to the imaginative creation, thoughtful composition, meticulous editing and professional production of new artwork;
- *documentation of process* – recording evidence of ongoing practical, experimental and iterative design including tool sets, methodology and outputs and capturing moments of insight and happy accident;
- *critical reflection* – making embodied 'performer knowledge' explicit – comparing and contrasting other work, finding resonance between this research and contemporary debates, offering new insights into the conceptual framework and theory implicated within the practice;
- *complementary writing* – locating this praxis in a lineage of similar practices and relating and referencing this specific inquiry to broader contemporary debate;
- *research frameworks* – describing the various research methods, techniques and structures and critical approaches and tools subscribed to, adapted or developed in order to guide and direct the research;
- *papers, presentations and showcases* - online links to published papers, scripts of various conference and symposium presentations and documentation from opportunities to showcase work - in order to provide useful *'*snapshots*'* into an evolving practical experimentation and insights into areas of focus and attention reflected through current reading and thinking;
- *Ph.D. milestones* – key proposals and reports required in the procedural pathway towards a Ph.D.

Maintaining this framework over the course of the study has made it possible to write/think aloud about key developments and share the practice as the study progressed. The online documentation of the research also serves as the "evidence box" of materials which helps make the research context manifest. It includes:

- The Augmented Tonoscope - a WordPress research journal (http://www.augmentedtonoscope.net);

and supporting documentation including:

- a Tumblr digital sketchbook (http://augmentedtonoscope.tumblr.com);
- video via Vimeo (https://vimeo.com/album/1454262);
- and photography via Flickr (https://www.flickr.com/photos/lewissykes/sets/72157627089569359/).

Specifically, it has allowed the research to share knowledge and insights with the research and wider communities through a decidedly *'*open-source*'* modus operandi – making its evolving tool set, techniques, code and software, electronic and design schematics, documentation and outputs freely available under a Creative Commons Attribution-Noncommercial-Share Alike licence. This reflects the decidedly *maker* strategy of the practice - the frequently collaborative development and free exchange of information, tools and approaches characterised by *"*a growing community of *makers* who bring a DIY mindset to technology*"* (Maker Media, 2004:online).

Creativity, openness, politics, ethics and economics seem to be essential strands in this new *maker* culture which includes:

- the global yet direct distribution network offered through the Internet;
- the *'*communities of interest*'* engendered through Web 2.0 Social Networking platforms and tools;
- the opportunities for creative DIY electronics offered through the proliferation of the IC or integrated circuit;
- the indubitable rise of the creative-developer and artist-engineer;
- frustration with the restrictions of commercial hardware and software that drives people to create their own custom made tools and instruments;
- the pursuit of elegant, ergonomic design combined with flexible, adaptable functionality;
- the desire for small scale, locally sourced, self sufficient models of economic development;
- an openness and willingness to share, extend and adapt creative endeavour amongst a community;
- and the striving towards environmentally sustainable practice and an ideological stance.

As a result, this emerging scene is a sophisticated, interwoven and synergic lace of filaments that is more than a sum of its parts. Consequently it has provided the backdrop to the research as well as the essential tools, starting examples and knowledge and expertise which have supported and informed the practice.

4. The Augmented Tonoscope

4.1 Introduction

This chapter outlines the developmental process of the design, fabrication and crafting of a hybrid analogue/digital audiovisual instrument, *The Augmented Tonoscope*.

It serves to:

- summarise this approach as key method for the research;
- and describe the evolution of the conception of the instrument from integrated device to modular performance system.

4.2 On Making an Instrument

The ambition for this Practice as Research project was to build a new audiovisual instrument that could create a real-time, direct and more elemental connection between what is heard and what is seen. A general model for how this might be realised, albeit lacking in detail, had been conceptualised at the outset of the study. The device would generate musical tones. An analogue tonoscope would display physical cymatic patterns induced by this sound. These patterns would be captured by a camera, processed and then projected onto a screen. Superimposed over them would be real-time motion graphics derived from a secondary but integrated emulated tonoscope. This virtual system, modelled according to real-world physics and mathematical laws, would behave like the analogue device, yet have the ability to be extended, twisted and abstracted in ways the analogue never could. In combination the analogue and digital elements would create an augmented device where real and virtual outputs interplayed and were artistically analysed and treated.

With the instrument so central to the study, it was appropriate to find a relevant framework that might position *The Augmented Tonoscope* within a genealogy of similar devices, as well as inform its development through discreet stages. A suitable frame of reference was found in the history of instruments argued by Hankins and Silverman (1995) - from the "devices of wonder" of natural magic circa the 16th century, through the instruments of demonstration of natural philosophy of the 17th & 18th centuries and onto the devices of entertainment, art and culture of the modern era. An exemplar that illustrates these evolutionary stages is the wondrous "magic lantern", which led to the demonstrable overhead projector and onto the entertaining cinema projector. *The Augmented Tonoscope* reflects these aspects too - attempting to re-capture something of the sense of awe and wonder in the world around us; showing an adeptness for use within experimentation, observation and demonstration; and generating audiovisual works of a different quality for installation, screening and performance.

> Historians and philosophers of science traditionally debated the relative roles of observation, experiment, and theory in science with the assumption that instruments are made and used in obvious ways in response to the demands of observation and experiment. More recently they have begun to recognise that instruments are much more problematic. Instruments have a life of their own. (Hankins and Silverman, 1995:5)

In asserting that instruments do not merely follow theory, often they determine it - because they offer new possibilities and so open new lines of thought - the authors also validate this research's instrument making method. This suggested a welcome potential for speculative development through the praxis, effected through the instrumentation of *The Augmented Tonoscope*.

Yet subsequent research of academic and artistic literature that might inform and guide this method uncovered limited role models. Despite a rich tradition of instrument making within *Visual Music* (McDonnell, 2007) - resulting in the many mechanical light-projection inventions which include colour organs and Lumia - this new audiovisual instrument was not based on mapping qualities of sound to qualities of light. As such, these historical devices had limited relevance to the study. A broader perspective of contemporary musical instrument design, while certainly fertile and diverse and which provided useful insights and techniques, failed in an overarching way, to engage with the ambition for *The Augmented Tonoscope*. The goal wasn't to build a modern evolution of an existing instrument; or to explore the potential of new technological platforms for audiovisual composition; or to experiment with novel musical interfaces - as foci which typify the field of "designing human-computer interfaces and interactions for musical performance" (NIME, 2014:online) promoted by the likes of NIME - the International Conference on New Interfaces for Musical Expression. Even current Cymatics research and art practice yielded limited precedents. The design and intimate workings of the *Cymascope* coinvented by John Stuart Reid - "a scientific instrument that makes sound visible" (Reed, 2008:online) - is carefully safeguarded and protected through patent. With the notable exception of Suguru Goto's *Cymatics* (2011), the various sound visualisation tools and techniques documented by those artists who employ Cymatics within their work can hardly be described as instruments.

So this research turned to and built upon an MA and subsequent artistic and professional personal practice developed through numerous technically challenging creative and commercial projects. Especially in realising intuitive, real-time, interactive audiovisual performance systems while exploring the complexities that underpin them - through collaborative projects such The Sancho Plan (2013) and Monomatic (2009). However, this had invariably meant working with others - often in large collaborative teams with multiple skill sets and clearly delineated areas of responsibility.

In contrast, the Ph.D. offered a rare opportunity to explore individual practice and develop personal expertise across the many aspects of realising artistic works. This meant being cognisant of a personal creative process and more aware of its dynamic, pulse and trajectory - letting these factors guide progress iteratively and in intended rather than incidental ways. So responding to an artistic preoccupation with the act of 'making' - of engaging with "a growing community of makers who bring a DIY mindset to technology" (Maker Media, 2004:online) - determined a primary creative technological strategy for this study. Drawing heavily on the *maker* modus operandi prescribed building an instrument from scratch, with minimal help and at own expense - using contemporary computer aided manufacturing (CAM) technologies and open-source micro-controller platforms and creative coding environments alongside a distinct bias towards *technology misuse* - working with unconventional materials, repurposing tools, modifying commercial products and using 'found' items for purposes other than that for which they were designed.

4.3 On Making An Instrument as Method

Still, settling upon the design, fabrication and crafting of an instrument as a key method from the outset and pursuing this *maker* strategy as core process had its strengths and weaknesses.

It certainly provided a clear, robust and extensible framework for applying Practice as Research. Despite a personal practice which is decidedly experimental and occasionally playful, it is also intrinsically systematic - conceptualising a work; planning a course of implementation; managing the realisation through a running list of 'things to do' (continually refined and reorganised to identify next steps and shift priorities); and documenting and assessing developments as work progresses. In some ways, akin to Descartes' four rules of method as described by Peters (2009) who argues that Descartes' discourse amounts to a patient method, a slow walk, one step after another.

While unconventional, it offered potential benefits, allowing the study to:

- build a custom tool designed specifically for the job - a device that behaved in ways determined by the research;
- engage in a design dialogue with the device - allowing it to inform and contribute to the design process;
- develop an intimacy with the device - making interaction with it more intuitive like a musical instrument;
- follow a slow, step-by-step, back-to-basics approach - facilitating a deeper gaze into the simple interplay and elemental relationships between sound and image (particularly in the early stages of the research) and without the distractions of more sophisticated commercial tools and software;

- court serendipity or “the art of making the unsought finding” - by being more open to *‘happy accident’* and the latent potentialities within custom made electronic circuits and creative code.

Yet a strategy based in a personal enthusiasm for the burgeoning *maker* movement had its downside. It channelled the study into a speculative, iterative design process with unexpected outcomes. Considerable effort was put into pursuing certain lines of thought or solving specific technological challenges only to reject the results as developmental cul-de-sacs later on. There were also several fabrication bottlenecks - particularly in the earlier stages of the research, while the grasp on the instrument was still nebulous - when realisation of a particular component or stage in the process was stymied by either the limitations of a chosen solution, technical expertise or available resources. Occasionally, it became evident that a course of development simply couldn’t be realised - so there was no option but to concede defeat, learn from the failure, retrace steps and look for alternative routes. These junctures, while intrinsic to the method, were often a precursor to a watershed in thinking.

Moreover, while artists have always worked with new technologies, an inherent danger is a tendency towards a technological fetishism - founded on an erroneous belief that the novel will lead to the innovative. Moritz (1986) illustrates this through

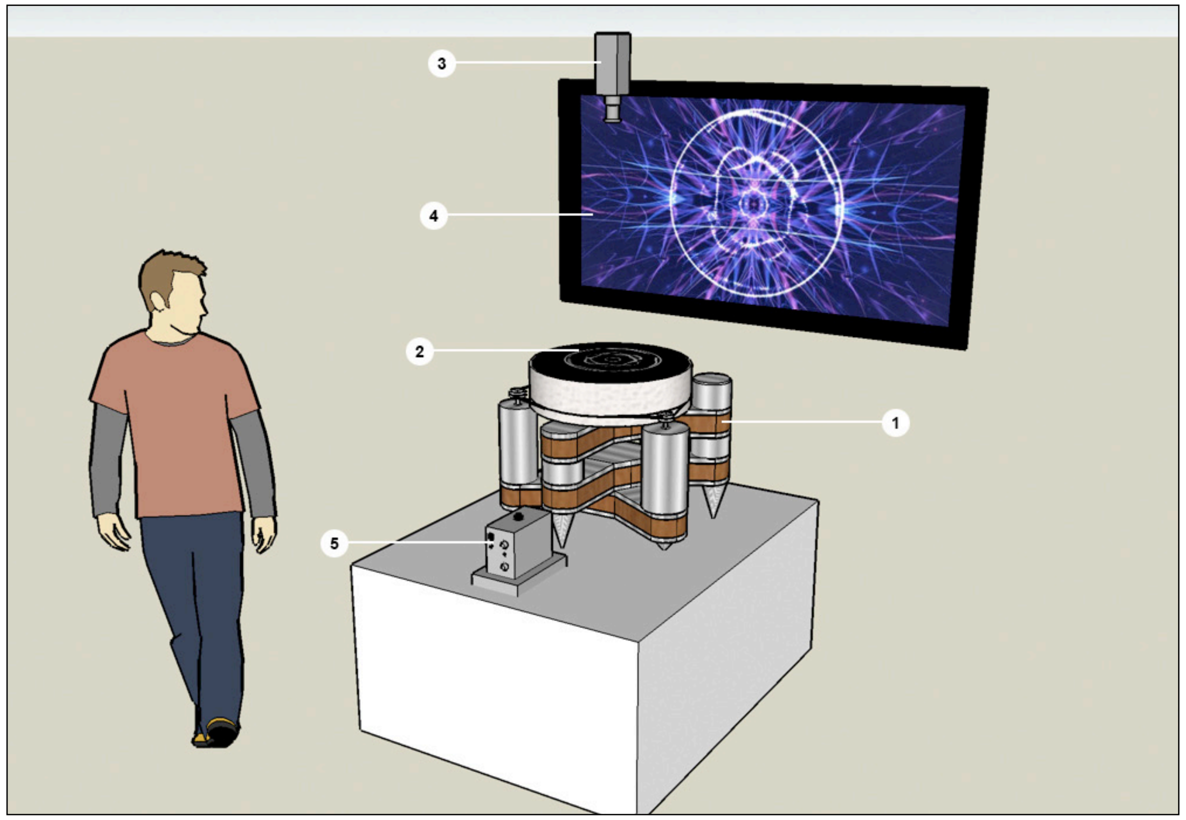


Figure 9 - A SketchUp mock-up of *The Augmented Tonoscope*

As prepared for the initial Ph.D. interview Keynote presentation, May 2010.

his “delusion of technology” - that the history of audiovisual art is littered with new inventions heralded as breakthroughs by their inventors which history shows us to be little more than technological dead-ends and eccentric curiosities.

So this *maker* strategy had to be moderated - utilised for as long as it remained useful without becoming dogma. This became increasingly evident as the study progressed - the research process needed to be adaptable as the practice demanded a more efficient use of time and a more effective pursuit of results. As such, the use of micro-controllers, creative coding and computer-aided manufacturing within *The Augmented Tonoscope* is not significant in and of itself - they are just the tools of this time at the practice’s disposal.

The intent was always to follow a considered and pragmatic approach to the technical problem solving required to turn theory into practice - to implement and investigate those principles, approaches and techniques revealed through the literature that seemed to resonate with the study - and which, more significantly, could only be tested and realised through the practice, making the practice itself the research. As an electronic arts practitioner, creative technical problem-solving is inherent to the practice - the realisation of artistic ideas frequently depends upon finding and implementing unorthodox technological solutions. So the adage of “writing as thinking” (Menary, 2007) commonly cited within Ph.D. study is reflected in an implicit maxim of “making as understanding” within electronic arts.

The Augmented Tonoscope was imagined, comprehended and rationalised through the act of making it - and as a result, the conception of the instrument changed over the course of the study.

4.4 From Mental Model to Physical Device

Snapshots of the instrument at its conception and two years into its realisation illustrate its transition from an object of the imagination to working prototype.

An early SketchUp mock-up (Figure 9) illustrates how the instrument might be exhibited in a gallery setting. A physical device (1), drawing on the aesthetic and minimalist styling of audiophile turntables, generates a cymatic pattern (2) induced by sound. This pattern is captured by an overhead camera (3) and projected onto a screen. Superimposed over and augmenting this pattern is a visualisation generated from a virtual system (4). A controller (5) allows the user to interact with the device and adjust its output.

Figure 10 - *The Augmented Tonoscope* showcased at Brighton Mini Maker Faire 2012, UK, 8th September 2012

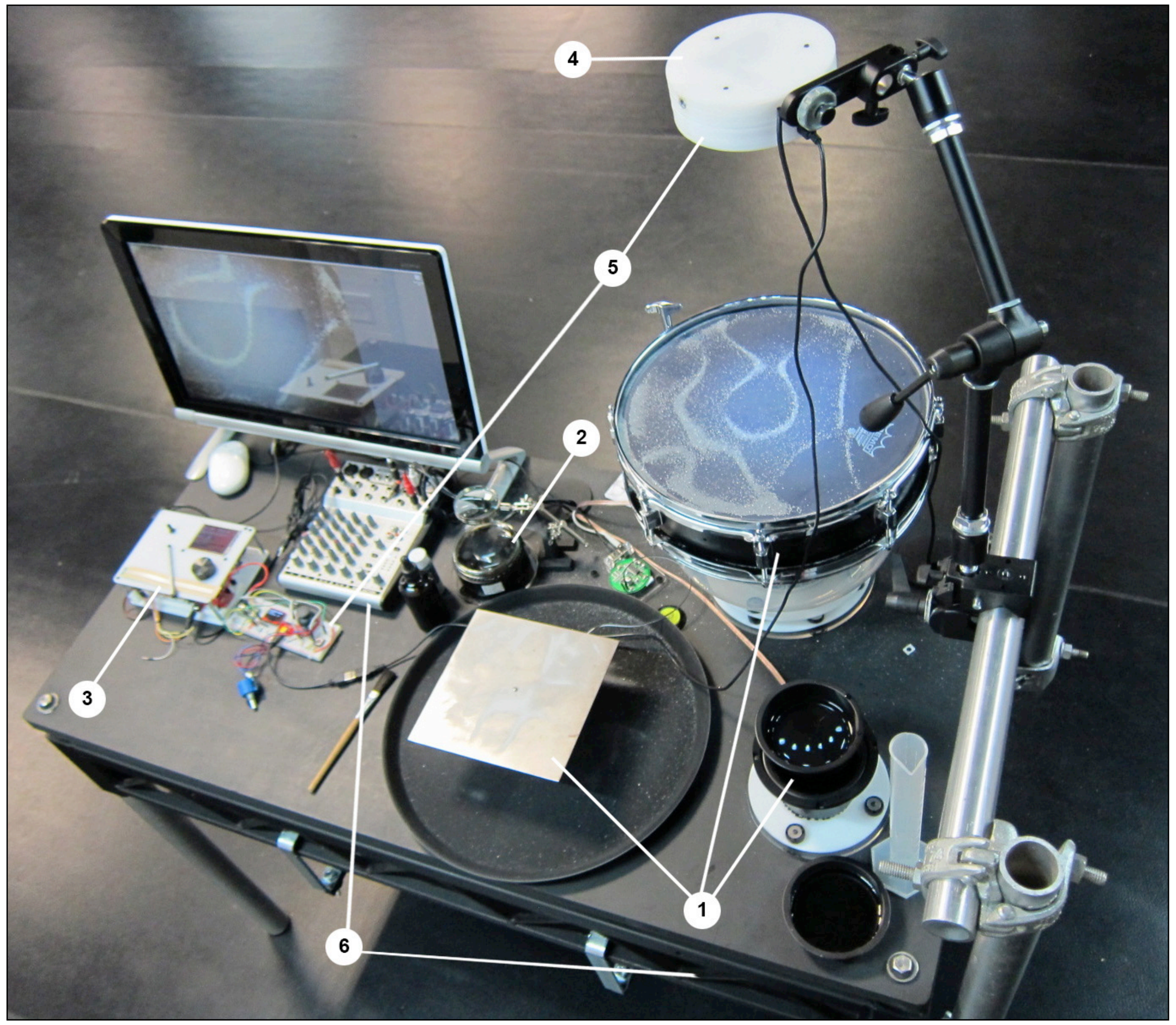


Figure 11 - *The Augmented Tonoscope* showcased at BEAM 2012, Brunel University, UK, 22nd-24th June 2012

Almost two years into the study, and despite an emerging industrial/scientific aesthetic, the instrument (Figure 10) retained the components outlined above. It had three physical devices (1) that generated cymatic patterns induced by sound (and a fourth (2) exploring the magnetic properties of ferrofluid). These patterns were captured by an overhead camera (3) and displayed on a monitor - although the visualisation generated from a virtual system had not yet been integrated. Various controllers (4) and a tailor-made musical interface (5) allowed the user to interact with the device and adjust its output.

4.5 Key Developmental Stages

Understanding the evolution of the instrument from concept to prototype requires highlighting key stages of its development.

Between May-November 2011 studio focus was on experimenting with different approaches to analogue tonoscope design. This resulted in a family of devices integrating speakers and transducers that created distinct cymatic patterns on the surface of:

- liquids in small bowls;
- plates of different size, shape and material;
- and the drum skin of an adapted 16” floor tom.

Interestingly these various device types provided distinct ‘windows’ onto different ranges within the sonic spectrum - the liquids at low, inaudible frequencies between 8-25 Hz, the drum skin at audible frequencies between 80-500 Hz and the plates from 400 Hz and upwards. So rather than limit the instrument to a single cymatic pattern device, all of these analogue tonoscope types were incorporated.

By June 2012 and for *The Augmented Tonoscope* showcase at the BEAM 2012 Open Call at Brunel University, UK the instrument had started to take on a distinct form (Figure 11). It comprised several hand-fabricated, ‘modded’ and custom-coded prototype components:

- three analogue tonoscope devices (1) - including a next stage development of modifying drums by adapting a 13” piccolo snare;
- a device exploring the magnetic properties of ferrofluid (2);
- a sine wave generator (SWG v3.0) (3);
- a PlayStation3 Eye camera (4) which captured the cymatic patterns and displayed them on a 22” touchscreen monitor via a video processing openFrameworks sketch;
- an LED ring light with a rudimentary controller (5) to create various lighting effects;
- audio mixer and amplifier (6);
- and a customised presentation table.

By September 2012 and for *The Augmented Tonoscope* showcase at the Brighton Mini Maker Faire 2012 it has been further refined to include (Figure 10):

- a final iteration SWG v4.0 including wireless control via an iPad;
- a *Frequency Measurement* device that provided accurate evaluation of pitch to 0.01 Hertz;
- a completed controller for the LED ring light - with these three units mounted side-by-side (from left to right) in a modular frame;
- an updated audio mixer;
- and a tailor-made musical interface driven by a monome64 - a minimalist, ergonomic controller with an 8x8 grid of buttons.

Having combined prototype analogue tonoscopes and video capture with sound making and analysis devices accessible through a musical interface - the instrument had developed to the point where it was possible to play musical tones; induce cymatic patterns; and capture, process and display these forms on a screen. While progress was promising, future development still required integrating the virtual system that would augment the physical cymatic patterns with computer animations and more significantly, a mechanism for composing audiovisual works by recording and editing live performance and sequencing individual parts.

Several prototypes of virtual models as Processing and openFrameworks sketches had been realised. There was also a working prototype of a novel composition tool, inspired by a family of node based sequencers, that would enable the recording, editing and sequencing of musical refrains - not as the traditional notes along a score but rather as a series of interconnected nodes (see Section 5.7.1 Ki-No-Seq (Kinetic Nodal Sequencer). However, the various standalone prototypes had yet to be integrated into a single, 'über' control system.

The idea for an overall design was relatively clear - a 2D 'floor plan', akin to an architectural drawing, positioned within 3D space, with distinct zones where the graphical user interfaces (GUIs) for the various components would lie side-by-side. An additional 'heads-up display' (HUD) would provide an overview of the system - yet it would be possible to move around and 'zoom in' to particular functionality as required. Integrating the existing standalone sound generation and analysis, video capture and processing, emulated tonoscope and musical interface components into this layout was relatively straightforward if onerous.

However, significant problems emerged with the recording and sequencing component - a notoriously difficult area of implementation within custom-coded musical software solutions due to the challenges involved in maintaining an accurate and dependable musical clock while accommodating all the other demands on the system. As a standalone, the nodal sequencer prototype

managed to keep time, but adding other processes caused timing glitches and drifts. Despite many weeks of development attempting to integrate the various components and overcome this issue, it proved impossible to achieve the essential requirement of an accurate and dependable musical clock. This turned out to be a critical bottleneck in the progression of the instrument - as it became increasingly evident that this course of development couldn't be realised within the timeframe of the Ph.D. without additional help and resources.

4.6 A Modular Performance System

Thinking generally about the nature of musical instruments had helped develop an initial conception of *The Augmented Tonoscope*. A common understanding is of a device created or adapted to make musical sounds, integrating:

- a mechanism for generating sound;
- an interface for playing different tones;
- and means to amplify and modulate the sound.

Despite this in-built multifunctionality, the instrument is considered complete within itself - a distinct object. The initial attempt to design a single, overarching control system for *The Augmented Tonoscope* was based on this premise. Although the various components had been developed independently alongside suitably sourced and modded 'off-the-shelf' solutions, they fitted together into an overall conception of the instrument as complete within itself - a distinct object, or rather set of objects. Yet the bottleneck in this course of development forced a reconsideration of this idea.

The solution was to shift perspective and to conceive of the instrument in a different way. On reflection - and by allowing the emerging instrument to inform and contribute to the design process overall - the early standalone prototypes actually intimated a complex union of discreet modular components that would collectively produce the functionality of *The Augmented Tonoscope*. More akin to the haptic and almost organic form of the modular synthesiser with its separate yet interconnected specialised modules, than to a minimal, integrated audiovisual system such as Suguru Goto's *Cymatics* (2011). Describing the system through these modules would allow the research to highlight specific features of the instrument, and more importantly, illustrate the way these modules integrated - to define the connections between them. Appropriately, this perspective also reflected the alternative approach that had been argued could describe and define the research overall - as something more akin to an emergent system, a network of inter-relationships, connections and congruences.

So the study came to conceive of *The Augmented Tonoscope* as a modular performance system comprising of the following discrete, specialised but interconnected *'modules'*:

- sound making;
- sound analysis;
- analogue outputs;
- virtual systems;
- musical interface;
- recording and sequencing.

Once considered in this way, the research had a viable framework for developing and refining the functionality of individual modules - through a more independent and parallel design process that could overcome the blocks experienced in the earlier, more linear developmental model. Still, a significant repercussion of this shift in perspective, would most likely be that while certain modules would develop well beyond initial expectations, others would not. So it was unlikely that the instrument would be completed within the course of the study, and as a result, it would not be possible to produce a series of artistic works for live performance, screening and installation using it. However, it would be possible to produce a series of artistic works that reflected the development of specific modules - and this is how the research reframed its objectives.

5. A Modular Performance System

5.1 Introduction

This chapter outlines the developmental process involved in the design, fabrication and crafting of *The Augmented Tonoscope* - once it had been conceived as a modular performance system as outlined in Section 4.6 A Modular Performance System.

It details these modules in turn sharing significant underpinning concepts, favoured technical realisations, significant experimental outputs and a critical reflection of research outcomes.

Development within all the modules progressed through several phases each contributing to the ongoing evolution of the instrument. Each phase involved multiple design iterations which produced sophisticated final versions of components compelling in their own right, but which successively failed to deliver an appropriate 'fit' for the evolving conception of the instrument. So progression between phases was frequently the result of rejecting a given technique as a developmental cul-de-sac (or a knock on effect of rejecting development within an associated module) - a consequence inherent within the creative technical problem-solving strategy of the research.

5.2 Sound Making

This aspect of the research focussed on an effective means to generate and control musical tones. *The Augmented Tonoscope*, though described as an audiovisual instrument, has a hierarchy and natural ordering of sonic and visual components - and it begins with sound - *sound making* is primary. The physical cymatic patterns of the *analogue outputs* are induced by sound. Early *virtual systems* were driven by analysis of sound.

Research into Cymatics indicated essential requirements for any sound making technique:

- Tones needed to be simple and 'pure' - the smooth repetitive oscillation of the sine wave. The timbres that characterise traditional musical instruments and synthesiser patches are the result of a complex blending of wave types, harmonics, resonances and dissonances which would likely muddy the search for distinct cymatic pattern;
- High quality sine waves were vital - lower grade stepped approximations would likely introduce visual artefacts created through unwanted noise;
- Frequencies needed to be accurate and consistent - to an increment approaching one-hundredth of a Hertz and maintained without wavering. This

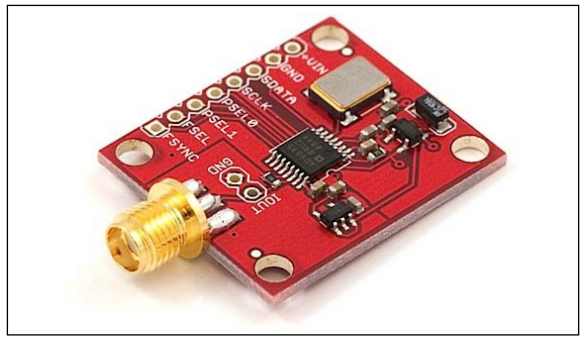


Figure 12 - AD9835 Signal Generator with Sparkfun Breakout Board

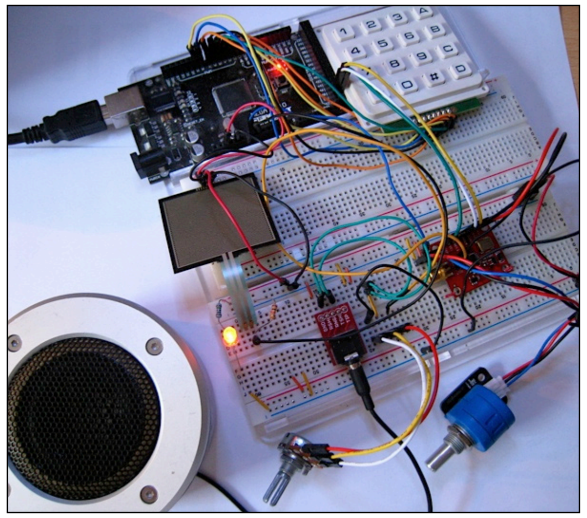


Figure 13 - SWG breadboard prototype

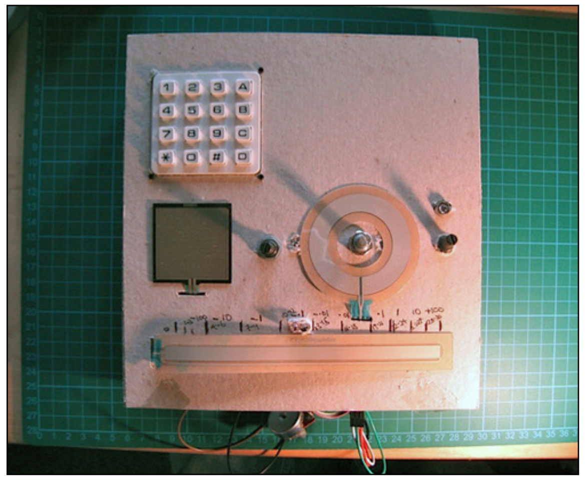


Figure 14 - SWG v1.0

Figure 15 - SWG v2.0

resolution of pitch adjustment, while imperceptible to the ear, would allow for a level of fine tuning that might reveal subtlety and nuance - particularly in the steady vibrational states of liquids in bowls which occur at low frequency and over a relatively narrow frequency range of 8-25Hz.

While it would have been easy to buy a commercial tone generator, what was required was a custom-made device designed specifically for the job.

5.2.1 Sine Wave Generator (SWG)

An obvious starting point was exploring the sine wave generating potential of the Arduino (2014) open source electronics prototyping platform - partly out of a curiosity as to how far the micro-controller could be pushed and partly out of expediency since it could simultaneously control other aspects of the instrument (such as the LED ring light and camera). While there are several ways to generate sine waves with an Arduino, the method which produces the highest quality output with the minimum CPU overhead is by controlling an external, dedicated signal generating integrated circuit (IC) - specifically the AD9835 with Sparkfun (no date) breakout board (Figure 12) driven by an Arduino Mega 1280 clone.

An early breadboard prototype (Figure 13) implemented functionality to:

- change frequency via a helical pot - a DFRobot rotary sensor V2;
- enter a frequency to two decimal places via a keypad;
- switch between the AD9835's two independent (yet not simultaneous) frequency registers using a Force Sensitive Resistor (FSR);
- save up to 9 different frequencies to volatile memory - and recall them via the HOLD event on the keypad;
- save and recall up to 9 different frequencies via non-volatile EEPROM memory - so values could be retained once the device had been powered down.

Early iterations (Figures 14 & 15) structured and refined the initial code, tested physical layouts and integrated:

- a touch sensitive slider divided into sectors to provide 'finger-on' frequency increase and decrease in increments of +- 0.01, 0.1, 1, 10 & 100 Hz - via a Spectrasymbol Softpot Linear 170mm;
- a touch sensitive wheel as the coarse component of a 'two-ring' input system - via a Spectrasymbol Softpot Rotary;
- switching between various operational modes - via a simple state machine architecture and Bournes ECW Digital Contacting Incremental Encoder;
- low frequency oscillator (LFO) like control between frequencies: a simple sinusoidal and square wave with pulse width modulation - via found Arduino libraries;
- a better quality logarithmic audio volume pot;
- and hefty, tactile knobs for the pots and encoder.

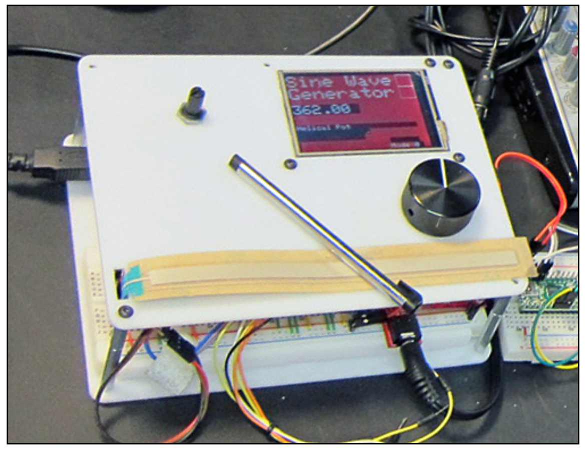


Figure 16 - SWG v3.0

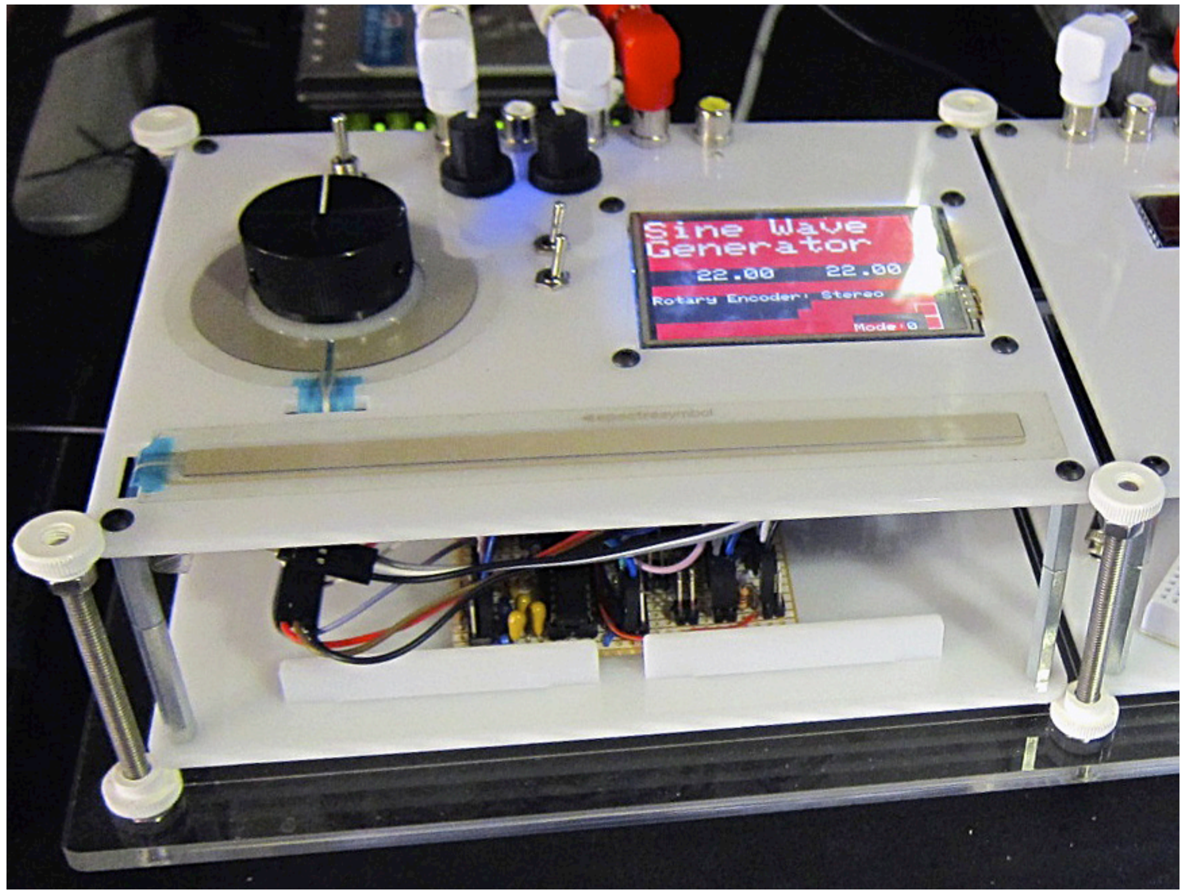


Figure 17 - SWG v4.0

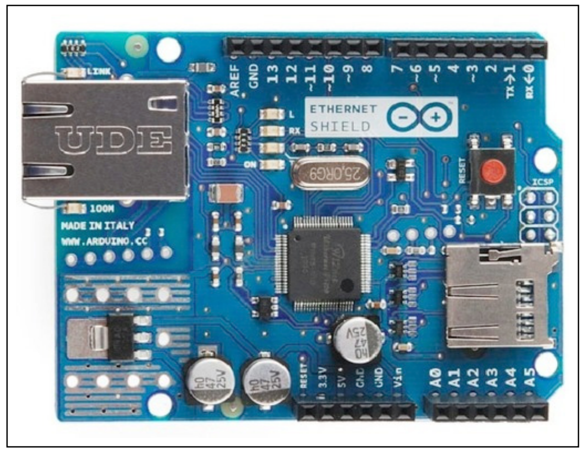


Figure 18 - Arduino Ethernet Shield R3

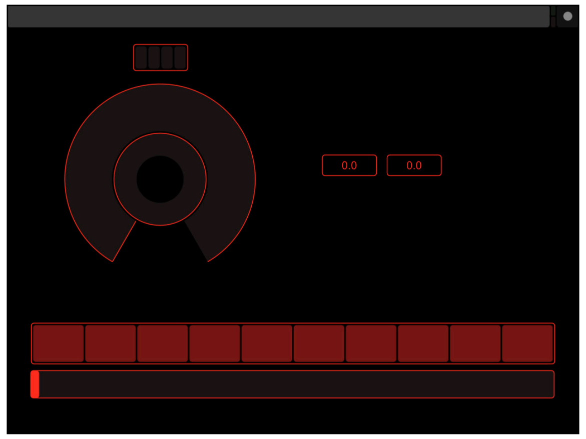


Figure 19 - SWG v4.0 TouchOSC interface

Although v2.0 had an Adafruit 2.8" TFT LCD Touchscreen and a button and pot intended for the LED ring light control fitted, these weren't integrated in time for its showcase at the Practice, Process and Reflection (PPR) group *State of Play…* exposition at RIBA Hub, Manchester, July 2011. While the device was temperamental, as a *proof of concept* it had a fair degree of hands-on control and sufficient range in its various modes of operation to demonstrate a potential for musical expressivity - a prerequisite for the project overall.

SWG v3.0 (Figure 16) was more streamlined and portable - with a single encoder, helical and Softpot Linear pots - but also integrating the colour LCD and touchscreen functionality:

- displaying operational modes and values for several SWG variables;
- and replacing earlier physical sensors, buttons and switches with 'virtual buttons' (the two white square outlines just visible in the upper right of the screen were first iterations).

However development focussed on extending the automation of portamento - controlling the way the SWG moved between two frequencies - as detailed in Appendix 2 - Automating Portamento. Yet despite some success using the techniques developed, the sweep through the frequencies was blocky - the Arduino couldn't process the Serial data stream quickly enough. To produce real-time, smooth frequency curves required stripping out all but the essential tone generating functionality from the code - a somewhat retrograde step. The Arduino Mega 1280 DFRobot clone was overstretched, so the micro-controller was upgraded to an Arduino Mega 2560 R3 and the code was rationalised and optimised for an SWG v4.0 (Figure 17).

This final iteration incorporated much of the previous functionality into a more streamlined, ergonomic and practical design. The main additions were:

- an emulated keyboard mode - via the Spectrasymbol Softpot Linear 170mm;
- remote control via OSC or Open Sound Control (Center For New Music and Audio Technology, no date) - integrating an Arduino Ethernet Shield (Figure 18) and developing a TouchOSC (hexler.net, 2014) interface on an iPad 2 (Figure 19);
- a second AD9835 signal generator - turning the SWG into a two voice, dual oscillator device;
- and a mixable stereo and two mono audio outputs plus power and I2C[12] data buses.

[12] I2C (Inter-Integrated Circuit), pronounced I-two-C, is a multi-master, multi-slave, single-ended, serial computer bus invented by Philips Semiconductor used for attaching low-speed peripherals to computer motherboards and embedded systems (i2c-bus.org, no date).

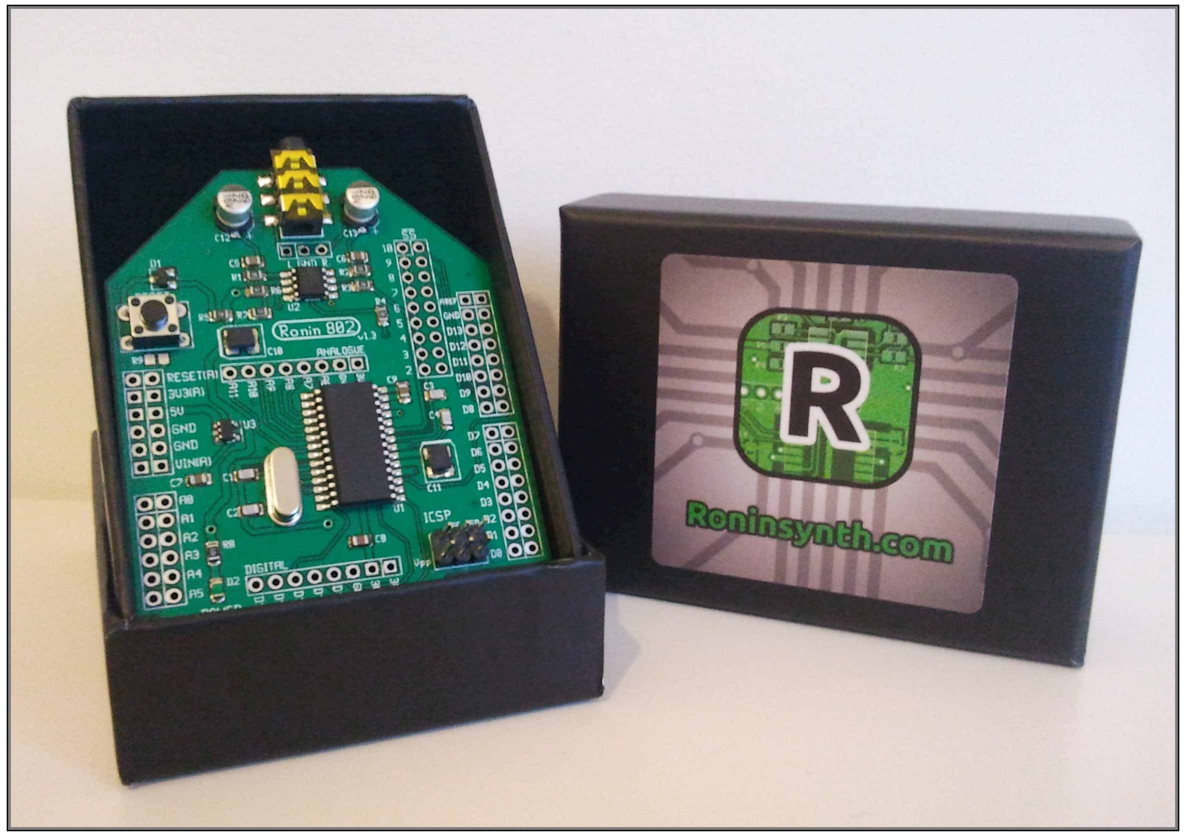


Figure 20 - Ronin 802 stand alone digital synthesiser

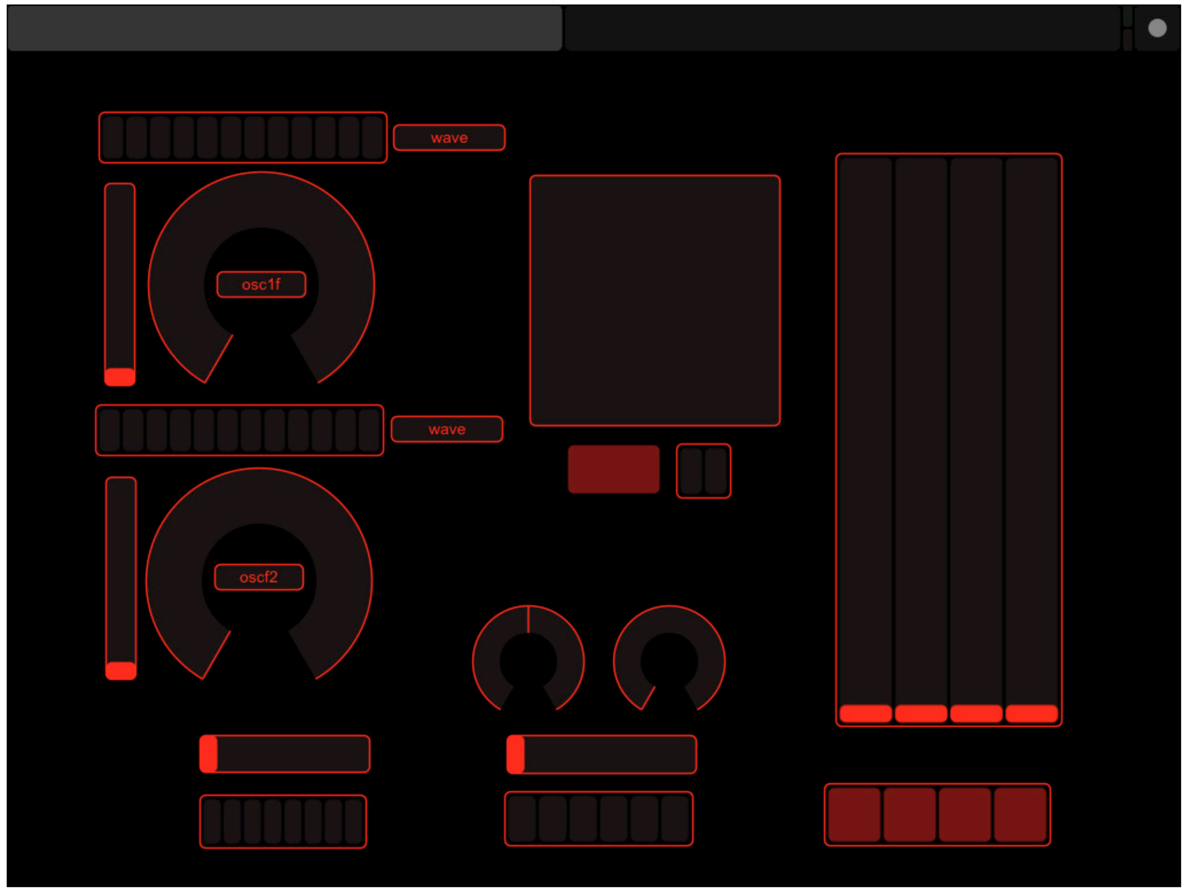


Figure 21 - Ronin TouchOSC interface

The SWG could now store a set of frequencies that induced distinct cymatic patterns and play them back using the Softpot Linear touch sensor or TouchOSC interface like a keyboard - essentially a *cymatic scale* with a set key for a given pattern. Exploring the dual oscillators, also produced sonic detuning and beating effects which created fascinating pulsing and transitionary effects between cymatic patterns.

Yet the device had distinct issues. Phase offsets between the two AD9835s caused intermittent destructive interference in the mixed audio output, reducing the volume and affecting the tonal colour - and there was no easy way to overcome this. Also the SWG output pure unmodulated sine waves, resulting in a percussive attack and fixed volume whenever a frequency was triggered. A custom-made amplitude envelope circuit using an AD5206 digital pot may have overcome this - but at the risk of 'reinventing the wheel'.

So while the back-to-basics strategy of building the various components of *The Augmented Tonoscope* from scratch had proven valuable in allowing early functionality to grow more organically as well as shaping thinking about the instrument overall, it appeared that it had run its course and exhausted its usefulness. This meant leaving outstanding issues within the current iteration of the SWG and aligned components unresolved.

5.2.2 Ronin Synth

Needing a more sophisticated tone generator but reluctant to abandon a *maker* ethos and buy a commercial device led to the Ronin Synth (Figure 20) (Sonodrome, 2011) - *"... a new breed of stand alone digital synthesiser. This programmable hardware module is a versatile platform for the creation of custom electronic musical instruments and sound processing units. The Ronin 802 is also a fully compatible Arduino shield ..."* (Sonodrome, 2011:online).

Its specifications were appropriate - stereo output, dual oscillator, 16-bit stereo DAC @ 100KSPS, 5 different waveforms, 6 different modulation types and multiple sound manipulation modules. Within an hour of setup and testing, a single shot dual sine wave with an ADSHR envelope and global volume and balance had been created - exceeding the functionality that had taken about a year to realise with the DIY SWG.

While much of the implementation for the SWG input hardware could be ported to the Ronin easily enough, the more promising remote control via OSC required re-integrating the Arduino Ethernet Shield and developing a new TouchOSC interface (Figure 21). However, this proved a time-consuming and somewhat hit and miss exercise:

- OSC frequently froze (though this could have been due to unresolved SPI conflicts between the Ethernet Shield and Ronin);

- adjusting the Ronin parameters via OSC caused multiple glitches and pops in the output signal (most likely as the Arduino tried to juggle between reading and sending OSC via the Ethernet Shield and controlling the Ronin);
- and the Arduino code became a complicated mass of functions for reading and sending the numerous OSC messages (GUI's are notoriously longwinded to programme).

Moreover, the longer spent working with the Ronin Synth the greater the suspicion that the module itself was quirky. Certain controls only worked intermittently in the RoninGUI and didn't seem to work at all over OSC, while others seemed to have no effect at all. Also the quality of the Ronin's sonic output was questionable with unwanted artefacts audible in its output - particularly at low frequencies. The AD9835 based SWG, despite lacking much of the Ronin's functionality, did at least produce a very clean and pure sine wave.

So concluding that the Ronin Synth was another developmental cul-de-sac, the research looked for an alternative and faster-track approach - choosing to dispense with micro-controller based hardware altogether.

Figure 22 - KORG MS2000 synthesiser

5.2.3 Maximilian Library

The solution was computer software based - specifically Dr. Mick Grierson's *Maximilian* C++ Audio and Music Digital Signal Processing (DSP) Library (Grierson, 2011) within the C++ creative coding toolkit, openFrameworks (oF). Designed to be cross platform and simple to use it easily generated tones, amplitude/frequency modulation and envelopes and filters. Yet Maximilian also presented significant additional benefits:

- It would make the instrument more self-contained. Audio could be generated from within the oF sketch rather than produced externally and controlled by the oF sketch (albeit with an additional overhead for the computer). This would streamline things considerably - there'd be no external Arduino driven tone generator, no WiFi router or Arduino Ethernet Shield to enable remote control via OSC. More significantly, development in this area could easily be shared with advisors and supporters - something that hadn't been possible with earlier 'one-off' custom hardware;
- It featured a reliable timing mechanism - promising a possible solution for driving a tailor-made recording and sequencing mechanism. Prior efforts had involved faltering attempts to route MIDI Time Code and MIDI Clock into oF;
- With its scalable software implementation, it had the potential to be a more sophisticated sound source than the Ronin and easily the SWG - and within a context of a sound synthesis architecture that was well understood.

Somewhat seduced by the potential of Maximilian, development bypassed an oF based version of the SWG in favour of emulating the functionality and architecture of a previously owned and nostalgia inducing synth - the KORG MS2000 (Figure 22) (vintagesynth.com, 1996-2014). Its intuitive signal processing flow seemed a useful reference and starting point, though this wasn't to be a faithful recreation.

The final version of the *Maximilian KORG MS2000 Emulator* (Figure 23) featured a signal flow much akin to a KORG MS2000:

- dual oscillators - each with selectable wave types - sine, triangle, saw, square - and for VCO1, an additional pulse wave type with variable width;
- a white noise generator;
- dual LFOs to modulate the VCOs - LFO1 for VCO1 and LFO2 for VCO2, each with selectable wave types - sine, triangle, saw, square - and variable depth and rate;
- VCO2 could also be set to modulate VCO1 as well as recreate the distinctive sync and ring modulation effects characteristic of analogue synthesisers;
- a VCF filter section - with selectable hires and lores filter types and variable frequency cutoff and resonance;
- a MIXER section - to adjust the relative volumes of the VCOs and noise as well as add distortion and switch between stereo, auto pan, left and right output types;

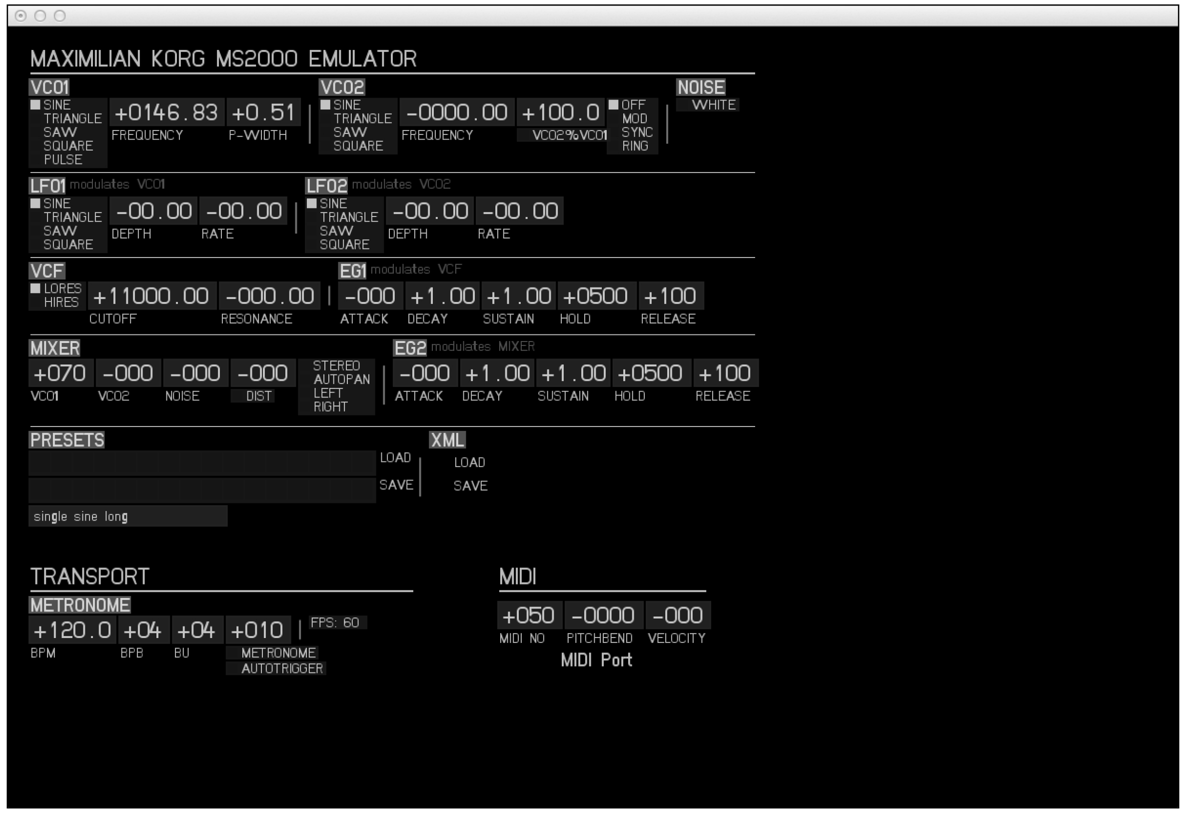


Figure 23 - *Maximilian KORG MS2000 Emulator* - a virtual synthesiser using the *Maximilian* library and emulating the signal processing flow of the KORG MS2000

- dual envelope generators - ADSHR type with variable attack, decay, sustain, hold and release. EG1 created time-variant change in the filtering, EG2 created time-variant change in the amplitude;
- six voice polyphony.

Additionally it featured:

- functionality which locked VCO2 to a percentage of the VCO1 frequency to create fixed tunings between the two;
- presets - named patches which could be refined and saved to one of 16 memories and recalled, updating the GUI in the process. A bank of 16 patches could be saved to an XML file and reloaded;
- transport - a metronome with adjustable volume, BPM (beats per minute) and time signature and an auto-trigger mode which played a single voice of the synth on every beat (useful for refining the sound of a patch without having to physically trigger a note);
- input via OSC - frequencies generated from the *Lamdoma Monome* developed within the *musical interface* module and detailed in Section 5.6.2 Lamdoma Matrix & monome64 could trigger tones;
- input via MIDI - selectable MIDI In port from a drop down list of available system ports and display of incoming MIDI Note No, pitch bend and velocity values.

An evolutionary leap from the SWG, it made some phenomenal sounds, although there were still noticeable artefacts in the audio output. Yet in responding to both input via OSC and MIDI it proved a flexible, custom-coded tone generating tool and was used in studio tests comparing the physical patterns produced by the modified 16” floor tom and 13” piccolo snare tonoscopes of the *analogue outputs* module to the ideal computer model drum skin of the *virtual systems* module as detailed in Appendix 3 - Comparative Tests to Virtual Drum Skin.

Still, on switching to the commercial Digital Audio Workstation Ableton Live Studio 9.1 (Live) (Ableton, no date) within the *recording and sequencing* module, it was limited compared to commercial software synths such as Native Instrument’s *Massive* and U-he’s *Diva*. While it could be triggered via MIDI from Live as an external standalone it was cumbersome compared to these soft synths which are integrated within Live using the Virtual Studio Technology (VST) and Audio Units (AU) architectures, making access to their control interfaces more direct, intuitive and self contained.

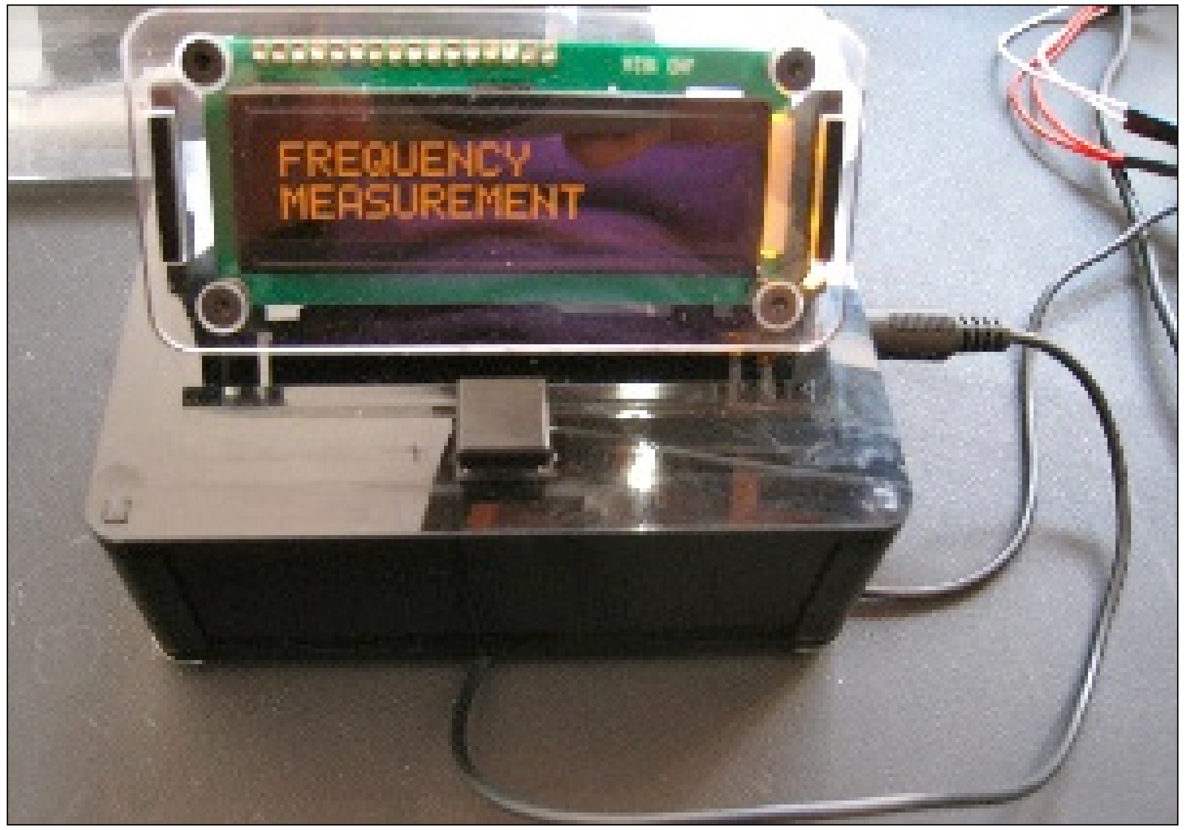


Figure 24 - Frequency Measurement Device v1.0

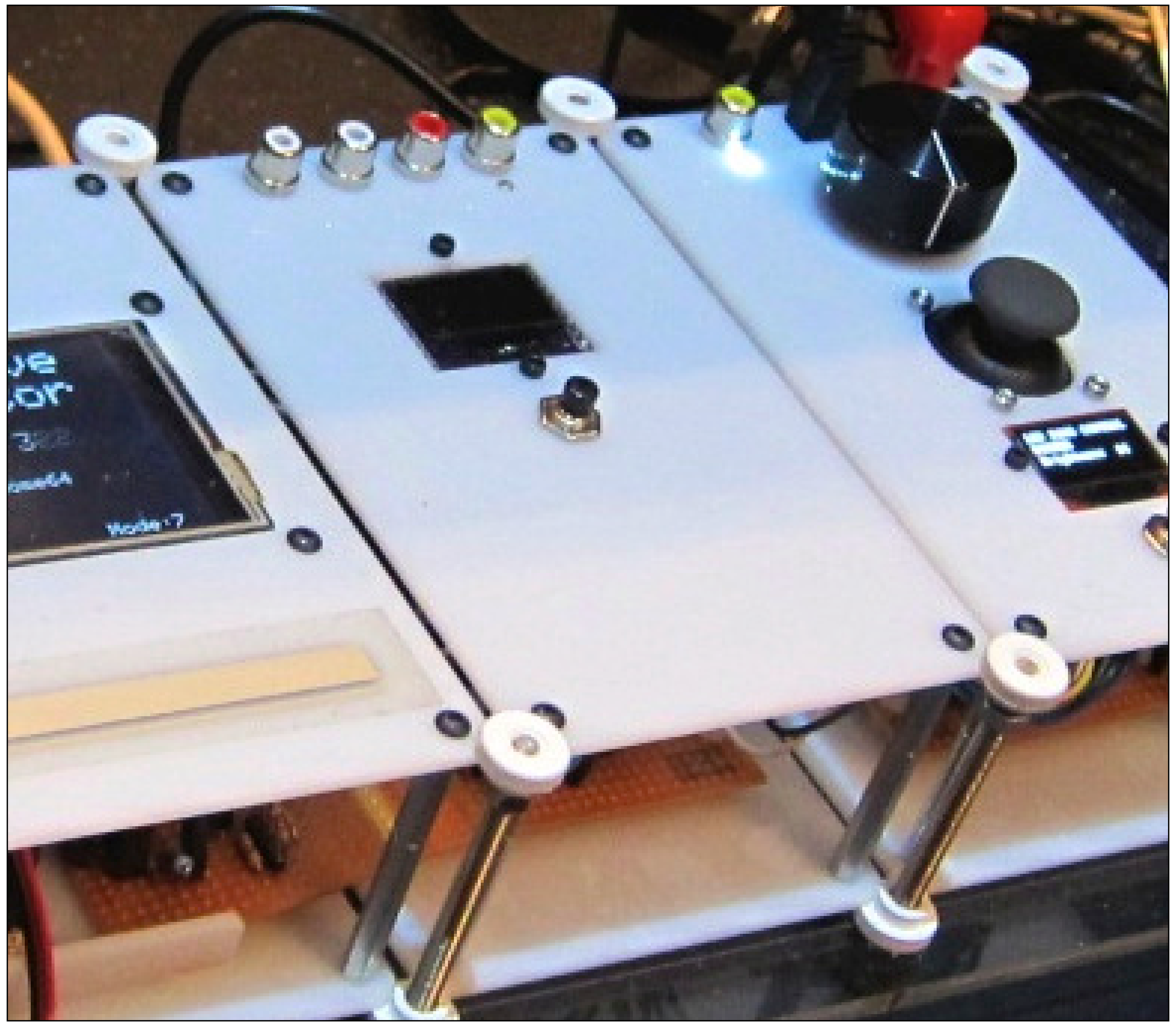


Figure 25 - Frequency Measurement Device v2.0

5.3 Sound Analysis

These sound making devices generated tones of specific frequency and with a fine resolution of adjustment. Yet shortcomings inherent in their design - the rounding of decimal point values, the prioritisation within the code of generating a tone over the display of its value - meant there could be inconsistencies between the actual frequency produced and the value displayed. This demanded a separate unit for accurately measuring and calibrating frequency - to know a frequency precisely to two decimal places. Furthermore, as development within the *virtual systems* module progressed, it became necessary to analyse sound in real-time - to extract frequency and amplitude values from live musical performances and audio recordings and use this data as input to drive the digital visualisations.

5.3.1 Frequency Measurement Device v1.0 and v2.0

An initial found solution came via the Frequency Measurement Library (Lab3, 2010) developed by Martin Nawrath at Lab3 - the Laboratory for Experimental Computer Science, Academy of Media Arts, Cologne - *"For frequency measurement in the audio or sub audio range the determination of the signal period length delivers the most accurate results. The architecture of the ATMEGA chip provides a special Counter and Capture unit which is designed to do this job with a high precision"* (Lab3, 2010:online).

For a first iteration (Figure 24), the circuit schematic detailed in the project notes was built on a DFRobot Prototyping Shield for Arduino; the code was tweaked - integrating Arduino libraries to even out occasional spikes and glitches in the measurement through a running average and two alternately calculated running median outputs - with a button to switch between these types; and values were displayed on a 16x2 LCD display driven by a SpikenzieLabs I2C LCD Interface kit. Finally the Arduino and shield; and a 9V battery, power switch and LED were housed in a laser cut acrylic case - with the button and a 16x2 LCD display holder mounted in the top plate.

V2.0 (Figure 25) of the device replaced the original circuit with a rationalised custom-made Arduino shield; the 16x2 LCD with a 128x64 OLED display; added power and I2C data buses; and redesigned the casing so that the unit fit into a modular frame - alongside the SWG v4.0 and LED ring light controller.

5.3.2 Minim library in Processing

A first use of sound analysis to create a sound-responsive digital visualisation was for the *Cymatic Adufe* - as detailed in Section 6.7 Gallery Installation - The Cymatic Adufe. A first iteration, for Porto, November 2012, used the Fast Fourier Transform (FFT) analysis within the Minim library (Di Fede, 2007) in Processing 1.5.1 (Fry & Rea, 2004), to track the melody line of the traditional folk song of the *Senhora do Almortão*. The amplitude of specific notes was used to change the variables within Reza Ali's *2D SuperShapes* sketch (Ali, 2010) creating dynamic naturalistic patterns driven by the music. A second iteration for Lisbon, May 2013 overhauled the sketch significantly - the FFT analysis data was optimised, smoothed and mapped more effectively to the ranges of the variables within the formula to maximise the impact on the dynamic pattern. Also the harmonic relationship between successive notes and the tonic or root note - the song is in C# Major - was used to set the symmetry of the shape.

5.3.3 MaxMSP fiddle~ object

An opportunity to create real-time visualisations to accompany live musical performances, came via an artist residency collaboration with the Manchester Camerata - Manchester's world class chamber orchestra - and specifically their second *UpClose* season - *"*an eclectic series for the curious who want to experience Classic and modern chamber music in a laid-back intimate setting*"* (Manchester Camerata, 2013:online).

The *Cymatic Cello* was performed at UpClose 3 (Manchester Camerata, 2013), International Anthony Burgess Foundation, Manchester, March 2013. The work visualised the slow and very beautiful *Sarabande* from J.S Bach's *Suite for Cello no. 2 in D minor*, as performed by Hannah Roberts, by making the vibratory patterns that occur naturally on the back plate of the instrument visible as it was being played. *Stravinsky Rose* was performed at UpClose 4 (Manchester Camerata, 2013), Deaf Institute, Manchester, April 2013. The work visualised Igor Stravinsky's colourful and witty *3 Pieces for Clarinet Solo*, as performed by Fiona Cross, by adapting a geometric algorithm developed by John Whitney Sr., to create dynamic, alternately diverging and converging, naturalistic patterns, more or less equivalent to the harmonies within the music itself.

Although keen to find more use for the Frequency Measurement device above, computer music producer and researcher Dr. Matthew Yee-King (Yee-King, no date) recommended the most effective way to measure pitch in real-time was the fiddle~ object (for pitch following and sinusoidal decomposition) (Apel & Zicarelli, no date) within MaxMSP- a visual programming language for media (Cycling '74, no date). Ben Lycett helped build a MaxMSP patch integrating the fiddle~ object which tracked the pitch from either an audio file played back from the computer hard

drive or from a live audio input. The patch sent this value out as MIDI pitch values via UDP into the oF visualisation sketch which rounded the value to a whole MIDI number and calculated the corresponding frequency.

For the *Cymatic Cello* this value was used to select and display a processed image nearest in value to the actual note of the instrument being played - from a series of 26 studio photographs documenting the vibrational patterns induced by a given frequency on the back plate of a 3/4 student cello and across its register - from G#2 to A5 (the cello actually has a professional range from C2 to C6, but not every tone produced a discernibly different pattern). For *Stravinsky Rose* this value was compared to the frequency of the dominant note for each of the three works as advised by Fiona Cross (Stravinsky didn't write these pieces in any given key) to calculate a ratio and 'scrub' the rose algorithm to that position along its timeline - as detailed in Section 5.5.3 John Whitney Sr.'s Differential Dynamics.

For the *Cymatic Cello* the MaxMSP fiddle~ object patch was far too jittery, sending out a constantly changing range of values - in part due to the threshold of the mic input but also the realtive coarseness of the object settings. These issues were somewhat resolved for *Stravinsky Rose* for which it behaved much more dependably. It was refined further still for later iterations which used a studio video recording of Fiona Cross performing the pieces. A current iteration of the patch is included on the accompanying hybrid DVD.

5.4 Analogue Outputs

With Cymatics so central to the research, building a device - an analogue tonoscope - which could generate distinct cymatic patterns consistently was paramount. Yet for the device to produce a recognisable pattern for a given tone, essentially a *cymatic scale* (even if this was considered a set of formal constituents for pattern making rather than a call to a musical framework per se) it needed to behave like an instrument - to produce a predictable output for a given input - that is, have 'agency' - "Action or intervention producing a particular effect; means, instrumentality, mediation" (oed.com, 2010:online). This turned out to be far harder than anticipated.

Early research had identified three types of vibrating systems[13] in nature that could produce cymatic effects relevant to this study. These were the steady vibrational states that appear on the surface of:

- thin plates of different size, shape and material;
- liquids in bowls;
- and vibrating diaphragms.

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[13] These systems present two distinct types of boundary conditions - the first fixed at the centre but free at the edge, the latter two free at the centre but fixed at the edge.

The first of these, also known as Chladni plates, is well understood as outlined in Section 1.5 Cymatics.

The second, favoured by Cymatics artists/researchers such as Suguru Goto (2011), Dan Blore and Jem Meninma of cymatica.org (2009) and John Telfer (2010), has as a result, examples of DIY rigs - sound visualisation devices that produce general cymatics effects and the symmetrical multifold shapes of steady vibrational states on the surface of liquids in bowls. However, these are produced at low, inaudible frequencies - 8-25Hz. While audible frequencies do produce patterns on the surface of liquids, they are complex, shifting forms not particularly suitable for exploring a recognisable correlation between cymatic pattern and musical tone. For this system to be a viable way to visualise music requires a dual voice sound making device (the SWG v4.0 had this functionality) - one voice to produce tones in the inaudible range to drive the system and a second, transposed up into the audible range while retaining the harmonic relationship between frequencies.

The third of these systems, used in Hans Jenny's tonoscope and the many table-top Cymatic experiments that employ a rubber sheet stretched in an embroidery hoop (Aeolus Outreach Programme, 2011), is well described mathematically (such as the notes for an an intermediate level course on Mathematical Methods in the Physical Sciences (Royal Holloway (University of London), 1999) and the subject of several scientific and acoustic academic enquiries e.g. (Zhang, & Su, 2005) - yet appears to be relatively unexplored artistically. So although this research investigated and produced devices using all of these systems, it favoured this last approach as the focus for developing its main analogue tonoscope.

5.4.1 Early Studio Prototypes

Between May-November 2011 studio focus was on experimenting with device designs based on these systems - involving a plethora of materials, mediums, containers and audio components:

- thin steel, aluminium, acrylic and vinyl plates / rubber sheets cut from large party and weather balloons and clothing grade black latex / injection moulded plastic trays;
- water, alcohol, glycerol, mineral and vegetable oils, washing up liquid, non-Newtonian fluid (corn starch in water) / salt, sand, ball bearings, decorative beads, the small polystyrene balls of bean bag filler, coarse/medium/fine reflective glass beads (used to make motorway signs highly visible);
- metal and silicon rubber baking trays, spherical glass tumblers, clear acrylic cylinders and a 40cm dome, a custom-made steel 15” embroidery hoop;

- and 15” Celestion Truvox 1525 speaker, Rolen Star 30 Watt transducer, DYH-810 8” speaker, I-mu I-Jerry & Dwarf 26 Watt resonance speakers, Sure 2x100 Watt TK2050 Class D amplifier.

These early experiments highlighted some interesting behaviours - the shifting geometric forms of beads suspended in liquid and the distinct Lissajous like figures discerned in the reflection of an LED torch on the surface of glycerol which shifted with frequency. There were also a number of technical developments which paralleled these tests - the fabrication of custom-made acrylic anti-vibration ‘floating plate’ bases integrating neoprene ring and bush mounts and anti-vibration gel; the discovery and use of Museum Gel - a non permanent adhesive material used to fix delicate exhibits in earthquake zones; and customising commercial products with replacement parts produced in the MMU Metal Workshop.

These experiments led to prototype devices which created distinct cymatic patterns on the surface of liquids in bowls and plates of different size, shape and material. However, while numerous tests based on vibrating diaphragms realised a wide range of dynamic cymatic forms, they failed initially to produce any distinct cymatic patterns. This was finally achieved by stretching latex rubber over a 20cm acrylic tube and later a 40cm acrylic dome. Yet irregularities in the patterns pointed to uneven tensioning - partly due to variations in the thickness of the rubber but mostly because there was no systematic mechanism to realise it - making these prototypes unsuitable for further development.

5.4.2 16’’ Floor Tom

While pondering how to realise a mechanism for a systematic tautness - and with input from Prof. John Hyatt, Director of Studies, sinking in - it finally dawned that humanity has been successfully stretching and tensioning vibrating diaphragms over resonant chambers for millennia. There was no need to ‘reinvent the wheel’ - just buy a drum.

A 16” floor tom was an ideal choice - the diameter of the shell being almost exactly equal to the diameter of the 40cm acrylic dome. A temporary configuration resting the drum on the acrylic dome with the Celestion Truvox 1525 speaker mounted inside was made permanent sometime later by drilling notches in the edge of the dome flange and fixing it to the bottom of the drum using the existing shell fittings, metal mounting ring and longer lugs (Figure 26). Using the mid-sized reflective glass beads as medium generated distinct, static cymatic patterns on the drum skin to a degree sufficient to justify *proof of concept*.

Figure 26 - 16” floor tom tonoscope with Celestion Truvox 1525 speaker mounted inside a 40cm acrylic dome

Figure 27 - 13” piccolo snare drum tonoscope

Using the drum’s tuning rods to tighten and loosen the skin adjusted its tension and dramatically affected the nature of the cymatic patterns induced. This not only confirmed that control over the tensioning of the diaphragm could result in a high degree of fine tuning of the visible cymatic patterns and forms - but also indicated that *The Augmented Tonoscope*, like any instrument, would require tuning before use.

5.4.3 13” Piccolo Snare

A second-hand 13” piccolo snare realised a table-top version of the 16” floor tom prototype (Figure 27). The snare mechanism and bottom skin were removed and a second-hand Vibe Slick 12” 1200 Watt woofer was fitted to the shell using the existing fittings and a custom fabricated acrylic mounting ring. This drum and speaker assembly was then rested onto the rim of a 32cm clear plastic then stainless steel bowl fitted with rubber edging strip. However, despite its power rating the speaker seemed to struggle - probably due to being ‘choked’ by the too limited volume of air in the bowls - so these were replaced with the shell of a 13” tom. Several drum head types were tested to determine which performed best as a diaphragm for creating cymatic patterns - settling on the relatively heavy black suede Remo coated drum head. Later refinements upgraded the Vibe Slick 12” with a Faital Pro 12” speaker and the original second hand FLI Underground 720 Watt 4 channel amplifier with a Cambridge Audio integrated amplifier. A ‘collar’ made out of card helped prevent the medium grade reflective glass beads bounce out of the drum when the skin was vibrating particularly violently.

This device generated upwards of 24 distinct cymatic patterns over a frequency range between 100-420Hz - although some of these patterns appeared to be transitional forms between more distinct modes (as detailed in Append 2 - Comparative Tests of Drum Based Analogue Tonoscopes to Virtual Drum Skin). However, it exhibited an uneven response - the energy of the vibration of the drum skin varied considerably across frequencies that induced a stationary wave patterns and required constant riding of the volume slider on the iRig Mix mixer channel to compensate. This effect, noted empirically, was explained by subsequent research into the physics of vibrating circular drum skins. Vibrational modes which feature radial rather than diametric nodal lines are more efficient at dissipating energy. Under the normal conditions of being hit by a stick these modes decay very quickly, contributing little to the pitch of the drum - but under the constant excitation by sound wave from the speaker they resonate particularly strongly (Russell, 2004-2011).

Still, an intriguing experimental discovery was made using this analogue tonoscope device and the functionality programmed into the SWG v4.0. For any frequency which generated a distinct cymatic pattern on the drum skin, all subsequent values in the arithmetic progression of undertones or subharmonics of that frequency i.e. frequencies determined by the small whole number ratio series of 1/2, 1/3, 1/4 etc., also generated a distinct cymatic pattern - e.g. if the given frequency was 600Hz then 600/2 = 300Hz, 600/3 = 200Hz, 600/4 = 150Hz etc. down to about a ratio of 1/8 after which the differences between successive frequencies became too small. This suggested a strong correlation between frequency, subharmonics and cymatic pattern warranting further investigation.

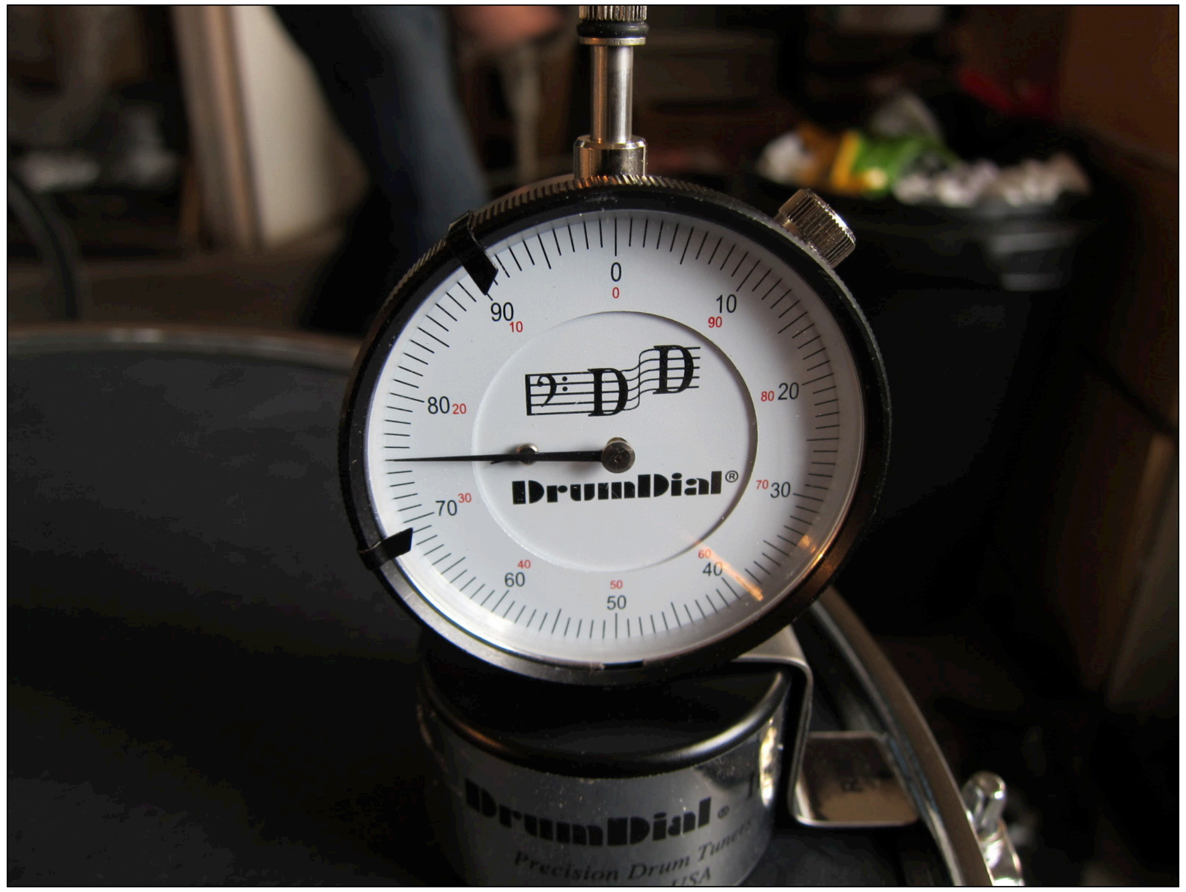

Figure 28 - DrumDial drum tuner

5.4.4 Drum Tuner

Since adjusting the tension of the drum skin dramatically affected the cymatic patterns it produced, a means to tension the skin more systematically was required. There are a couple of types of drum tuner but the DrumDial - *"timpanic pressure meters quickly and precisely tune all drums by accurately measuring drumhead tension NOT tension rod torque"* (DrumDial, 2013:online) - seemed the optimal choice (Figure 28). The device sits on the drum skin a set distance (defined by a metal spacer) from the tension rod and provides a reading. This enabled systematic measurement of the six tuning rods of the 13” piccolo snare and five tuning rods of the 16” floor tom - but it also highlighted issues with these prototype devices. Either due to thread wear, corrosion or a general fatigue through age it was just not possible to achieve the same value at each tension rod (changing the tension of one subsequently changed the values of all the others to varying degrees - so it was a repetitive process to adjust each in turn and gradually hone in on a desired value). Furthermore, realising close to a consistent value for all the rods didn’t necessarily guarantee that the drum skin behaved particularly well cymatically. Through trial and error the best approach appeared to be: aim for a set value on the drum tuner dial - 70 say; select a frequency which was known to generate a distinct cymatic pattern around this tension value; subsequently adjust each tuning rod to optimise the geometry of that pattern; and then measure the value for each rod in turn. This provided a set of values for the 16” floor tom i.e. 70.5, 71.5, 72.0 68.5, 69.5 (clockwise from the Remo logo) which could then be used as baselines when tuning the drum for future sessions. This went someway to realising the requirement that the tonoscope produce distinct cymatic patterns consistently.

5.4.5 Comparative Tests to Virtual Drum Skin

Having coded a mathematically ideal drum skin model as part of the *virtual systems* module it seemed appropriate to test how well these analogue tonoscopes actually behaved - how many discreet standing wave patterns they generated and how closely these correlated to the ideal. This analysis is detailed in Appendix 3 - Comparative Tests of Drum Based Analogue Tonoscopes to Virtual Drum Skin.

5.5 Virtual Systems

This aspect of the research focused on developing a secondary but integrated emulated tonoscope. This virtual system, modelled according to real-world physics and mathematical laws, was to behave like the analogue device, yet have the ability to be extended, twisted and abstracted in ways the analogue never could. In combination the analogue and digital elements would create an augmented device where real and virtual outputs could interplay and be artistically analysed and treated.

While this general principle was clear from the outset, the emulated tonoscope was amongst the least detailed conceptually - there was no preconceived notion of what its outputs might actually look like. So its emerging simulations and aesthetics developed as a direct result of undertaking the research. Moreover, investigation in this area suggested compelling new directions for the study, revealing fascinating lines of thought and lineages of practice which came to predominate within the project overall. Accordingly, *virtual systems* is amongst the most developed and resolved of the modules - as illustrated through the associated artworks.

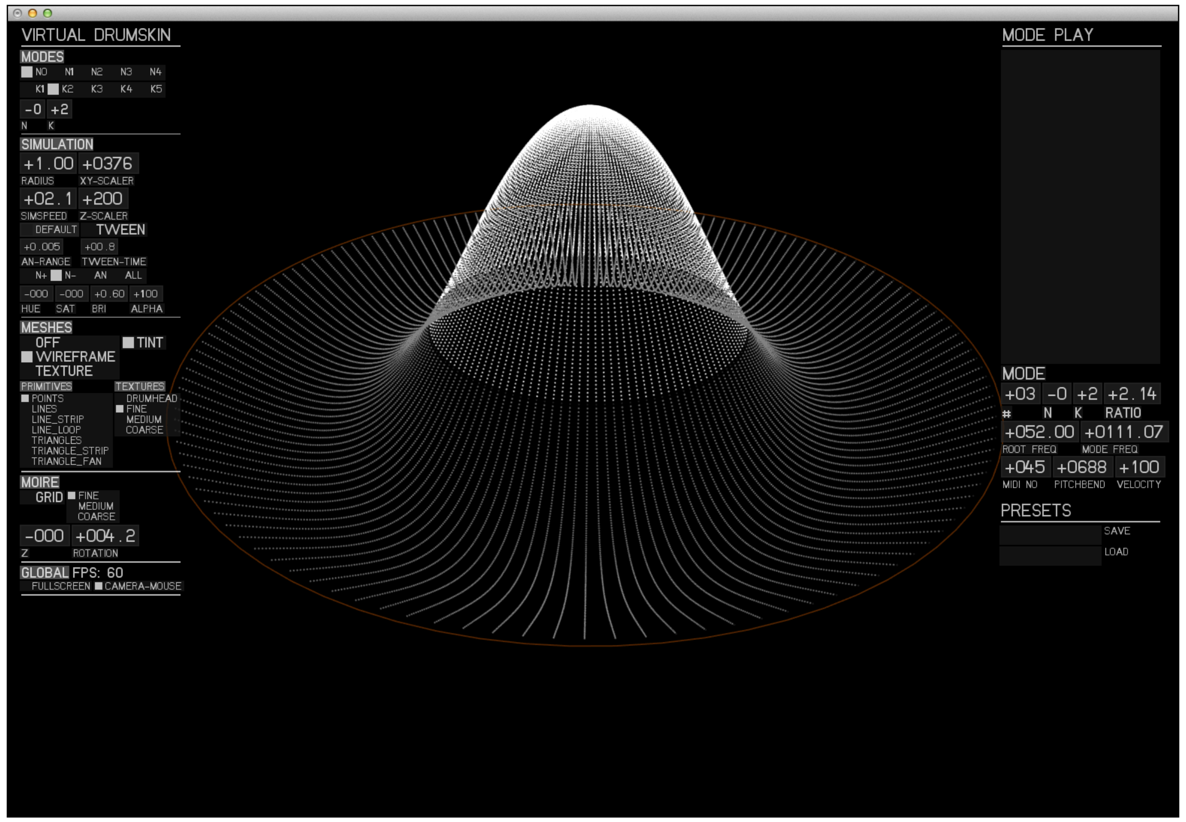

Figure 29 - *Virtual Drum Skin* model in openFrameworks - displaying the third or (0,2) mode (no diametric nodes and two radial nodes) of the steady vibrational states of a drum skin

An obvious starting point was to model the behaviour of a Chaldni plate or drum skin - and the later has been realised. Yet an emerging focus on movement as a key intermediary between sound and image - particularly a search for qualities similar to the 'harmonic motion' within music but in the visual domain - led to an exploration of the legacy of John Whitney Sr. and his *Differential Dynamics*. So development in this module drew on derivations and formulas from mathematics and physics along with the Pythagorean laws of harmony, to code several symmetrical, oscillating and harmonic systems. The real-time computer animations generated from these models were then used to visualise music.

5.5.1 Virtual Drum Skin

The underlying principles and an illustration of the modal vibrational states of a circular drum skin were introduced in Section 1.4 Stationary Waves and are detailed in Appendix 3 - Comparative Tests of Drum Based Analogue Tonoscopes to Virtual Drum Skin - and include images captured from an earlier version of the *Virtual Drum Skin*. However, the mathematics to describe these effects is not trivial. While it was investigated and is referenced in the Bibliography (Royal Holloway (University of London), 1999), the derivations are too complex to justify inclusion within the context of this thesis. Suffice it to say, that the solution to the various modal vibrational states of a circular drum skin can be found in the roots of the regular cylindrical first kind Bessel function J_nu(x).

An initial search for suitable starting points within open source creative coding examples identified Paul Falsted's *Circular Membrane Waves Applet* (Falstad, no date) - as an exemplar in visualising "the vibrational modes of a 2-d circular membrane (drum head)" (Falstad, no date:online). However, his Java code, though thorough and systematic, was too dense and interwoven to unpack. So Dr. Mick Grierson provided a simple implementation of this Bessel function via an openFrameworks addon - ofxGSL (Noble, 2012) - a port of the General Scientific Library (GSL) - a free numerical library for C and C++ programmers that provides a wide range of mathematical routines (GNU Operating System, 2009).

Subsequent development extended this into a functional virtual model of a vibrating circular drum skin - this was an ideal, no real world drum head would behave as perfectly as this - with GUI control over numerous aspects of its behaviour and aesthetics, including:

- the speed of the 'vibration' and height of vertical displacement;
- meshes and textures - to simulate the physical material of a drum skin;
- virtual dampening - to emulate the drum being hit and decaying to a zero state;
- discreet HSB (Hue Saturation Brightness model) colours for the antinodes and nodes of opposing direction;

- a 4x8 virtual button matrix to trigger any of first 32 vibrational modes;
- a bank of six presets - saving particular aesthetic and behavioural selections to an XML file;
- and MIDI functionality - calculating the frequency of a triggered mode based on its theoretical ratio of the fundamental or root frequency, then sending this out as a combined MIDI Note On and pitch bend value / receiving MIDI Note On messages and linking specific pitches to specific modes / and automating the switching between presets and various camera positions by sequencing this within Ableton Live.

A particularly satisfying aspect of this development was integrating Moiré effects - interference patterns produced by overlapping two grids of closely spaced straight lines with transparent backgrounds rotated a small amount from one another - to visualise the modes as the virtual drum-head 'vibrated'. Although this technique had been attempted on the 16" floor tom of the *analogue outputs* module using Letratone grids it had proven technically challenging and inconclusive. The virtual model allowed this line of thinking to be pursued and demonstrated as a *proof of concept*.

A performance version of the *Virtual Drum Skin* provides the visualisation for one of the associated art works - *Moiré Modes* - detailed in Chapter 6. Creative Outputs.

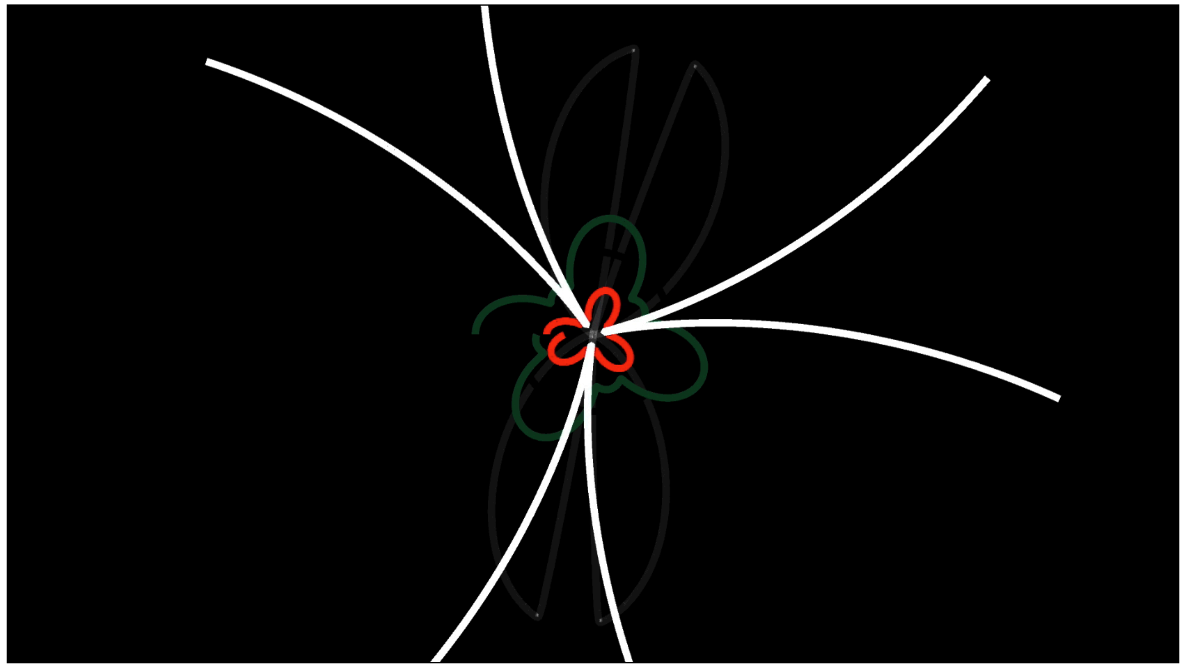

Figure 30 - A sound-responsive adaptation of Reza Ali's *2D SuperShapes* in Processing

5.5.2 Superformula

The plan for an associated art work, the *Cymatic Adufe*, involved projecting a dynamic digital visualisation based on the patterns often found in traditional Portuguese decorative design and architectural elements. These frequently draw upon natural forms but also reflect a Moorish geometric influence. An appropriate mathematical formula to underpin a virtual system that might realise this was the Superformula - a generic geometric transformation equation based on the Superellipse, first proposed by Johan Gielis (2003), which he suggests can be used to describe many complex shapes and curves found in nature.

Many creative coders have explored the Superformula as a means to generate naturalistic 2D and 3D shapes. One of its limitations is that it can be difficult to control the tidiness of the shape - the start and endpoints often misalign resulting in 'broken' outlines. On reflection, this didn't matter - it actually suited the aesthetic of trying to emulate hand-drawn, naturalistic patterns.

A suitable starting point was found in Reza Ali's *2D SuperShapes* (Ali, 2010) built in Processing (Fry & Rea, 2004). By the exhibition in MUDE, Lisbon, Portugal, May 2013 this sketch had been significantly overhauled, including:

- a move to Processing 2.0b8 and version 2.0.4 of the ControlP5 library (Schlegel, 2012);
- custom-coded Superformula, colour and Array List classes;
- FFT analysis as detailed in Section 5.3.2 Minim library in Processing;
- maximising the attraction and minimising the dampening variables in Reza Ali's code - to keep the dynamic figure (light grey in Figure 30) as elastic and 'bouncy' as possible so that it changed dramatically over time - even though this had the effect of lots of 'broken' outlines;
- beat detection of the audio to 'snapshot' the dynamic pattern and draw it rhythmically to the screen using one of the colours chosen randomly from the palette.

The video documentation, Processing application and sketch of this visualisation can be found on the accompanying hybrid DVD.

5.5.3 John Whitney Sr.'s Differential Dynamics

Many audiovisual practitioners have been inspired by Whitney's praxis - yet have interpreted his work in different ways. Grierson (2014) emphasises a temporal rather than scalar relation between music and visuals in Whitney's *Differential Dynamics* (as introduced in Chapter 2. Literature Review) i.e. a closer correlation between sonic texture/timbre and pattern than tone/pitch and pattern. Alves (no date) has realised a vision of *Differential Dynamics* and dynamic Just intonation through musical tuning structures known as 'hexanies'[14] allowing these pitch sets to retain the integrity of Just harmonic structure together with the ability to float free. This research has also looked for a correspondence between musical pitch and the convergence of the patterns in Whitney's algorithms - by testing several speculative criteria in applying Whitney's techniques alongside more conventional animation tools. These criteria and techniques go a fair way towards realising the essential requirement of agency within *virtual systems* - of producing a predictable output for a given input - even if the relationship between pitch and pattern is based on the unorthodox subharmonic series of the arithmetic progression rather than the more conventional harmonic series of the harmonic progression.

Exploring Whitney's legacy has become central to this research. Several of his original algorithms, programmed in Pascal, have been ported into Processing by Jim Bumgardner (Bumgardner, 2009-2014). Extending these examples, porting them to openFrameworks and then successively applying and refining the speculative criteria and animation techniques detailed in Appendix 4 - Adapting John Whitney Sr.'s Differential Dynamics has resulted in a series of experimental, associated and collaborative art works:

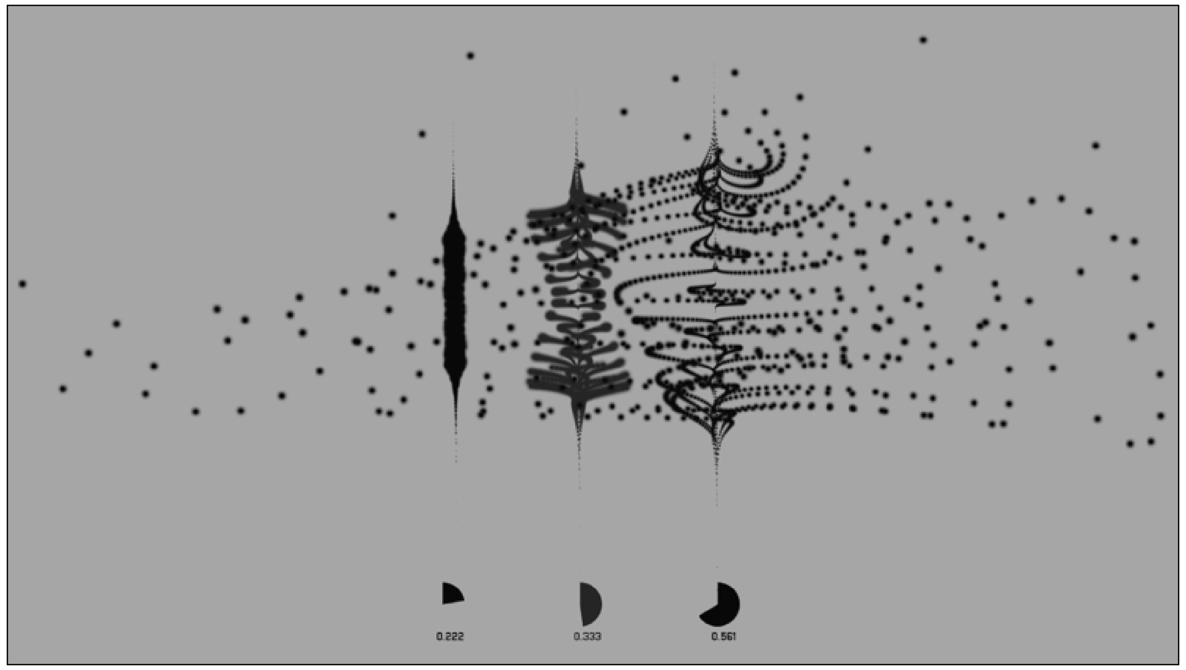

Figure 31 - *Whitney Triptych* v1.2

[14] "Hexanies, a type of "combination product set" invented by the visionary tuning theorist Ervin Wilson, are sets of six pitches created through the various possible pairings of four selected integer factors (Wilson 1989; Grady 1991). A characteristic of combination product sets that distinguishes them from traditional approaches to Just intonation is that no one pitch in the set necessarily has priority over the others. Like ever-expanding tessellation patterns that offer multiple perspectives of what functions as a center" (Alves, 2005:48).

- *The Whitney System* at Whitney Evolved, Kinetica Art Fair, London, Feb 2012;
- *The Whitney Modality* at WAYS TO ESCAPE_, Manchester, March 2013;
- *Stravinsky Rose* v1.0, v2.0 and v3.0 at UpClose 3, Manchester, April 2013 / Understanding Visual Music 2013, Buenos Aires, August 2013 / and Seeing Sound 3, Bath, November 2013;
- *Whitney Triptych* v1.0 at Seeing Sound 3, Bath, November 2013 with subsequent refinement to v1.2 (Figure 31);
- *Three Space* v1.0 at Seeing Sound 3, Bath, November 2013 with subsequent refinement to v1.2 (a collaboration with Ben Lycett beyond the scope of this thesis).

More detailed descriptions of the later of these works can found in Chapter 6. Creative Outputs.

5.6 Musical Interface

A prerequisite for any musical instrument is an interface to actually play it. Acoustic instruments use mechanisms such as keyboards, fretboards and sophisticated finger key systems over tone holes. Contemporary digital instruments such as synthesisers retain the traditional keyboard while introducing additional controls such as modulation and pitch bend wheels to add expressivity. The advent of software based instruments and Digital Audio Workstations has given rise to a proliferation of commercial, hand-crafted and DIY tactile controllers and grid-based interfaces. More experimental and inventive approaches - such as those based on air gesture, touch screens, capacitive touch sensors and eye control - are being developed by musicians/researchers working in the field of "designing human-computer interfaces and interactions for musical performance" (NIME, 2014:online) promoted by the likes of NIME.

So while mastering musical interface remains a central aspect of musicianship, the focus of much contemporary design in this field is on refining ergonomics and musical expressivity - drawing on the theories and practices of human-computer interaction (HCI) and embodied cognition to optimise the interface between the player and the instrument so that the making of music becomes as intuitive, natural and automatic as possible. Yet, in the main, this still assumes working within orthodox musical frameworks - specifically the 12-tone Equal Temperament.

The Augmented Tonoscope obviously required a musical interface - but akin to the *virtual systems* module, it was amongst the least detailed conceptually at the outset, developing as a direct result of undertaking the research. Initial efforts focussed on the ergonomics of the SWG - aiming to embed this with a considered, hands-on functionality and musical expressivity distilled from the literature, years of musicianship and a design dialogue with the device. Yet research by John Telfer (2010) suggested that an interface for *The Augmented Tonoscope* should be informed, not just by the physicality of the system, but also by consideration of alternative musical frameworks.

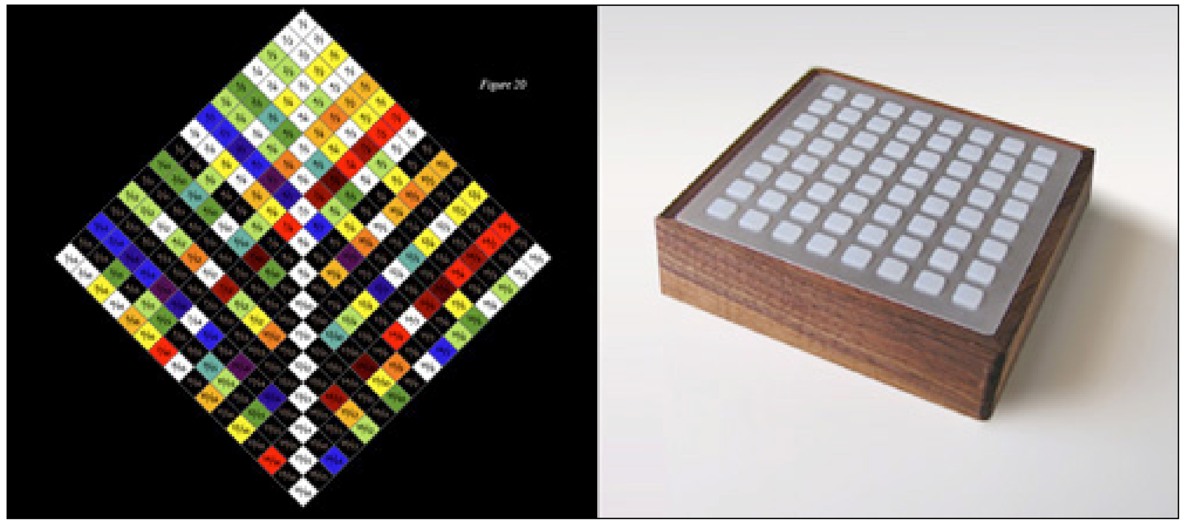

Figure 32 - John Telfer’s *Lamdoma Matrix* alongside a momone.org walnut 64 controller

Figure 33 - The *Lamdoma Monome* musical interface

5.6.1 Sine Wave Generator (SWG)

Development of the SWG attempted an integrated system of hands-on inputs and operational modes using:

- hardware components - a touchscreen, keypad, Softpot linear and rotary touch sensors, rotary encoder, rotary pots and toggle switches;
- remote control - via Serial over USB and OSC via a TouchOSC interface on an iPad 2;
- automation - LFO-like controls and implementation of Andy Brown’s Arduino *Easing* library (Brown, 2010) to ‘tween’ between frequencies;
- memories - up to 10 frequencies stored in volatile and non-volatile EEPROM memory;
- outputs and buses - 2 x mono and mixable stereo audio, I2C data and 5V power buses.

Though adept as a device for experimentation, observation and demonstration, it proved comparatively clunky and coarse as a hands-on instrument. While the remote control over OSC showed promise for a more intuitive and natural interaction, it didn’t go far enough and lacked the haptic feedback of a physical interface. Even the functionality that stored a set of frequencies that induced distinct patterns and played them back via an emulated keyboard using the Softpot Linear touch sensor or TouchOSC interface - essentially a *cymatic scale* with a set key for a given pattern - seemed too superficial.

5.6.2 Lamdoma Matrix & monome64

The Augmented Tonoscope required a musical interface that would allow a simultaneity between musical tone, cymatic pattern and digital visualisation - and the pervasive, 12-ET tuned, chromatic keyboard wasn’t an appropriate fit. Telfer (2010) proposes that his Lamdoma Matrix - a musical tuning framework based on perfect intervals derived from his theory of harmonicism as outlined in Chapter 2. Literature Review - can be used as a practical, creative resource for music making - though he prefers exploring its musical potentialities by building acoustic stringed instruments. Yet struck by the similarity (Figure 32) of the Lamdoma Matrix to the form of the monome64 (Crabtree & Cain, 2005-2014) - a minimalist, ergonomic controller with an 8x8 grid of buttons - this research integrated both into a custom-coded musical interface - the *Lamdoma Monome* (Figure 33). This allowed access to the tunings of the Lamdoma using the monome as physical ‘window’ - its buttons becoming the ‘keys’ of a 2D keyboard. As this 8x8 ‘window’ moves around the 16x16 matrix the software maps the physical buttons of the monome64 on to those whole number ratios defined by that section of the matrix it lies over. Pushing a button accesses that ratio defined by the cell directly ‘below’ it - sending the value either directly over OSC or as a combined MIDI Note On and pitch bend message equivalent to that ratio of the base frequency. Utilising the decoupled LEDs of the monome made it possible to map a pseudo, monochromatic version of Telfer's colour coding back onto the physical device - to see something of the structure of the matrix on the monome itself and so aid real-time performance. The research then set about exploring the harmonic landscape of this tuning framework - as detailed in Appendix 5 - Analysis of the Lamdoma Monome.

Still, the Lamdoma isn't a musical tuning system as such - not in the sense of Pythagorean 3-limit tuning described in Section 1.7 The Pythagorean Laws of Harmony or other more sophisticated perfect interval based tuning systems - rather it is a framework for accessing Just Intonation derived frequencies (see Appendix 5 - Analysis of the Lamdoma Monome). It does show a definite musical potential in its essentially 2D pattern based ergonomics - akin to the chord shapes of a guitar fretboard - and flexibility in accommodating conventional 12-tone scales while maintaining perfect intervals. However, like any musical interface, it requires time and practise to develop a familiarity and all being well master - and that

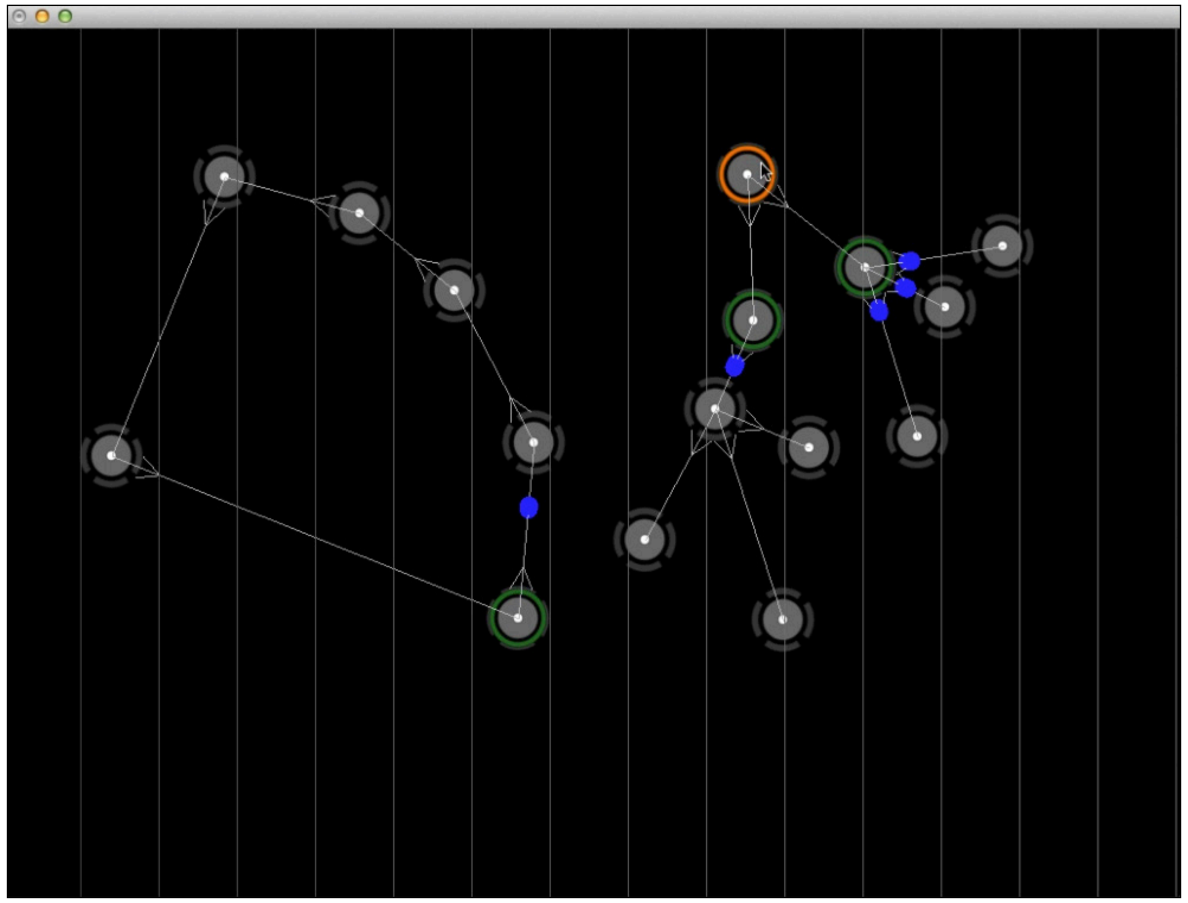

Figure 34 - A nodal sequencer prototype realised in openFrameworks

The green nodes are active and currently playing, the orange node is currently selected and awaits being triggered. The blue dots show the progression of the sequence along the connecting links between nodes - when a blue dot reaches the next node it is triggered, that node then turns green and the previous active node deactivates and turns grey.

process is far from complete. This was mainly due to the bottlenecks (as described in Section 4.5 Key Developmental Stages) in realising a custom-made nodal based *recording and sequencing* tool as described below in Section 5.7.1 Ki-No-Seq (Kinetic Nodal Sequencer), which shifted development in this area towards using Ableton Live. The *Lamdoma Monome* wasn't designed to work with Live and doesn't integrate that well - so development in this area remained relatively incipient. Accordingly it is difficult to offer any informed critical feedback on its feel as as a performance tool or more embodied perspectives on its functional design and musical expressivity. Still, the key melody line of *Three Space*, a collaborative work with Ben Lycett beyond the scope of this Ph.D., was devised using the *Lamdoma Monome* and recorded directly into Live using the technique outlined in Section 5.7.3 Recording Pitch Bend Data.

5.7 Recording & Sequencing

The development detailed above effectively describes the evolution of *The Augmented Tonoscope* to the stage of being a live performance instrument - outlining the various components required to generate and analyse musical tone, induce cymatic pattern and drive computer animation from a virtual model - all interconnected through a musical framework and physical performance interface (though a full integration of these modules was yet to be realised). Nevertheless, to develop refined audiovisual works - artistic outputs which demonstrated the capabilities of the instrument and showed rigour in respect to the imaginative creation, thoughtful composition, meticulous editing and professional production of new artwork, the project required one last, yet essential module - the ability to record and edit performance and sequence individual parts - a mechanism for composition.

Having conceded “a remarkable indifference” (Heidegger, 1929) to music composition using conventional sequencing software such as Cubase, Logic and Ableton Live - and despite, but most likely due to, more than 20 years of active music engineering and production experience within a personal practice using these de rigueur tools - initial development in this area looked to alternative, more serendipitous approaches.

5.7.1 Ki-No-Seq (Kinetic Nodal Sequencer)

Inspired by a family of node based sequencers e.g. Hans Kuder's *Tiction* (Create Digital Music, 2008) and the *Nodal* “generative software for composing music” (CEMA Research, no date) and with support from Ben Lycett, the research realised a working prototype of a novel composition tool - *Ki-No-Seq* (Figure 34). This would enable the recording, editing and sequencing of musical refrains - not as traditional notes along a score but rather as a series of interconnected nodes.

In this initial version, each node had an associated note determined by its position along the X-axis - each column designated successive notes in a preset heptatonic (7-note) musical scale. Each node was joined to its immediate neighbours by links - the length of which represented the time between notes. Chains of nodes could form closed loops where melodies played repeatedly - but by leaving the chain open and by linking a node to multiple neighbours they could also form 'one-shot' refrains, scalar cascades and polyrhythmic patterns. A node could be selected and dragged to a different position on the screen, pulling any connected node(s) along with it. The system also integrated a basic physics engine - chains of nodes could bounce around the screen and certain nodes could be set to attract or repel other nodes creating dynamic interactions within and between the sequences. This system had the potential to create complex yet dynamic musical compositions somewhere in the interesting middle ground between authored commercial sequencers and generative music apps.

Yet this 2D prototype was only a starting point. The longer term goal was to move the tool into 3D - and to associate pitch with height in the Z-axis, not with position along the X-axis (this would be used for some other form of musical expressivity - cutoff, resonance, filtering etc.). This would essentially mirror the translation in the Z-axis of the cells in the *Lamdoma Monome musical interface* module detailed in Appendix 5 - Analysis of the Lamdoma Monome, by creating and positioning nodes at the same height as the cell which created it. Also the links between

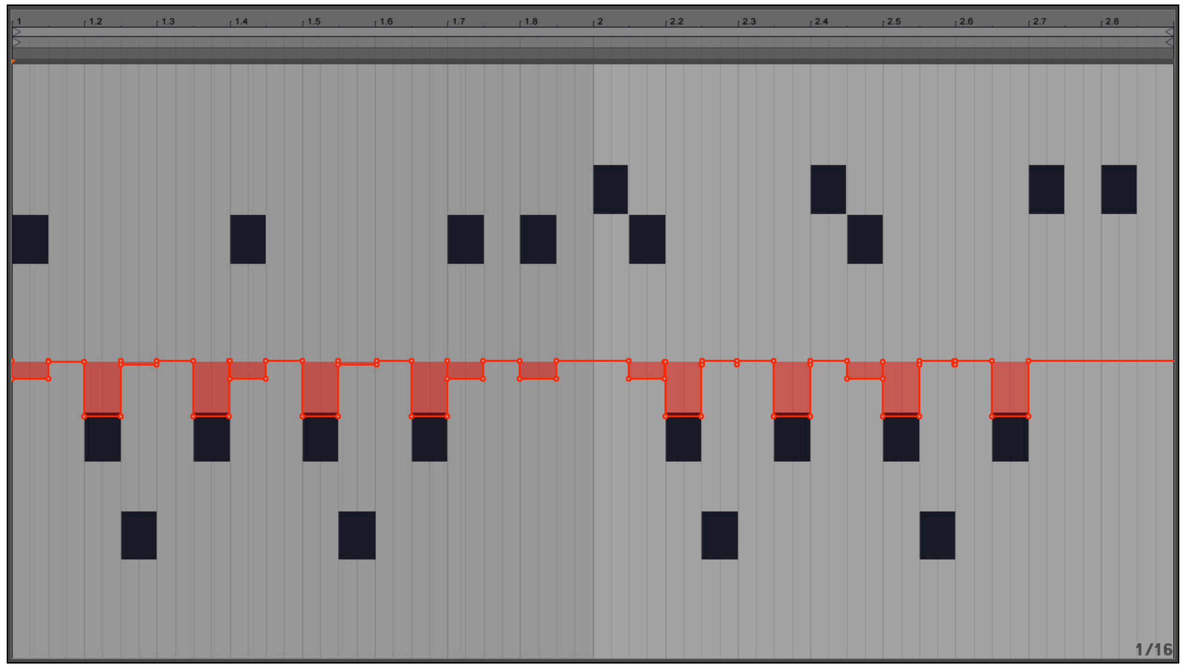

Figure 35 - Pitch bend envelope data recorded in Ableton Live

nodes, while appearing to be straight lines when viewed from a 'birds-eye' pseudo 2D perspective, would actually be Bézier curves - a next stage development of the prototype real-time Bézier curve controller outlined in Appendix 2 - Automating Portamento - and which would allow for more subtle and controllable portamento between frequencies. However, the bottlenecks in realising *Ki-No-Seq* as described in Section 4.5 Key Developmental Stages, forced a reconsideration of this approach.

5.7.2 Ableton Live Suite 9.1

Somewhat reluctantly, the research returned to the Digital Audio Workstation Ableton Live Suite 9.1 (Ableton, no date) as a default *recording and sequencing* mechanism. There were pros and cons. Live was intimately familiar, industry standard, well-implemented, robust and extensible through third-party instruments, effects and Live packs. Of special interest was the potential of *Max for Live* (M4L) (Ableton, no date), an integration of MaxMSP within Ableton Live - with a user Website offering *"both a world of devices and a community of device builders"* (maxforlive.com, 2009-2014:online). Working with Live would also make it straightforward to include other parts, loops and samples and to arrange, mix and produce audiovisual composition. However, Live, as a consequence of its core General MIDI (GM) infrastructure, is decidedly locked into the 12-tone Equal Temperament and generally unsuited to working with Just Intonation based tuning. Live also has other low level restrictions which only became obvious as the research attempted to find working solutions that might enable it to deal with perfect intervals more effectively.

5.7.3 Recording Pitch Bend Data

While the various modules within *The Augmented Tonoscope* err to frequencies and ratios, Live uses MIDI. Still, MIDI (MIDI Manufacturers Association Incorporated, 1995-2014) is a flexible enough protocol to accommodate alternate tunings using pitch bend - a MIDI message type which retunes the pitch of any currently playing MIDI note to a given fraction of a semitone. 12-ET tuning divides the octave into 12 semitones of 100 cents each yet pitch bend has a resolution of up to 4096 steps per semitone - a level of fine tuning capable of recreating the frequencies of the Lamdoma accurately. So it was possible to record the combined MIDI note and pitch bend messages sent out from the *Lamdoma Monome* into Live - it appeared as a separate pitch bend envelope track overlaying the MIDI note data (Figure 35). However, while version 9.1 of Live has improved handling and editing of pitch bend envelopes, pitch bend remains independent from the note data and it is not possible to lock the two together. Edit the position or length of a note and it is then necessary to separately edit the pitch bend data to suit - a cumbersome and inefficient work flow.

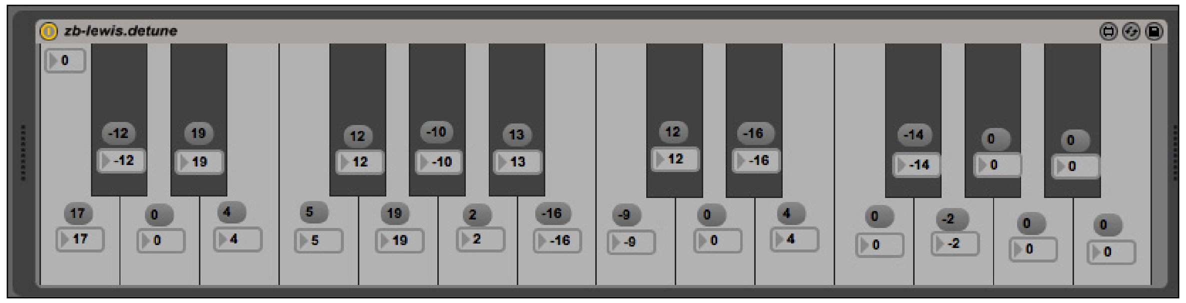

Figure 36 - Adapted *zb.detune* Max For Live device

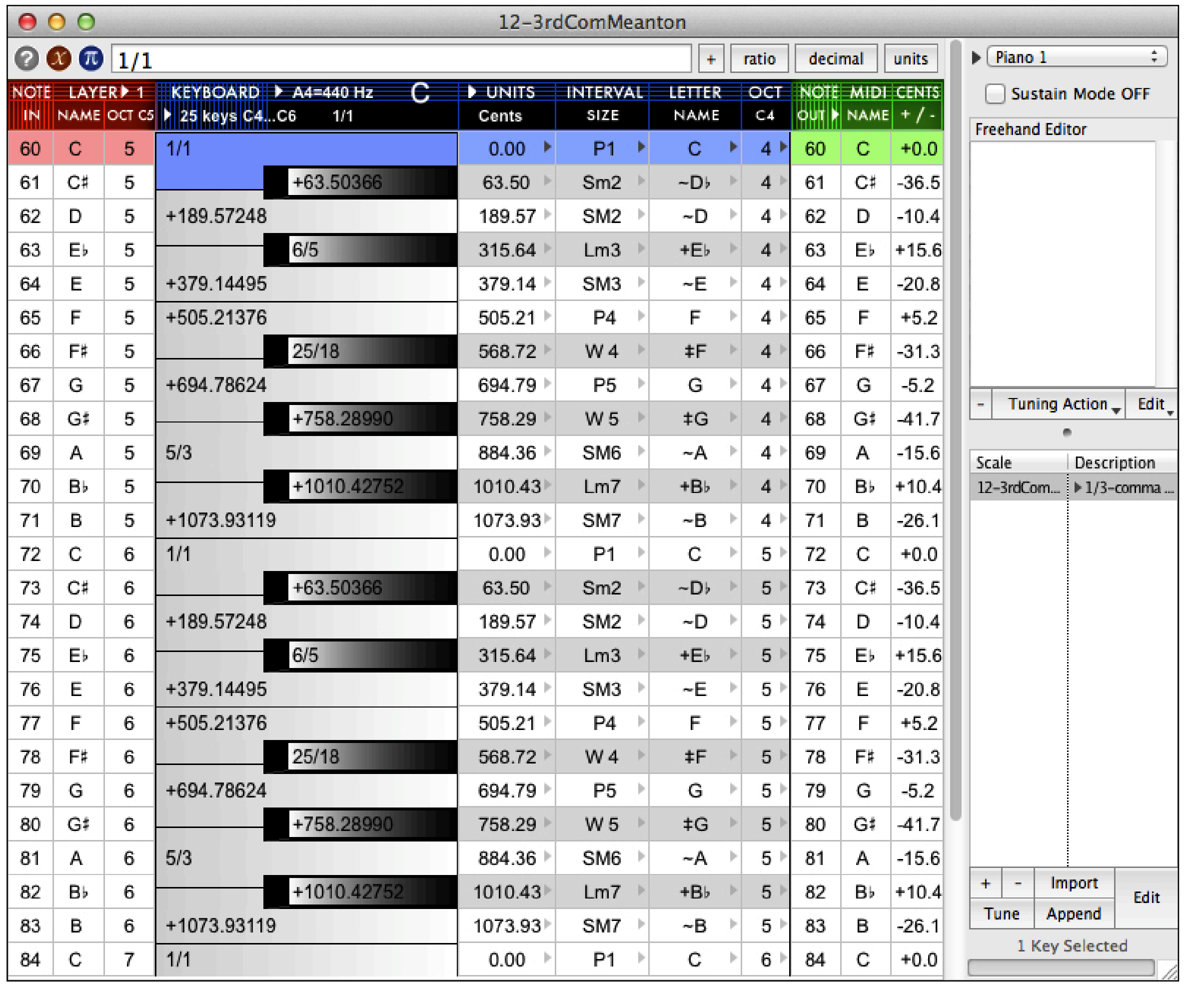

Figure 37 - Hπ Instruments *Custom Scale Editor* loaded with a *Scala* tuning file for the 12-tone 1/3-comma meantone scale (Salinas)

5.7.4 Max4Live Pitch Bend Device

So the research turned to an alternative approach using Max for Live - attempting to build a M4L device that could store and apply the pitch bend values of those frequencies within the Lamdoma that has been selected as closest to the 12-ET value - but within Live itself. It wouldn't be necessary to record the pitch bend data - just the note data. Any MIDI Note On message received or played back via a Live MIDI track that contained this M4L device would have the associated pitch bend value added automatically. A suitable starting point was found in Zlatko Baracskai's *zb.detune 1.0* (Baracskai, 2013), a M4L device which "detunes the MIDI notes by changing the pitchshift control" (Baracskai, 2013:online). However, it proved to be fairly rudimentary and awkward to extend despite efforts to: broaden its range to two octaves; up its resolution (it used a MaxMSP operator which only scaled pitch bend values between 0-127); switch data input type (replacing its rotary knobs with number boxes - much more straightforward for entering values); and implement the saving and loading of values (Figure 36). It worked well enough as a *proof of concept* but not as a working solution. Also in a restriction within Ableton Live where all MIDI within a given track is remapped to channel 1 by default, such a device could only be monophonic without significant development. However, Max for Live still had potential.

5.7.5 Micro-tuning Software

A search for alternative solutions to produce this functionality led initially to likely VST MIDI plug-ins - in particular Toy Bear's *Microtuner* from his MidiBag VST plug-in set (Toybear Productions, 2001-2004) which looked ideal but only worked under Windows. The best option for OS X, *Li'l Miss' Scale Oven* (Scott, 1997-2014), was too outdated and expensive to justify testing. Switching the search to more general micro tonal software led to *Scala* (Op de Coul, 2006-2014) "a powerful software tool for experimentation with musical tunings, such as Just Intonation scales, equal and historical temperaments, microtonal and macrotonal scales, and non-Western scales" (Op de Coul, 2006-2014:online). While Scala has established itself as a standard for micro tuning - its tuning files can frequently be loaded into other software - the current version 2.3.6, in a known issue, wouldn't install on OS X Mavericks.

So the research turned to Aaron Hunt's *Hπ Instruments* (Hunt, 2008-2014) and his range of microtonal MIDI hardware controllers and software that utilise his own Hunt System (H-System) of musical tunings. Of particular interest was *Custom Scale Editor* (CSE) (Figure 37) "... a free, full-featured tuning editor for Mac OSX and Windows which allows you to tune any MIDI key to any pitch using ratios, Hz values, decimals, constants and functions, code snippets, user definable algorithms… import Scala files… [and] quickly edit and export tunings in a variety of popular tuning formats" (Hunt, 2008-2014:online). The Pro license unlocked several features, including Live Input, allowing output from sequencers to be retuned in real-time. So using CSE it was now possible to send GM MIDI Note data out of a MIDI track in Live, retune it to a custom or Scala preset micro-tuning scale by adding pitch bend, and route this MIDI data back into an Instrument track in Live.

Using CSE also highlighted a previously unappreciated aspect to pitch bend - it affects the instrument globally - but only on a specific MIDI channel. While it is not possible to play more than one note with different pitch bend values simultaneously on the same MIDI channel - it is possible to play more than one note with different pitch bend values simultaneously - so long as each note is on its own MIDI channel. Hunt has implemented this strategy within his hardware and software - "TBX1 [and CSE's Live Input mode] achieves microtonal polyphony through a MIDI channel assignment system, called a dynamic channel allocation algorithm" (Hunt, 2014:15). This opened a doorway to polyphonic composition and to the exploration of more complex musical works - efforts to date having focussed on the solo instrumentation and essentially monophonic nature of instruments such as the clarinet and cello.

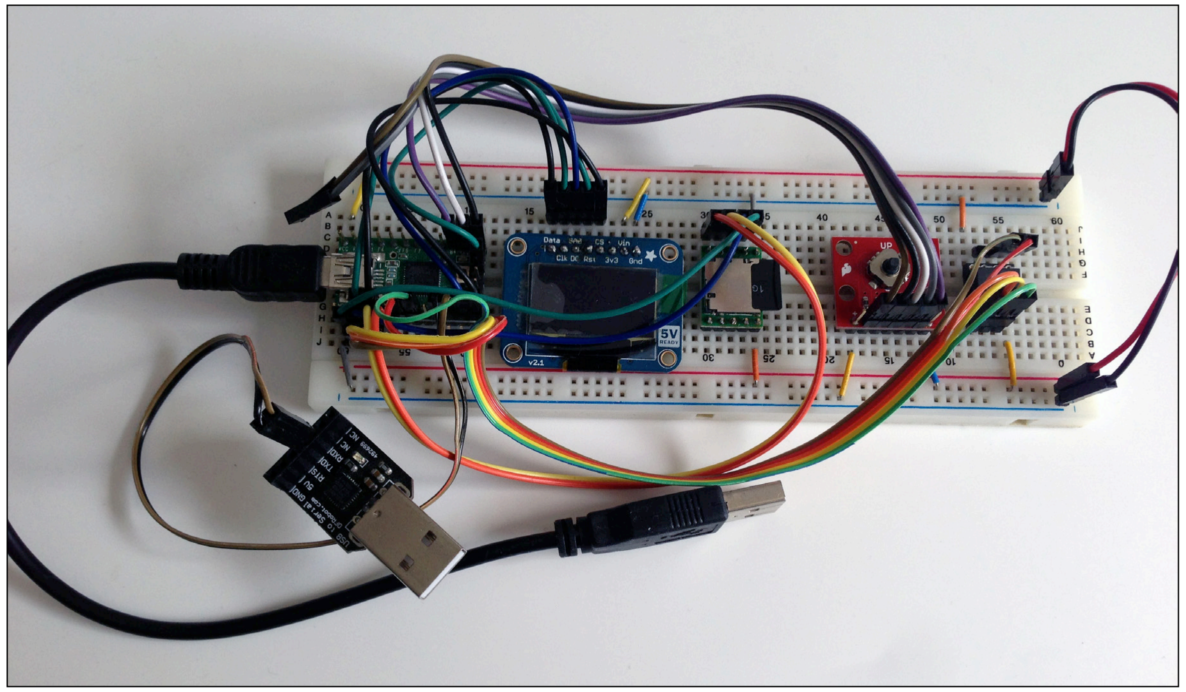

Figure 38 - The *Teensy Weensy Micro-tuner* breadboard prototype - a custom micro-tuner hardware device using a Teensy 2.0 micro-controller

5.7.6 Custom Micro-tuning Hardware

While CSE is well implemented and flexible, a significant limitation is that it can only retune one MIDI part at a time - and the practice was beginning to explore composition with two or more parts, each of which required retuning. An exchange with Aaron Hunt suggested it might be possible to run multiple instances of CSE at the same time - and this did work - but it was an inelegant solution. Reflecting on this problem suggested that an alternative approach could be to limit polyphony in favour of multi-timbrality i.e. limit the micro-tonal polyphony to say 8 voices rather than the full 16 used by CSE by using only MIDI channels 1-8 for an input on MIDI channel 1 but enabling a second timbre on MIDI channel 2 to have its own 8 voice microtonal polyphony using MIDI channels 9-16. CSE didn't have this feature, but this shift in thinking, along with further investigation of Hπ Instrument's hardware *TBX1 Tuning Box*, suggested the possibility of coding a custom micro-tuner device using a micro-controller - and building this functionality into it.

So a latest iteration prototype version of the *Teensy Weensy Micro-tuner* features:

- listing the long file names of multiple 12-tone Scala tuning files saved on a microSD card, parsing the file content of a selected file and applying its retuning ratios to incoming MIDI notes;
- re-configuring the Teensy 2.0 (PJRC, 1999-2014) firmware to create three independent MIDI ports - relinquishing the need to limit polyphony in favour of multi-timbrality (though this functionality was successfully integrated initially) by creating a single device which can simultaneously micro-tune up to three MIDI parts each with full 16 voice polyphony;
- displaying incoming and outgoing MIDI data on an Adafruit monochrome 128x64 SSD1306 OLED display;
- adding an additional 1Mbit of Serial SRAM to extend the limited memory of the Teensy 2.0;
- input via a 5-way tactile button;
- and outputting additional information via Serial using a USB TTL Serial adaptor and the simple serial port terminal application CoolTerm (in MIDI device mode the Teensy can't use the USB cable for Serial communication).

This device was subsequently used in the production of associated art works, specifically *Whitney Triptych* v1.1 and v1.2, has become an essential tool in collaborative artistic practice beyond the Ph.D. and will be developed further from a breadboard prototype to a production unit creating a compact, flexible and affordable micro-tuning device.

5. 8 Conclusions

This chapter has outlined significant underpinning concepts, favoured technical realisations and critical reflection on the effectiveness of research outcomes - within the key method of developing *The Augmented Tonoscope* as a modular performance system.

It shows how progress and impasse within particular modules influenced and impacted on others. For example, how the functional virtual model of a vibrating circular drum skin helped to analyse and evaluate the outputs of drum based analogue tonoscopes (Appendix 3 - Comparative Tests of Drum Based Analogue Tonoscopes to Virtual Drum Skin) and how the realisation of the *Lamdoma Monome* musical interface focussed development of micro-tonality within a 'locum' Ableton Live.

It demonstrates the nature of the praxis - of practice imbricated with theory - arranged so that they overlap like roof tiles. For example, how the concept of musical gestures (Godøy & Leman, 2010) and of a shape created over time through music, led to exploring ways to 'shape' portamento and the transition from note to note - initially through the unconventional tweening functions of motion graphics (Penner, 2002) but leading to Bézier curve modelling techniques (Battey, 2004).

It also illustrates, through a detailing of the practice and its processes, how the repeating motifs recognised within the varied perspectives of the disparate sources have been formalised - resolved, reduced and oriented into a more concentric alignment. For example, the congruence that has emerged in the significance of the arithmetic progression or subharmonic series within both John Telfer's *Lamdoma Matrix* and John Whitney Sr.'s *Differential Dynamics* as well as the experimental discovery of a strong correlation between subharmonics and cymatic pattern.

Most significantly, it provides a deeper understanding of how development of *The Augmented Tonoscope* as a modular performance system has informed, shaped and given rise to the associated art works produced as the study - as detailed in the following chapter.

6. Creative Outputs

6.1 Introduction

The focus of this chapter will be to describe, contextualise, specify the technical realisation and reflect critically on several artistic works produced as the research.

Declared at the outset of the study, a key method was the design, fabrication and crafting of a sonically and visually responsive hybrid analogue/digital instrument - a contemporary version of Jenny's sound visualisation tool - *The Augmented Tonoscope*. The intent was to interact, play and record with it to produce a series of artistic works for live performance, screening and installation. These works would be the main evidence submitted, supported by a thesis and an "evidence box" of materials which made the research context manifest.

Yet Section 4.6 A Modular Performance System details how an understanding of *The Augmented Tonoscope* as instrument evolved from being complete within itself - a distinct object, or rather set of objects - to a complex union of discreet modular components that would collectively produce its functionality. So the artistic works actually produced and submitted as the research are a response to this shift in thinking - retaining the template of creative outputs (works for live performance, screening and installation) yet reframing them as a series of artistic works that instead reflect and contribute towards the development of specific modules and so to the instrument overall.

6.2 Submitted Works

Accordingly, the research has produced the following resolved works:

1. *Installation*: **Cymatic Adufe** (v1.0 & v1.1) - exhibited as part of the *21st Century Rural Museum* in the Palácio das Artes – Fábrica de Talentos, Porto, 3rd November to 31st December 2012 and subsequently in MUDE – Museu do Design e da Moda, Lisbon, 16 May to 31 August 2013;
2. *Screening*: **Stravinsky Rose** (v2.0) in Dome format - featured as part of the *Understanding Visual Music* - UVM 2013 Concert, Galileo Galilei Planetarium, Buenos Aires, Argentina, 9 August 2013;
3. *Performance*: **Moiré Modes** (v1.1), **Whitney Triptych** (v1.2) and **Stravinksy Rose** (v3.0) - part of the Performance 2 session at *Seeing Sound 3*, Bath Spa University, UK, 23rd-24th November 2013.

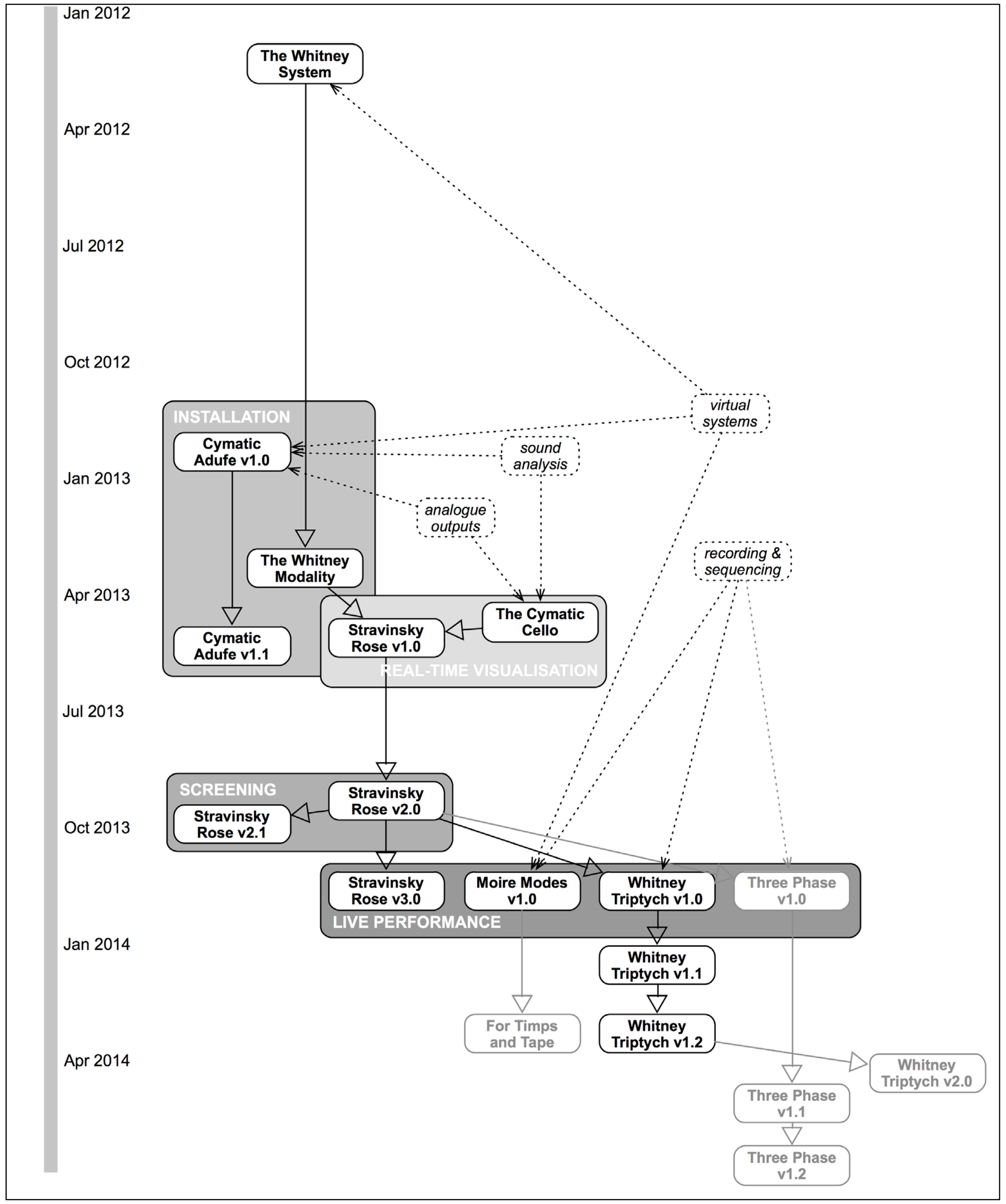

Figure 39 - *The Augmented Tonoscope*: Creative Outputs Timeline

Notes:

a. Solid lines with large arrowheads show the progression from work to work;
b. Dotted lines with small arrowheads show the focus on specific modules within and through the works;
c. Grey outlines and text indicate works outside the scope of this Ph.D. - either collaboratively developed, already showcased or currently in progress.

6.3 A Note on Naming Convention

Unlike more traditional art forms in which the work, once completed and exhibited, is rarely revised, in electronic art it is invariably the case that first iterations are prototypes. So the version numbers indicate an innate strategy to the development of these works[15] - that of an iterative, ongoing evolution and refinement - much akin to the products of interaction design and software engineering. It is the subsequent opportunities to exhibit the work that allows it to be stabilised, refined and modified. In this respect electronic art practice differs from more established and traditional art forms such as painting and sculpture and even more technologically oriented forms such as photography. Artists working with these more established forms may well experiment, settle upon a method and then create a series of variations on a theme, but this is significantly different to the practice of building and refining prototypes through an iterative design process within electronic art. Yet as Lindell (2013) argues, this artisanal approach to working with technology also differentiates electronic arts practice from more commercial interaction design and software engineering:

> The digital arts rely on programming and appropriation to craft technology that explores artistic problems and to be used in exhibitions and performances. To this end, the digital arts have succeeded in both creating and making, where the community of interaction design and software engineering struggle. (Lindell, 2013:1)

So these key works represent *'milestones'* along a progression of development - and though the intermediary stages are clear within the overall practice, they are not necessarily evident through these works alone. Consequently, the intent is to draw on earlier works and prototypes that explored ideas that led to these creative outputs and perhaps more importantly, also provided the *'toolkit'* of assets, techniques, electronics and code that was subsequently adapted to realise them.

6.4 Creative Output Timeline

Figure 39 illustrates the loci of the associated works as part of an overall developmental process that draws on earlier work and creative experiments and feeds into subsequent works. The process is ongoing and new collaborative works beyond the scope of this Ph.D. are in development - while some have already been showcased.

6.5 On Description, Context, Technical Realisation and Critical Reflection

Works are discussed using the following format:

- *Description* - briefly summarises the work, its essential workings and where applicable, an assertion of intent;

[15] This convention is not uncommon within the electronic arts - as evidenced by a practitioner contemporary Paul Prudence and his Daub / Daub II, Talysis I / Talysis II and ryNTH[n1] / rynTH[n9] / Rynth[n3] series of works as listed on his Transphormetic V6 website (Prudence, 2012).

Figure 40 - *Cymatic Adufe* (v1.1) - MUDE – Museu do Design e da Moda, Lisbon, 16 May to 31 August 2013. Photographs by André Castanheira.

- *Context* - discusses the work within the frame of reference of its specific showcase opportunity;
- *Technical Realisation* - offers developmental highlights of key stages in the realisation of the work. It details aspects of design, fabrication and construction; audio and video production; aesthetic considerations; and problem solving of technical challenges;
- *Critical Reflection* - offers an assessment of the work based on how well it served to develop the instrument overall. It also offers a personal evaluation of aesthetics, highlighting how well the work responded either to its context, engaged with its audience or realised its intent.

6.6 A Note on Formalism

In trying to find an amalgam of music and moving image that engages the viewer in a subtlety shifted way, the practice has used the techniques of artistic media to try and capture the essence of the audio-visual contract, its true inner nature, its “significant form”. The work has no subject per se - the focus is on the aesthetic experience and the emphasis is on audio and visual compositional elements such as line, shape, colour and texture. As such, it is the work itself which “gives pleasure to the mind” (Denis, 1890). The artistic value of the work is determined by its form - the way it is made, its purely visual and sonic aspects and its medium. The context for the work - including the reason for its creation, the historical background and the experience of the artist - are of secondary importance. Everything necessary to comprehending the work is contained within itself. Accordingly this research argues that the artworks produced in the process of realising *The Augmented Tonoscope*, are essentially formalist in nature - at least in an early 20th century definition of formalism described above and proposed by the Post-impressionist painter Maurice Denis in his 1890 article *Definition of Neo-Traditionism* and by the Bloomsbury writer Clive Bell in his 1928 book, *Art*.

6.7 Gallery Installation - The Cymatic Adufe

6.7.1 Description

The *Cymatic Adufe* (Figure 40) is a sound-responsive, audiovisual installation that explores the rich musical tradition of the Raia region of central, rural Portugal. The work investigates the interplay between sounds and images, materials and forms emblematic of rural life. Physically it resembles a minimalist architectural column - 0.4m square and 2.4m tall - the base plinth laminated in natural cork and the top sections of clear acrylic. A speaker is fitted into the plinth and above this, held part way up the acrylic, sits an adufe - a square, framed hand-drum of Arabic origin. A compact micro-projector mounted at the top of the column projects onto the skin of the adufe below.

The work deploys Cymatics - and specifically stationary wave patterns induced by sound - to visualise the traditional Portuguese folk song of the *Senhora do Almortão* as dynamic and shifting patterns on the surface of the adufe. Simultaneously projected from overhead, superimposing on and augmenting these physical cymatics forms, is a dynamic digital visualisation of geometric patterns often found in time-honoured Portuguese decorative design and architectural elements. These are generated in code using a sound responsive adaption of the Superformula - a generalisation of the Superellipse first proposed by Johan Gielis (2003), which he suggests can be used to describe many complex shapes and curves that are found in nature.

Video documentation of the *Cymatic Adufe* as exhibited at MUDE along with a supplemental video of its making for Porto, a screen recording of the Processing v1.1 visualisation and the Processing application and working sketch are available on the accompanying hybrid DVD.

6.7.2 Context

The *Cymatic Adufe* was made for the *21st Century Rural Museum* (Rodrigues, 2012) - the travelling exhibition component of Manchester Metropolitan University (MMU) postgraduate Cristina Rodrigues and her *Design for Desertification* Ph.D. project. The exhibition aimed to highlight the issues facing the Portuguese rural world affected by the phenomena of depopulation, environmental desertification and economic decline. The artistic brief was to create an artwork that brought these narratives and issues to life in an attempt to engage the public in the debate about the importance of rural regeneration.

In search of creative inspiration, a study trip to Monsanto - a small, mountain top village in the borough of Idanha a Nova - offered an experience of local culture. A highpoint was the *Adufeiras de Monsanto* (Rádio Clube De Monsanto, no date), a group of mostly elderly women from the village who performed in brightly coloured traditional costumes and sang a repertoire of classic folk songs accompanied by rhythms played on an adufe. The *Adufeiras* offered an archetypal sonic motif for rural culture - and the adufe, so integral to their performance and a potent symbol for the region in its own right, an ideal linchpin around which to conceptualise a work.

So the *Cymatic Adufe* attempts to show how the haunting melody of the much loved and interpreted traditional folk song of the *Senhora do Almurtão* not only has an analog in visual form - seen through the wondrous Cymatics effects of sound and vibration - but that these forms show some correspondence to traditional geometric patterns of decorative design. The intent was to illustrate that traditional music and imagery shouldn't perhaps be seen as separate and distinct forms of cultural output, but just two ways of expressing the same thing. By making

these correlations more explicit the work aims to illustrate how traditional wisdom understood and appreciated these underlying relationships as part of a holistic and interconnected worldview expressed through arts and culture.

6.7.3 Technical Realisation

Construction

The width (and depth) of the column were determined by the 40cm square adufe (there is also a larger 45cm square version). The overall height and distribution of the various sections of the column by additional factors, such as:

- the height of the adufe relative to the viewer;
- the 'throw' the mini projector required to display an image that filled the adufe;
- the volume of air needed to create a ported cabinet that optimised the performance of the 12" Faital Pro speaker;
- the space required to house the equipment to drive the work - Mac mini, audio amplifier etc.;
- the overall dimensions and aesthetic proportions of the column;
- as well as more pragmatic restrictions such as the maximum dimensions of 4mm acrylic that could be cut on the University laser cutter.

Rationalising these requirements realised a final design for the column, including a component list of the various mountings and fixings required. The acrylic top boxes and speaker mounting were cut on a laser cutter and the 12mm birch ply base plinth on the CNC router in the MMU Workshops. A prototype was built initially - its construction practised and its design refined - and then all the parts for a second production version were cut, sent by courier to the exhibition venue as 'flat pack' and constructed in-situ.

Audio

A version of the *Senhora do Almortão* as sung by Cristina Rodrigues was recorded against a looped sample of a found adufe rhythm (later supplemented with a rhythm played on the actual adufe used in the work). An underpinning MIDI synthesiser line was extracted from the melody and pitched down a couple of octaves. The vocal and synthesiser line were hard panned to one channel and played through the main 12" speaker and then a synthesiser patch of particular timbre which caused the adufe to vibrate sufficiently to show stationary wave patterns on its surface while not overwhelming the vocal recording was carefully selected - somewhat surprisingly a 'Jazz Guitar' on the KORG M1. So as not to interfere with these cymatic patterns the accompanying adufe rhythms were hard panned to the other channel and played through a small Altec Lansing Orbit iM237 USB speaker embedded into the side of the plinth. This required a Multi-Output device in OS X's Audio MIDI Setup, grouping the built-in output and iM237 so that each channel of the stereo file could be sent to its respective device.

Palette

Struck by how closely the colours of the *Adufeiras*' costumes matched the hues of the regional flora, these were used as the palette for the visualisation. Additional colours extracted from the decorative tassels of the adufe itself were added later.

Visualisation

The dynamic patterns projected on the adufe were generated from a mathematically derived virtual model based on the Superformula - as detailed in Section 5.5.2 Superformula.

Interaction

Being a sound-based artist engenders an awareness of the sonics within an exhibition space - particularly a sensitivity to the *'abrasive'* quality of sound and how an endlessly repeating loop or motif can quickly become tiresome to visitors (and especially staff). So for MUDE the software was developed into a simple state machine[16], playing the audio either once every quarter of an hour or as a visitor approached it - triggered via PIR motion sensors fitted to the bottom edge of each side of the plinth and attached to an Arduino via a custom sensor shield. The Arduino code and on-board sensor settings were tweaked to optimum values in situ.

Projection

For Porto, the mini projector had been attached to the supporting aluminium profile (running the power and HDMI data cables up the second slot of this 4cm wide metal strip) using a Manfrotto 259B Extension For Table Tripod. However, this extendable arm didn't provide sufficient level of adjustment, so for MUDE it was replaced with a robust but flexible Joby GorillaPod SLR and custom acrylic mounting disk allowing the projection from the Optoma ML300 to be perfectly aligned onto the surface of the adufe.

Lighting

For MUDE, a set of 12V white LED strip lights were fitted slightly inside of the bottom edge of the plinth. The result was a subtle glow that spilled onto the concrete floor of the exhibition space around the base of the column. It looked particularly agreeable as night drew in and the general lighting level in the gallery dropped.

Static Electricity

The white bean bag filler used to visualise the stationary wave patterns responded well and suited projection, but suffered badly from static. In Porto, it had stuck to the inside of the box gradually creeping up the acrylic over time through static build up.

[16] *"A… state machine is a mathematical abstraction used to design algorithms. In simple terms, a state machine will read a series of inputs. When it reads an input it will switch to a different state"* (Shead, 2011:online).

So for MUDE:

- the bean bag filler was thoroughly coated with an aerosol spray of a special anti-static coating used in industrial settings, reducing the inherent static behaviour of the polystyrene balls considerably;
- an anti-static gun - the type used to de-static vinyl record - was used to dissipate the static build up on the acrylic;
- a professional anti-static cloth and cleaner were the only things used to clean the acrylic during the construction and setup of the work. MUDE were instructed to use these and the anti-static gun regularly to treat the acrylic during the exhibition run.

Connectivity

It was difficult to access the installation's Mac mini, so a compact, USB powered wireless router was added - proving invaluable during set up and testing by allowing remote access to the Mac mini via *'Screen Sharing'* from a MacBook Pro. The wireless router was left in the plinth in case it was required by a technician for maintenance during the 3½ month exhibition run - though it never was.

6.4 Critical Reflection

The *Cymatic Adufe*, in employing Cymatics as a mechanism for an installation artwork, reflects that aspect of the *modular performance system* conception of *The Augmented Tonoscope* defined by *analogue outputs*. Through the Fast Fourier Transform (FFT) analysis of the melody of the traditional folk song of the *Senhora do Almortão*, it reflects that aspect defined by *sound analysis*. By integrating real-time computer animations generated from mathematically derived virtual models - in this case a sound responsive version of the Superformula - it also reflects that aspect defined by *virtual systems*.

Empirical research within the *analogue outputs* module had led to working tonoscope prototypes that adapted a 16" floor tom and 13" piccolo snare drum. This suggested that a similar sympathetic vibration of the skin of the adufe could be achieved - the stationary wave patterns induced by the melody visualised via the medium of bean bag filler. Yet this was still something of *'an act of faith'* - the *Cymatic Adufe* had to be built in order to test whether and how well its design might work. That it displayed such clear and dynamic steady vibrational modes reinforced an underlying supposition of the research - that stationary wave patterns, while mostly hidden from sight, surround us - and it is entirely possible to coax them into view. The square adufe also introduced an alternative form factor for a vibrating diaphragm, producing distinctly different patterns from the circular drum prototypes and opening the study to additional empirical evidence and mathematical models that provided further insight into the overtones of these vibrational systems.

Looking to explore less contemporary and familiar musical traditions through the research, particularly those influenced by perfect intervals, there had been some expectation that the melody of the traditional Portuguese folk song of the *Senhora do Almortão* might reflect an Arabic Maqam scale - though subsequent analysis of the recording intimated a conventional key of C# Major. Still, the FFT analysis via the Minim library (Di Fede, 2007), while limited to Processing (Fry & Rea, 2004) and to generating a frequency spectrum rather than tracking pitch, provided the first computer software based, real-time audio data interpretation within the *sound analysis* module. Although not the first symmetrical, oscillating or harmonic system to be explored within *virtual systems*, the Superformula based visualisation was the first to be driven by an analysis of sound. The principle techniques developed here - of using audio derived pitch and harmonic relationship data to control a computer animation generated from a virtual model - have since been adopted and refined within the practice overall. Consequently, the *Cymatic Adufe* is the work which most closely reflects the core configuration and functionality of *The Augmented Tonoscope*.

Aesthetically, the work achieved a delicate balance between a clean, reductive minimalism based on formal proportions and a restrictive palette of materials - and an intimate connection to the rural through the adufe, the typically Portuguese cork laminate of the plinth and the colours and shapes of the projected visualisation. Yet the adufe itself managed to remain the focus of the piece - through the effect of it *'floating in space'* and by making it self evident to the viewer that it was only the sound of the folk melody played through the speaker that generated the physical pattern on the surface of the hand drum.

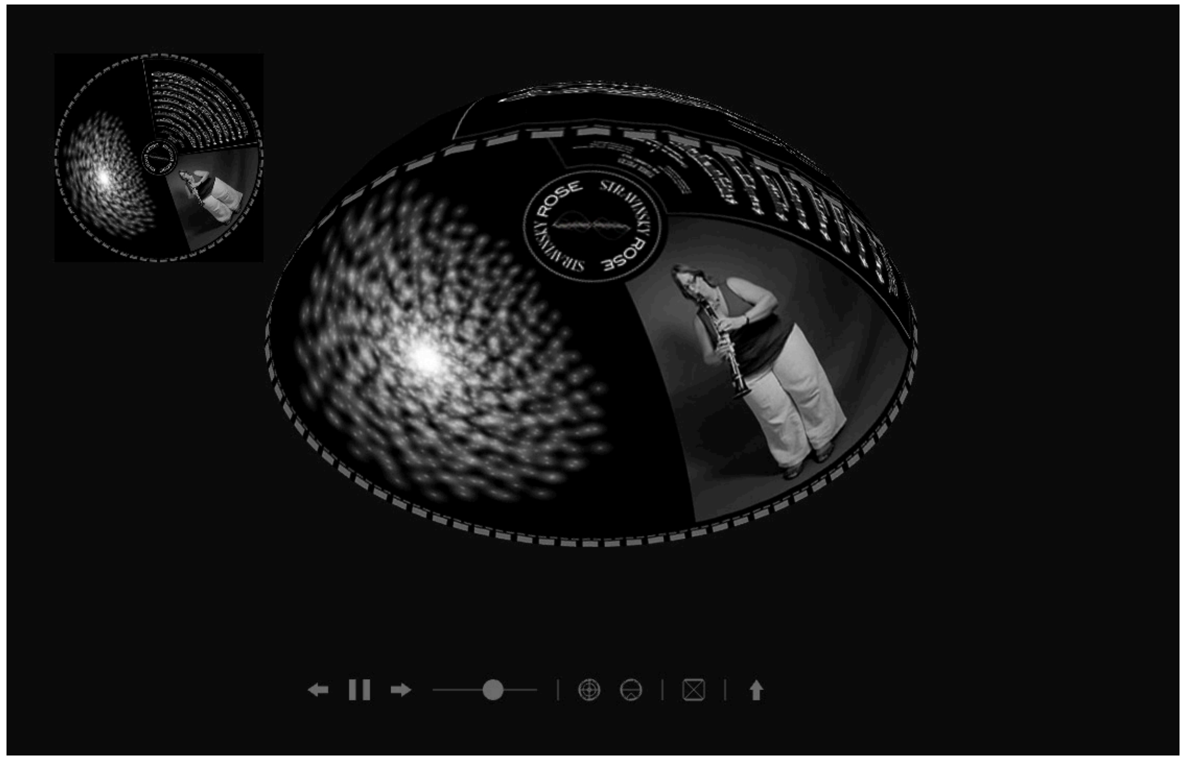

Figure 41 - *Stravinsky Rose* (v2.0) via DomeTester

6.8 Screening - Stravinsky Rose (v2.0)

6.8.1 Description

Stravinsky Rose (v2.0) is a short audiovisual film (total running time 7:20) in Dome or half-sphere format (Figure 41) - a "Whitney Rose" inspired real-time visualisation of Igor Stravinsky's *Three Pieces for Clarinet Solo* (1918) as performed by Fiona Cross of the Manchester Camerata.

> Stravinsky composed these colourful and witty works late in 1918, five years after *The Rite of Spring* and towards the end of his "Swiss" period. His focus at the time, on miniatures and spartan musical textures scored for just a handful of musicians, culminated in *The Soldier's Tale* - with its first production in September 1918 financed by Werner Reinhart. Composed immediately afterwards and closely linked to it, *Three Pieces for Clarinet Solo* were written as a thank you present to him. These three short monologues are among Stravinsky's "biggest" little works. The first slow and introspective piece, which explores the clarinet's low register, most likely began life as a song and was sketched as early as 1916. The second is Stravinsky's "imitation" of improvisation written without bar lines (he had recently heard live jazz for the first time). The third revisits the ragtime and tango of *The Soldier's Tale* (Huscher, 2010).

John Whitney Sr. is considered by many to be the godfather of modern motion graphics. *"*Beginning in the 1960s, he created a series of remarkable films of abstract animation that used computers to create a harmony - not of colour, space, or musical intervals, but of motion*"* (Alves, 2005:46). Based on the trigonometry of Euclidian geometry, Whitney used simple mathematical equations to generate elementary animated figures, arguing that their vital, alternately diverging and converging forms, could be viewed as a visual parallel to the sonic harmonic series. Drawing on Whitney's legacy, this custom-coded, real-time visualisation adapts his geometric algorithm, the "Rose of Grandii", to create dynamic *'*naturalistic*'* patterns representative of each piece and more or less equivalent to the harmonic structure within the music itself.

Fiona Cross is one of the leading clarinetists of her generation. She has a varied career, combining chamber music for numerous ensembles with a solo career and playing guest principal clarinet with all the leading British orchestras including the London Philharmonic orchestra, the Bournemouth Sinfonietta and the English Sinfonia. She is currently principal clarinet of the Manchester Camerata and Professor of Clarinet at Trinity College of Music, London.

The documentation of *Stravinsky Rose* (v2.0) available on the accompanying hybrid DVD is a screen recording from DomeTester (mapping a low resolution 512x512 pixel version of the half sphere format onto a virtual dome) along with supplemental video of a later *Stravinsky Rose* (v2.1) edit in standard 1080p format.

6.8.2 Context

The international *Understanding Visual Music Symposium* - UVM 2013 (CEIArtE, 2013) was hosted by the Center for Experimentation and Research in Electronic Arts (CEIArtE) of the National University of Tres de Febrero, Buenos Aires, Argentina, 8-9th August 2013. Through a Colloquium and Concert programme it aimed to create an opportunity for artists and researchers involved in *Visual Music* to share and discuss artistic, aesthetic, perceptual, technological, educational, and sociocultural themes relevant to this field. The organisers were particularly interested in *"*the process where the research and creation through interdisciplinary collaboration in different fields of art, science and new technologies becomes a key for the artistic results*"* (CEIArtE, 2013:online). A coproduction with the city's Galileo Galilei Planetarium, it offered a unique opportunity to produce work for projection on the entire half-sphere (format mapping) of its dome. Dome format systems are relatively rare and the production process is technically demanding compared to conventional formats. Accordingly, there are limited examples of artistic works within the *Visual Music* genre produced in this format - though it is a developing area.

Stravinsky Rose (v2.0) was a next stage iteration of *Stravinsky Rose* (v1.0), first performed as part of UpClose 4, Deaf Institute, Manchester, UK, 26th March 2013. It was screened to a full house as part of the UVM 2013 Planetarium Concert programme alongside works from the Jutojo Collective (German/Turkish), Larry Cuba (United States), José María D'Angelo and Hernán Huguet (Argentina), Bill Alves (United States), Matthew Biederman (United States) & Alain Thibault (Canada) and Ivan Zavada (Australia). Larry Cuba and Bill Alves were particularly notable artists to be featured alongside, both being former collaborators of John Whitney Sr.

6.8.3 Technical Realisation

Having never produced a half-sphere format film before this was an irresistible opportunity. However, the complexity of the production process, the consequential timeline and the sheer scale of making a work in this format was significantly underestimated. The final 7:20 film comprised almost 13,000 4K (4096x4096 pixels) PNG files totalling more than 51GB.

Filming Fiona Cross

For *Stravinsky Rose* v1.0 at UpClose 4, Fiona Cross had performed Stravinsky's *Three Pieces for Clarinet Solo* live. A subsequent studio session filmed and recorded her playing through the works several times, these video and audio assets were imported and aligned in Final Cut Pro 10 (FCP X) and those performances which felt best were selected and edited.

High Resolution Visualisation

Dome format is enormous - 4096x4096 pixels. By comparison, a personal early 2011 MacBook Pro 13" had a maximum built-in screen resolution of 1280x800px. Even if it were possible to screen record the visualisation at a high enough frame rate, these assets wouldn't be close to large enough. So Ben Lycett and his later model MacBook Pro 15" with retina screen, helped capture the visualisation at higher resolution. Several approaches were tested - outputting individual frames directly from openFrameworks and using dedicated screen recording software such as iShowU HD and ScreenFlow. Surprisingly, the best results were realised using the screen record function of Apple's inbuilt QuickTime X. By slowing down the audio to between half to quarter speed depending on the tempo of the piece and adjusting the easing times within the sketch accordingly, a resolution of ~2570x1920px was realised without dropping frames and at an acceptable* frame rate of ~20FPS (* exceeding the required 30FPS once adjusted back to *'*normal*'* speed using FCP X's Optical Flow retiming functionality). The retimed audio files were also used in the final edit of the film, underpinning the 'information*'* sections - so that the process of making the film was referenced within the film itself.

References

Online research realised program notes on *Three Pieces for Clarinet Solo* from the Chigaco Symphony Orchestra (Huscher, 2010) and a paper on interpreting the pieces (Emch, 2012) as well as a PDF of the score, photographs of Igor Stravinsky and John Whitney Sr. and other useful graphical assets including concert posters and film credits. These were used to compose the informational text and supporting notes, select suitable fonts for the logo animation and credits and were included within the later *Stravinsky Rose* (v2.1) edit in standard 1080p format.

FCP X and Dome format

While FCP X doesn't have a default Dome format preset, a work around was to create a new project and choose the option to set its format based on the first video clip - which could be Dome format. Several tests were made using this technique before realising that the spherical distortions inherent in projecting within a dome couldn't be accounted for using this approach. Learning more about how to create media for Dome format was required. Still, reflecting on the half-sphere format suggested that it would lend itself particularly well to rotation. The various on-screen elements could spin around the vertical axis of the dome, moving into and out of the audience's field of view as the work progressed. An impression of an orrery could be created by rotating the various on-screen elements at different speeds.

Andrew Hazeldean's Domemaster Photoshop Actions Pack

Further research on the Sky-Skan Definiti Projection Systems setup (Sky-Scan, no date) used within the 20 meter-diameter dome of the Galileo Galilei Planetarium and the various commercial (and expensive) software plug-ins - such as DomeFX for After Effects - used to develop content for this format, eventually led to Andrew Hazelden's Blog (Hazelden, 2009-2014) and his free *Domemaster Photoshop Actions Pack* - *"*a collection of custom Adobe Photoshop Actions that were designed to speed up the full dome content creation workflow*"* (Hazelden, 2009:online). Consequently the film could be edited in 4096x2048px format in FCP X, the final edit exported as a PNG sequence at 30FPS and then Hazelden's Photoshop Actions used to batch convert these PNGs to Dome format. An output test sent to the technical team at UVM 2013 confirmed this approach.

Assets & Layout

Tests showed that content at the top of the frame would be significantly distorted by the rectangular to polar coordinate conversion. So creating a circular animated logo that rotated slowly at the centre of the dome required several steps. The animation was created in Motion at its correct size for the final edit but on a 4096x4096 canvas; then exported as a PNG sequence; converted from polar to rectangular coordinates using Hazeldean's *Domemaster to Powerpoint* Photoshop Action; batch cropped from the resulting 4096x2048px PNGs to a 4096x600px strip; imported as an image sequence into QuickTime; and saved as a movie. Finally this file was imported as an asset into FCP X, positioned at the very top of the frame according to a template created in Photoshop to help align all the various assets accurately within FCP X and duplicated as required over the length of the timeline. Motion proved to be a really useful tool for creating other animations such as the various *'*marching-ants*'* style dashed lines that framed and separated the on-screen elements. With support from Ben Hudson, Technical Officer, Digital Video at MMU, Motion was also used to create several FCP X Effect templates - including one that slid the main content to the left but *'*wrapped*'* it to appear back on the right - creating the effect of a smooth rotation.

Credits & FOV

Close to finishing the edit, but uncertain how large text for the credits would appear in the field of view, prompted emailing Andrew Hazelden (he had shared his knowledge and tools so openly) - requesting advice on a rule of thumb font size, word count per line, width of screen real estate etc. that would make a block of text

readable on a full-dome screen. He responded promptly forwarding on examples of layouts for on-screen credits from The Fulldome Database (FDDB, 2011) and several dome reference grids to help work out the comfortable forwards viewing area. Unfortunately his feedback confirmed what was already suspected - there was too much text and it was well outside the preferred field of view.

DomeTester

Hazelden also recommended some full dome review tools that simulate the full dome screen viewing experience, including the free DomeTester[17]. The Mac version had some issues - the preview image was reversed using the MP4 codec - but nevertheless it proved an invaluable tool which would have been extremely useful earlier in the process. Unfortunately it also illustrated perspective issues within a dome and how much content is actually distorted - Fiona had ended up with too thick thighs and a pointed head. However, with a scheduled flight leaving imminently, there was no time to adjust the layout and overcome these comical distortions.

Rendering, rendering…

With an export from FCP X as image sequence on a hard drive, the batch conversion to Dome format using Hazelden's Photoshop Actions began. However, an estimate on the length of time it would take to convert the 12,899 frames of the film based on progress after 4 hours was a further 75 hours - another illustration of vastly underestimating the scale of working with Dome format. So every computer to hand was turned to the task of batch converting frames - though it was still necessary to take a Mac mini as well as MacBook Pro out to Buenos Aires to complete the task there.

Audio

Finally, a low resolution DomeTester version of the film was imported into Live; the audio from Fiona's audio recordings was aligned against the video; atmospherics, sound effects and the reduced speed audio used to generate the visualisations were sequenced along the soundtrack; and effects and signal processing added. The audio was a bit raw and under-produced, but the best achievable under the circumstances and in the time scale. The final mix was exported as a WAV file and passed to the technicians at the planetarium along with the requested format PNG files.

6.8.4 Critical Reflection

In integrating a custom-coded MaxMSP patch using the fiddle~ object to track the pitch of Fiona Cross' clarinet performance - in its first iteration live, and for this version via the audio track of a studio video recording - *Stravinsky Rose* (v2.0)

[17] A Cinder based application by Christopher Warnow and Dimitar Ruszev featured on the University of Applied Sciences, Potsdam website (Warnow & Ruszev, 2011).

reflects that aspect of the *modular performance system* conception of *The Augmented Tonoscope* defined by *sound analysis*. In generating a real-time visualisation of the music using variants of the "Rose of Grandii" algorithm developed by John Whitney Sr., the work reflects that aspect defined by *virtual systems*.

By *Stravinsky Rose* v2.0 the MaxMSP fiddle~ object patch had been sufficiently refined, not only to behave far more dependably, but also to demonstrate a surprising fidelity. Stravinsky's *Three Pieces for Clarinet Solo* vary dramatically in tonal range and pace - from the slow, low register of the first piece to the constant and driving almost frenetic quality of the third. Yet once fine-tuned, the patch handled these diverse dynamics without issue - successive notes, even those played in a flurry, were accurately detected and tracked with next to no latency. In truth, it would be difficult to conceive of a music selection that could test its abilities more comprehensively. Accordingly, the technique realised the real-time visualisation of traditional and contemporary classical solo works - an outcome to the research not considered at the outset. While limited to tracking essentially monophonic, single instrumentation, scaling up the technique could lead to real-time visualisation of duets and small ensembles - capturing the different instruments via multiple audio input streams and then routing these into a modified multiple fiddle~ object MaxMSP patch.

Although a next stage development of an earlier work, *The Whitney Modality* (WAYS TO ESCAPE_, 2013)), itself a port to openFrameworks of the earlier Processing based *The Whitney System* (Monomatic, 2012), *Stravinsky Rose* was a first attempt to realise a correspondence between musical pitch and the convergence of the patterns in Whitney's algorithms. As such, it contributed

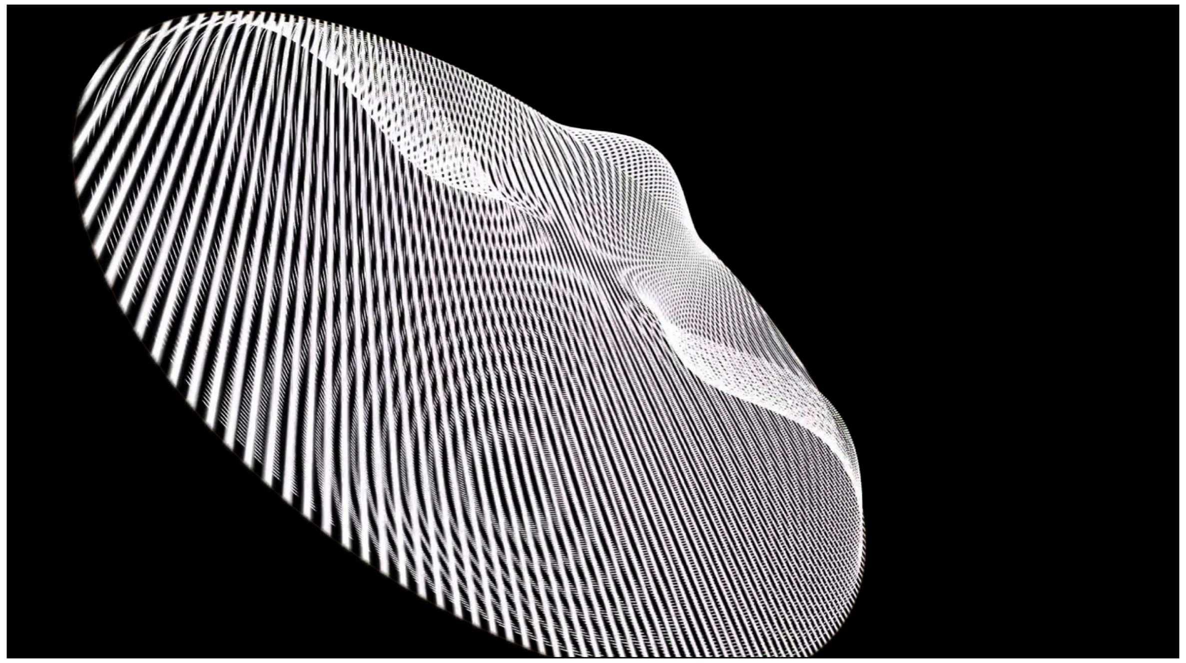

Figure 42 - *Moiré Modes* (v1.1)

significantly to the process of testing and refining the custom criteria applied to Whitney's techniques alongside more conventional animation tools - as detailed in Section 5.5.3 John Whitney Sr.'s Differential Dynamics. Crucially, it demonstrated that relatively simple variations of a Whitney algorithm could generate a family of visualisations with distinct looks and feels to suit music with dramatic variations in tonal range and pace. The system also demonstrated minimal latency - despite a signal path which included tracking the audio to MIDI Note On messages, sending and reading this data via UDP, calculating ratios via these values and applying these to the algorithm via a tweening function - there was no perceptible lag between audio and visual, an issue frequently problematic for real-time audiovisual work.

Aesthetically the work reflected the emerging minimalist, greyscale palette. Yet this wasn't only due to the essentially anti-synaesthetic position within the research which shied clear of mapping pitch to colour[18]. The UpClose residency experience had intimated a scepticism amongst the perhaps purist enthusiasts of classical music of the need for visualisation at all. *Stravinsky Rose* attempted to respond to this by making a less interpretative and more direct and literal connection between the music and visuals. Judging from feedback from audience and players alike, this was an effective strategy.

Producing a work in Dome format was a demanding yet ultimately satisfying process. Despite the steep learning curve of the production process and the obvious flaws in the final edit, it was gratifying to produce a work that was screened as part of the UVM 2013 Planetarium Concert and a rare and memorable experience to view it at a size that was actually too large for the eyes - and even for a personal documentation camera set to its widest field of view.

6.9 Live performance - Moiré Modes (v1.1), Whitney Triptych (v1.2) and Stravinsky Rose (v3.0)

6.9.1 Description

Moiré Modes (v1.1) visualises an unaccompanied solo for five timpani - *Up and Coming* from Tom Brown's *Solo Timp Collection* - using Moiré effects to help visualise the vibrational modes of a perfect, virtual drum skin retuned to the first five 'preferred modes' (Figure 42). Essentially the work is a construct - a performance version of the model detailed in Section 5.5.1 Virtual Drum Skin, illustrating yet abstracting the real-world behaviour of timpani by mapping each

[18] Cognitive neuroscience research has demonstrated that we do associate higher tones with brighter colours. So the work integrates a mapping of pitch to luminance by linking pitch to the transparency of the white dots that make up the Whitney figures - the higher the pitch the lower the transparency and so the brighter the patterns appear.

drum in the set to the pattern of a discreet vibrational mode and then retuning its pitch to the respective theoretically determined ratio of the fundamental frequency. In reality, all these modal vibrational states (and more) would be present on each drum skin and contribute to its pitch and timbre - this technique spotlights a single mode.

Video documentation of *Moiré Modes* (v1.1) along with an openFrameworks binary and sketch of the *Virtual Drum Skin* can be found on the accompanying hybrid DVD.

Whitney Triptych (v1.2) explores the counterpoint in J. S. Bach's *Fugue in F minor BWV 881* by visualising the right and left hand parts of the Prelude each as a "Whitney Rose" pattern with a third, central rose displaying the harmonic relationship between them. It is an audiovisual study of counterpoint - the harmonically interdependent parts in a piece of music that are independent in rhythm and contour - distinctive to the Baroque Period and exemplified by J. S. Bach. In visualising the harmonic structure within the music the rose variants display a wide range of forms - from curvaceous, vessel-like shapes to exploded spirals of sinusoidal lines - yet the point of view remains fixed throughout. Underneath each of the rose figures the sector of a circle graphically represents the current ratio of the frequency of the incoming note to the tonic which is also displayed numerically.

Video documentation of *Whitney Triptych* (v1.2) along with an openFrameworks binary and sketch can be found on the accompanying hybrid DVD.

Stravinsky Rose (v3.0) - a "Whitney Rose" inspired visualisation of Igor Stravinsky's *Three Pieces for Clarinet Solo* (1918) performed by Fiona Cross of the Manchester Camerata is described in Section 6.8.1 Description.

Video documentation of *Stravinsky Rose* (v3.0) along with an openFrameworks binary and sketch can be found on the accompanying hybrid DVD.

A fourth piece, *Three Space* (v1.0), was realised as part of an emerging collaborative practice with Ben Lycett. As such it is not appropriate to include within the individual research defined by this study.

6.9.2 Context

These works featured as part of a performance at *Seeing Sound 3*, Bath Spa University, UK, 24th November 2013. *Seeing Sound* (Seeing Sound, 2009-2014) is an informal practice-led symposium exploring multimedia work which foregrounds the relationship between sound and image. It explores areas such as *Visual Music*, abstract cinema, experimental animation, audiovisual performance and installation practice through paper sessions, screenings, performances and installations.

The performance at *Seeing Sound 3* included three, short, abstract audiovisual works created as part of this study. They attempt to show a deeper connection between what is heard and what is seen by making the audible visible. Looking for similar qualities to the vibrations that generate sound but in the visual domain, to create an amalgam of the audio and visual where there is a more literal harmony. The works explore real-time audiovisual performance using custom-made software systems developed in the creative C++ toolkit, openFrameworks, alongside commercial audio production tools. Later iterations of these works also involved custom-made hardware based on the Arduino micro-controller electronics prototyping platform.

Although the line up for this performance session was diverse, reflecting those areas explored by *Seeing Sound* outlined above, works most contemporary to *The Augmented Tonoscope* included Paul Prudence's *Chromophore* - "an audio-visual performance work that applies … transformations of three-dimensional geometric primitives and superellipses … tightly synchronised to an electro-acoustic sound composition constructed from field-recordings" (Seeing Sound, 2009-2014:online) and Ryo Ikeshiro's *Construction in Kneading* - "a live audiovisualisation of a Mandelbox fractal, one of several recent multi-dimensional fractals inspired by the famous Mandelbrot set … resembling the actions of kneading dough in bread making" (Seeing Sound, 2009-2014:online). It was particularly gratifying to perform alongside Paul Prudence - his audiovisual works have been influential on an emerging aesthetics for *The Augmented Tonoscope*.

6.9.3 Technical Realisation

Moiré Modes (v1.1)

The intent behind *Moiré Modes* was straightforward - use the *Virtual Drum Skin* developed as part of the *virtual systems* module to generate a real-time animation of a drum solo as audiovisual performance. The tuned drums of orchestral timpani being an obvious choice, a search for existing MIDI files for solo compositions for five timpani, led to a suitable Level 5 solo - *Up and Coming* from Tom Brown's *Solo Timp Collection* - via a website for the 7th Grade Band at Twelve Corners Middle School, Rochester, NY maintained by its music teacher, Mr. Baldwin (baldwinsmusic.com, 2014).

The MIDI file was played via Live and each successive timpani 'hit' (either G#0, A#0, C1, D1 or D#1) was sent directly into the *Virtual Drum Skin* sketch as a MIDI Note message. Within the oF visualisation, each note was mapped to a distinct pattern amongst the modal vibrational states of the perfect, virtual drum skin, specifically the first five 'preferred modes'. These are the first few modes

Preferred Modes of Timpani

Mode #	Preferred Mode #	Theoretical ratio of the first mode	Ratio of the 1st 'preferred' mode	Nearest fraction	Fractional value as decimal	Nearest small whole number ratio	As ratio
second mode (1, 1):	1	1.5933	1.0000				
third mode (2, 1):	2	2.1355	1.3403	1 16/47	1.3404	4/3	1.3337
fifth mode (3, 1):	3	2.6531	1.6651	1 141/212	1.6651	5/3	1.6667
seventh mode (4, 1):	4	3.1555	1.9804	1 50/51	1.9804	2/1	2.0000
tenth mode (5, 1):	5	3.6475	2.2892	2 11/38	2.2895	7/3	2.3337
twelfth mode (6, 1):	6	4.1317	2.5931	2 16/27	2.5926	8/3	2.6667

Figure 43 - A table of the six 'preferred modes' of timpani - showing ratios, nearest fraction and nearest small whole number ratios indicating its 'near harmonicity'

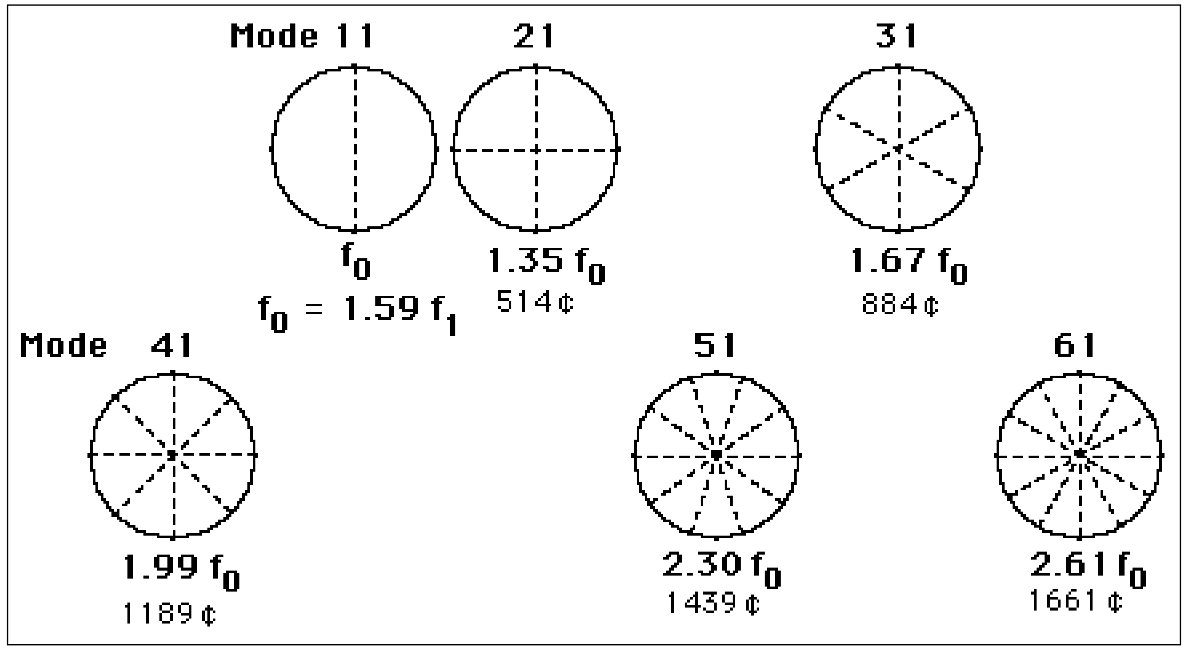

Figure 44 - The six 'preferred modes' of timpani - steady vibrational states which include only diametric nodes

(maximum six) that actually contribute to a timpani's sound spectrum with regard to giving the instrument its 'near harmonicity' - as detailed in Figure 43. These are found in the lower diametric modes (1,1), (2,1), (3,1), (4,1), (5,1) and sometimes (6,1) - as illustrated in Figure 44. While other modes contribute to envelope and timbre, giving the instrument its unique tonal characteristics, they don't really contribute to the timpani's sense of pitch (Jones, no date). So each of the five timpani from lowest (largest) to highest (smallest) triggered a corresponding modal vibrational pattern - mode (1,1) to mode (5,1) - in the visualisation.

The Moiré effects - interference patterns produced by overlapping two grids of closely spaced straight lines on a transparent background rotated a small amount from one another - one grid a texture on the dynamic mesh of the virtual drum skin with the second grid offset above it, provided an alternative way to visualise the vibrational modes as the virtual drum-head vibrated.

The oF sketch calculated the frequency of that triggered mode based on its theoretical ratio of the fundamental and sent this as a combined MIDI Note On and pitch bend value back into a MIDI track in Live hosting Native Instruments Kontakt 5 loaded with Orchestral Tool's *The Timpani* instrument. A MIDI pitch effect remapped the incoming MIDI note to the range of the instrument and a MIDI compressor effect evened out the dynamics. Consequently, the pitch of each timpani was retuned from the given note in the score to a pitch determined by its mapped vibrational mode.

In the *Moiré Modes* v1.0 live performance at *Seeing Sound 3*, the switch between the wireframe and Moiré pattern presets as well as the various camera positions were triggered by hand in real-time. V1.1 added additional MIDI functionality to sequence and trigger these automatically from a MIDI track within Live. Finally, several audio processing effects were used to produce the final mix.

Whitney Triptych (v1.2)

Participating in the Understanding Visual Music 2013 conference in Buenos Aires in August 2013, provided a fortunate opportunity to spend some time discussing this research with composer, writer and video artist Bill Alves - one of John Whitney Sr.'s last collaborators before his death in 1995. He encouraged developing the techniques of *Stravinsky Rose* to explore counterpoint - the harmonically interdependent parts in a piece of music that are independent in rhythm and contour. He suggested it would be possible to display each portion of a two-part counterpoint as independent Whitney patterns, with a third displaying the harmonic relationship between the two. He also hinted this was something John Whitney Sr. himself would have been very interested in - persuasion enough. In fact, Alves suggestion of exploring counterpoint was something that had already been considered but not rationalised.

Counterpoint has been most commonly identified in classical music, developing strongly during the Renaissance and in much of the common practice period, especially in Baroque music. So the Baroque Period offers the apex of the natural evolution of musical counterpoint from the 13th century onwards - and J. S. Bach arguably represents the pinnacle of the form. The chosen Prelude to the *Fugue in F minor BWV 881*, one of Bach's slower tempo works, was selected by listening to MIDI files downloaded from the online collection of the J. S. Bach's *Well-Tempered Clavier Book II* edited and sequenced by Yo Tomita (Tomita, 1998). This MIDI file was subsequently separated into the left and right-handed parts.

Whitney Triptych used a similar technique to *Stravinsky Rose* within the oF visualisation sketch to compare the incoming notes from the MIDI file of the Bach Prelude played via Live, with the separated left and right-hand parts on their own MIDI channel. Successive notes from each of these parts were compared to an F3 tonic for the left-hand and F5 tonic for the right, 'scrubbing' each respective *'rose'* figure to that ratio along its timeline. Finally, the ratio between the last incoming notes from each part was calculated and used to 'scrub' the central *'rose'* to that ratio along its timeline. The graphical processing techniques used to display the Whitney figures within the visualisation was also refined from *Stravinsky Rose* - updating the existing transparent PNGs graphic files used to represent the points within the Whitney figure with the textures and Vertex Buffer Objects (VBO) demonstrated in the default *Particles as Textures* oF example.

However, overall the technique had limitations and required some workarounds. First, certain sections of the Prelude featured right-handed parts only, so to maintain a dynamic left and central rose, those few notes that seemed to best reflect the counterpoint were moved into the left-handed part (they fell within the range played by the left hand anyway). Second, the Whitney algorithm requires a single ratio, so the visualisation can only work with monophonic parts. While there is limited polyphony in the piece there are occasional chords - so the code was adjusted to select only the lowest note of a chord - which was most likely to be but might not actually be its tonic. Lastly, but most significantly, while the MIDI file certainly uses 12-ET tuning, there is some uncertainty as to whether Bach composed and performed this Fugue using 12-ET tuning or an alternative 'well tempered' system - as intimated by Francis - "In more recent times... Bach has been seen, on the one hand, as a pioneer of Equal Temperament and, on the other, as a proponent of unequal Well Temperaments. In this latter regard, suggested temperaments have included those of Werckmeister and Kimberger" (Francis, no date:online). So despite arguing for a Just Intonation based tuning within the research, but with the micro-tuning approaches to working with Live as detailed in Section 5.7 Recording & Sequencing not yet implemented, the actual ratios generated for each note against the F tonics in the initial version used 12-ET tuning. As such these weren't based on small whole numbers and so the "Whitney Rose" animations failed to display their converging and diverging patterns as faithfully as they might.

A subsequent v1.1 iteration used a custom-made micro-tuning device developed using a Teensy 2.0 to retune the MIDI score to a tuning system more contemporary to Bach as proposed by Thomas Young circa 1799, but still had inconsistencies as noted by Aaron Hunt of Hπ Instrument - occasional wrong notes and notes sounding without release. A v1.2 iteration overcame these issues by replacing the Kontakt instrument and including MIDI Note Off within the micro-tuning device.

Stravinsky Rose (v3.0)

This final version further refined the previous iteration. It integrated the video recording of Fiona Cross' performance within the oF visualisation sketch itself. There was also an optimisation of the existing oF sketch and MaxMSP patch - carefully adjusting the aesthetics of the visualisation for maximum effect and fine tuning the responsiveness of the audio tracking.

6.9.4 Critical Reflection

Moiré Modes (v1.1)

In integrating a Bessel function within the General Scientific Library to create a model of a virtual drum skin and display a series of its vibrational modes, *Moiré Modes* (v1.0) reflects that aspect of the *modular performance system* conception of *The Augmented Tonoscope* defined by *virtual systems*. In using the Ableton Live Studio 9.1 Digital Audio Workstation to playback a found MIDI file of *Up & Coming* (Tom Brown, *Solo Timp Collection*), an unaccompanied solo for five timpani, it reflects *sequencing and recording*.

Realising *Moiré Modes* drove much of the development of an earlier demonstrable version of the model as detailed in Section 5.5.1 Virtual Drum Skin. Exploring the 'preferred modes' of timpani developed a deeper understanding of the empirical techniques employed by orchestral percussionists - accommodating inconsistencies in the contrasting behaviours of the steady vibrational states of circular drum skins to realise a 'near harmonicity' - at least across its lower modes.

This was the first work which used Live to playback a found MIDI file, routing the MIDI Note On messages into the oF visualisation sketch - and similar MIDI functionality has subsequently been duplicated across other visualisations within *virtual systems*. It was also the first work that implemented the notion of micro-tuning - of retuning the pitch of the notes within the MIDI file (invariably based on the ubiquitous 12-ET tuning system) to frequencies actually defined by the mathematical model of an ideal drum skin. As such it contributed to the development of working solutions to enable Live to deal with micro-tuning and so perfect intervals more effectively.

The work maintained the emerging minimalist, greyscale palette, with only minimal use of a highlight colour (the bounding ring of the drum and the active inputs in the GUI when visible). This particularly suited the Moiré patterns which elevated the work aesthetically to being more than just a functional virtual model of a vibrating circular drum skin. Despite being an ideal - no real world drum-head would behave as perfectly as this - it proved effective in visualising the dynamics, pace and physicality of percussion. It has since been extended beyond the scope of the Ph.D. to visualise a contemporary composition for five timpani performed by young percussionists at the Royal Northern College of Music.

Whitney Triptych (v1.2)

In extending the aesthetics and functionality of variants of the "Rose of Grandii" algorithm developed by John Whitney Sr., the work reflects that aspect of the *modular performance system* conception of *The Augmented Tonoscope* defined by *virtual systems*. In using the Ableton Live Studio 9.1 Digital Audio Workstation and a custom hardware micro-tuner to playback and retune a found MIDI file of the Bach Prelude it reflects *sequencing and recording*.

This work extended the solo nature of *Stravinsky Rose* which only visualises a performance by a single and essentially monophonic instrument, the clarinet, to a piece of music with two-parts - a right and left-handed part - written for and performed on the polyphonic harpsichord. While this highlighted limitations within the visualisation technique it also prompted creative workarounds - demonstrating that it could be successfully adapted to more complex musical forms, illustrating the inherent harmonic structures and cadences within a sophisticated musical work and opening the door to an abundance of musical composition beyond solo performance of music consisting of a single musical line without accompaniment.

Over its various iterations, the work prompted the most concerted development of the *sequencing and recording* module - realising the most complex routings of MIDI data to date within and between Live and the oF visualisation sketch. Development of a robust and flexible custom micro-tuner based on the Teensy 2.0 micro-controller developed a deeper understanding of the theories and practices entailed in working with alternative musical tuning systems and successfully overcame the general unsuitability of Live in working with micro-tonal tunings.

The work is certainly one of the study's more successful *proofs of concept* yet it does have its limitations. Despite Tomita's efforts to add more elaborate articulations, ornamentations and tempo changes, it still lacks the human feel, musical expression and natural cadence and dynamic of many of the performances of the piece found on Spotify. While efforts were made to extract the *'groove'* from selected audio recordings and apply it to the MIDI file using

Live's Melody to MIDI and Harmony to MIDI functions, despite being one of Bach's slower tempo fugues it is still typically complex and these tools weren't up to the task. Also stretching the MIDI file out to reflect these recordings bar-by-bar would have been too onerous. So a next natural step is to record the MIDI of a skilled pianist performing this or an alternative work.

Again the work maintained the emerging minimalist, greyscale palette although it refined the overall look through more sophisticated graphical processing routines. Despite being one of the more complex works technically, it is also one the most resolved aesthetically. It has something of a timeless quality - neither period nor modern, yet somehow elements of both. Its minimal formalism seems particularly well suited to the theme and variations form of the Bach Prelude. It is amongst those works that come closest to the ambition of engaging the viewer in a subtlety shifted way - a kinetic synchronisation between the senses of hearing and sight that results in a "co-sensing" of a "co-expressiveness" - where the mind is not doing two separate things, it is doing the same thing in two ways.

Stravinsky Rose (v3.0)

While the existing code was optimised it wasn't refactored (reworking the code without changing its external behaviour). The work represented a stage of development, certainly key to the research and influential upon later works, but using coding techniques and approaches since superseded by those developed within later works. In effect, a line was drawn in the sand - it was what it was.

6.10 Conclusions

In exploring cymatic effects within a gallery installation, the *Cymatic Adufe* is most akin to Suguru Goto's *Cymatics* (Goto, 2013), Calum Scott's *Cymatic Sculpture* (Scott, 2011) and though far more modest in scale, Thomas Macintosh's *Ondulation* (McIntosh with Hynninnen & Madan, 2002). However these works all employ alternate vibrating systems to the skin of the adufe - Chladni plates or water and non-Newtonian fluid in tanks and speakers. In its minimal, architectural form it reflects the aesthetics of Suguru Goto's *Cymatics* but also the installation based work of Robert Henke/Monolake (Henke, no date). Yet it is distinctive in balancing this clean, reductive minimalism against a rural aesthetic expressed through the adufe, the traditional folk melody of the *Senhora do Almortão* and the colours and shapes of the projected visualisation.

The works for screening and live performance employ and refine an aesthetic established by John Whitney Sr. and subsequently developed by the likes of Larry Cuba and Bill Alves. They sit well alongside the minimalist, synthetic aesthetics of contemporary *Visual Music* practitioners such as Paul Prudence, Yan Breuleux

(Breuleux, 2010) and Memo Atken (Akten, 1997-2014). Yet by connecting the visualisation primarily to pitch and to the harmonic structure within the music they differ from their general practice of integrating the visualisation to abstract composition and field-recording based soundscapes. This represents a distinctive quality to these works - attempting to realise visual equivalences to the auditory intricacies of rhythm, melody and harmony through ersatz, abstract visuals that echo the abstraction inherent within music itself.

While the initial intent had been to produce works through interacting, playing and recording with a completed instrument, this goal was subsequently reframed. Still, these works maintained the template established at the outset of the project to produce a series of artistic works for installation, screening and live performance. As such, this body of work reflects the development of *The Augmented Tonoscope* once it had been conceived as a modular performance system - demonstrating the evolution of its specific modules. *Virtual systems*, *sound analysis* and *recording and sequencing* progressed beyond initial expectations while *analogue outputs*, *musical interface* and *sound making*, despite a focus within early development, remained relatively incipient.

Yet more than this, the works represent a personal creative process with its own dynamic, pulse and trajectory and a stance on Practice as Research which has allowed these factors to guide the progress of a course of study iteratively and in intended rather than incidental ways. These works represent key *'*milestones*'* along a progression of development - a process that draws on earlier work and creative experiments and feeds into subsequent works. They demonstrate an approach of responding to opportunity, of developing new work iteratively, of evolving a *'*toolkit*'* of assets, techniques, electronics and code through the practice and of pursuing fascinating lines of enquiry revealed through the research and not fully appreciated at the outset. They reflect an attitude which has encouraged the research to mature and evolve beyond its initial conception - to be open to fresh insight and new understanding and driven by the praxis. As such, the research frameworks, objectives and key methods established at the outset of the study have been seen as useful mechanisms to focus and guide the research - not curtail it.

7. Conclusions

7.1 Introduction

This thesis has established the key questions and concepts that have driven and informed the practice - and through it, the research overall.

It serves as a working map for this exploration of the terrain - highlighting the significant features, contours and perspectives that guided the study, outlining the various routes traversed and making the research agenda and its selected traits explicit. The exercise of discerning a congruence between and recognising repeating patterns within the disparate sources of the research - albeit finding links in unexpected places - has helped to reveal an underlying topography to the study. In doing so it has established a broad, interconnected and suitably robust roadmap for realising a more intimate perceptual connection and harmonic *complementarity* between music and moving image. Akin to John Whitney Sr.'s declaration in *Digital Harmony*, *"*the purpose is to document my own approach and propose the seminal idea of making an approach*"* (Whitney, 1980:5).

In the introductory outline and throughout its earlier chapters, this thesis raised numerous questions. Some were rhetorical devices within the prose. Some helped frame a specific issue or technical challenge subsequently explained within the text. Some were and remain key:

- What might sound look like?
- Are there visual equivalences to the auditory intricacies of rhythm, melody and harmony?
- Is it possible to characterise a visual music that is as subtle, supple and dynamic as auditory music?
- Can a combination of sound and moving image create audiovisual work which is somehow more than the sum of its parts?
- By what means, methods and mechanisms might this be realised?

So this final chapter responds specifically to this last category of questions - to help reveal the fresh insight and new understanding realised through the research.

It also serves to look beyond the study, in part to outline current development previously intimated as being beyond the scope of this Ph.D., but also to envision future trajectories for post-doctoral research.

7.2 Shifting Emphasis

Over the course of the study and as the understanding of the research area matured, there were subtle but significant adjustments in focus. This is to be expected and is actively encouraged through the formal and informal procedural mechanisms that guide it. Still, this has been influential in shaping the way the research has been thought about, described, referenced and approached. So it is important to illustrate and be explicit this about this shifting emphasis.

In an initial proposal, attention was clearly on Cymatics - the study of wave phenomena and vibration - as the primary vehicle by which the research would explore the distinctive qualities of sound and a correlation between sound and image. It was argued that an artistic investigation into Cymatics would allow a deeper appreciation of the nature of sound and that building an instrument that deployed these effects might reveal new understanding about the elemental properties of sound.

Six months into the project, it had been acknowledged that the Ph.D. demanded less grandiose ambition, an apposite context and clear outcomes. A frame of reference was established in *Visual Music* and the project was oriented towards a deeper understanding of the interplay between sound and image within this area of artistic practice. The initial focus on Cymatics was tempered against the development of a hybrid device, in which the combination of physical cymatic patterns and virtual simulations might help realise a real-time correlation between the visual and the musical.

By 18 months in, the research had evolved into something more subtle and sophisticated still. It had been drawn towards fundamentals - to a reductionist, back-to-basics approach to exploring the real-time, elemental and harmonic correspondence between sound and moving image. A reading of the literature from the disparate disciplines that resonated with the research, pointed towards audiovisual works focussed on movement and underpinned by harmonic relationships determined by the small whole number ratios of the Pythagorean laws of harmony. In attempting to realise a synchronisation between sound and moving image that had a subtly shifted quality, the study had adopted a markedly phenomenal and perceptual perspective - an area of investigation hardly considered at the outset.

So while the study started with a clear set of objectives, as a direct result of what has been learnt through the praxis, the project's scope and remit has changed. This is illustrated in how the key method of building an instrument persisted throughout yet evolved over time, as described in Chapter 4. The Augmented Tonoscope. Perhaps more significantly, the research itself revealed that a central starting assumption - that cymatic patterns would be a meaningful way to visualise harmonic structure within music - was simply untrue. This initial supposition wasn't viable and as a consequence the project required an alternative approach. So the research has matured and evolved beyond its initial conception by being open to fresh insight and new understanding driven by the praxis.

7.3 Key Research Question

The overarching research question, declared at the outset of the study, asked:

- How far can artistic investigation into Cymatics - the study of wave phenomenon and vibration - contribute towards a deeper understanding of the interplay between sound and image in *Visual Music*?

Typically the answer to this question is far from straight forward.

7.4 Cymatics

This artistic investigation into Cymatics - in and of itself - certainly revealed fresh insights:

- its effects and manifestations frequently demonstrate an underpinning periodicity;
- its 'triadic nature' - the ability to simultaneously hear the sound, see the pattern and feel the vibration - offers three essential aspects and ways of viewing a unitary phenomenon;
- vibrating diaphragms are environments of extraordinary complexity - stationary wave patterns are only one manifestation of a complex system.

Reflecting on the periodic or cyclic nature of Cymatic effects - demonstrated not only in the macro: through centres of rotation and revolving heaps within the glass bead medium, but also in the micro: the paths individual beads followed within localised effects on the vibrating drum skin - shaped perspectives within other aspects of the research where periodicity had not been immediately evident. This is particularly true within Whitney's *Differential Dynamics* within *virtual systems*. Conceiving of his algorithms as being cyclic rather than linear in the macro - their end point at a ratio of 1.0 also being their start point at a ratio of 0.0 - made it possible not just to loop the algorithm within the code, but more significantly, create a plane of symmetry around the root note or tonic of a musical composition and so reflect the harmonic structure of the music within the periodic dynamic patterns it generated in the micro more effectively.

The 'triadic nature' of Cymatics indicated a distinctly multimodal sensory approach to the study overall, prompting further investigation into the perceptual processes involved in vision and audition. Of effecting a (kinetic) synchronisation between the senses of hearing and sight that might result in a "co-sensing" of a "co-expressiveness" - where the mind is not doing two separate things, it is doing the same thing in two ways[19]; and especially the creative potential offered through an artistic exploitation of the innate and universal effect of multi-sensory integration.

[19] As argued by David MacNeil (1992) in *Hand and Mind: What Gestures Reveal about Thought* - albeit within the area of speech and gesture.

Most significantly, an appreciation of the complexity of vibrating diaphragms shifted thinking beyond an initial focus on the stationary wave patterns of modal vibrational states of a drum skin. The notion of a *cymatic scale* - of a discreet pattern for a given frequency - while responding to the question 'What might sound look like?' and demonstrating that it was certainly possible to produce an analog of sound in visual form, proved too simplistic a mechanism to create audiovisualisation with any degree of sophistication. While it would have been possible to create a composition based on those frequencies which induced discreet cymatic patterns on the drum skin - even though this sequence of tones would bear little relation to any conventional 12-tone Equal Temperament scale - this would hardly achieve more than Hans Jenny had demonstrated 50 years previously.

This led to exploring the transitions between discreet cymatic patterns rather than the patterns per se - demonstrating the complexities of the shapes and forms on the vibrating drum skin between these points of resolution. It prompted research within the *sound making* module into the conventional but limited techniques for moving between frequencies - portamento and glissando (see Appendix 7 - Glossary of Terms) - and onto techniques to shape the movement between tones more controllably via tweening functions and Bézier curves. It also introduced the idea for future explorations into musical traditions beyond contemporary Western Music, for example pitch continuum traditions such as South Indian vocal performances. This broader perspective on cymatic effects also aligned with Whitney's analysis of the attractive and repulsive forces of harmony's consonant/dissonant patterns within music and a "complementarity" with the resolution from apparent disorder - points of dissonance - into distinct alignments - points of consonance within the vital patterns of his *Differential Dynamics*.

7.5 Cymatic Limitations

By initially focussing on frequency rather than a note value within conventional musical tuning, the research had attempted to avoid the pitfalls of correlating sound and image based on a contemporary understanding of harmonic relationships - considering a *cymatic scale* as a set of formal constituents for pattern making rather than a call to a musical framework per se. Discerning the frequencies at which cymatic patterns were induced on the various devices of the *analogue outputs* module was a first step, rationalising these findings through abductive reasoning of experimental evidence came second and looking for suitable fits within the theory came last. Getting back-to-basics, letting experiment, observation and intuition drive the research, allowed for a certain ingenuousness - of trying to not predicate the research within existing frameworks, models, structures or theorems.

However, developing a deeper understanding of Cymatic effects - not appreciated at the outset of the study yet consequently undermining starting assumptions for the research - highlighted significant limitations for employing stationary wave patterns as a means to visualise music - as concluded by John Telfer:

> Whether it be Chladni plates, dishes of water, bells or drumheads, the vast majority of vibrating systems in nature are anharmonic, that is to say that their overtones do not correspond with the harmonic series. Harmonic systems such as the stretched string are very much the exception (Telfer, 2010:online).

The implication of the anharmonic nature of these systems is that the frequencies which induced discreet stationary wave patterns on the circular drum skin diaphragms of *The Augmented Tonoscope's* various *analogue outputs* were not small whole number multiples of the fundamental. Even the square framed hand drum of the *Cymatic Adufe*, a vibrating diaphragm of a form factor more akin to a one dimensional stretched string but in two dimensions, demonstrated an anharmonic nature. Accordingly, these patterns cannot realise a visual equivalence to the auditory intricacy of harmony. There is only a 'near harmonicity' - reflected in the first few 'preferred modes' of timpani and explored through the associated artwork *Moiré Modes*. An appreciation of the significance of these findings came too late within the process of this research - which had focussed from its early stages on vibrating drum skins - to impact on its formative direction.

Furthermore, as described in Appendix 3 - Comparative Tests of Drum Based Analogue Tonoscopes to a Virtual Drum Skin, it was evident that the 16" floor tom and 13" piccolo snare prototypes developed within the *analogue outputs* module behaved far from ideally. While they certainly produced discreet cymatic patterns over a range of frequencies their correlation to the ideal modal vibrational states only held for a few earlier modes - as the frequency rose the correlation broke down and the patterns became irregular. Furthermore, certain patterns on the 16" floor tom that exhibited a five-fold symmetry could only be explained as a particular tensioning idiosyncrasy of the drum skin due to the number of its tuning rods. While these prototypes clearly demonstrated a *proof of concept*, the limitations of their affordable but second hand components thwarted ongoing development.

So despite an initial focus within the research, the limitations of these analogue tonoscope devices curbed artistic exploration of cymatic effects beyond a series of studio experiments and *proofs of concept*. They simply didn't offer the opportunity to demonstrate rigour in respect to the imaginative creation, thoughtful composition, meticulous editing and professional production of new artwork. On reflection, more should have been demonstrated of their relative strengths and of the subtleties and nuances they might effect - for example exploring the sonic detuning and beating effects produced through the dual oscillators of the

SWG v4.0 to create fascinating pulsing and transitionary effects between cymatic patterns; and investigating the way the SWG v4.0 moved between two frequencies via real-time Bézier curve control to produce not just a series of distinctly different portamentos to the ear, but also a visible difference in the transitions between cymatic patterns.

More refined iterations of these devices using new, high-quality components and professional design and fabrication services was certainly envisaged and a preliminary consultation was undertaken. These alternative designs were based on research into more sophisticated tuning mechanisms that might overcome the inconsistencies in tensioning introduced by conventional metal fixing rings, shell mountings and tuning rods. This included the more advanced tuning mechanisms of the rototom[20] and chain-tuned timpani[21]. However, development of these devices was unaffordable within the resources of the Ph.D. and more significantly, would compromise the integrity of the study by introducing external contribution to the development of the research. Fabricating more advanced tonoscopes, while certainly desirable, was beyond the scope of this Ph.D. study. Accordingly, the analogue outputs module, despite a focus within early development, remained relatively incipient.

7.6 Cymatic Art

However, considering Cymatics as a starting point and springboard to other areas of research and development certainly contributed towards a deeper understanding of the interplay between sound and image in *Visual Music*.

Inspiration and insight was gleaned from the processes and methods of a range of contemporary art practice exploring Cymatics (references to these and other examples are listed in Appendix 6 - Cymatic Art & Creative Coding Examples), in particular:

- Goto's (2011) *Cymatics* (as discussed in Chapter 2. Literature Review) but also;
- Joynes' (2011) *Frequency Painting Series*;
- Blore & Meinema's (2009) *cymatics.org* photographic studies;
- Marko's (2008) *Kymatika* live performance and video works;
- and Richards & Wright's (2008) *Cymatic Controller* - a DIY mechanical wave driver that vibrates conductive material across a 'prepared' Chladni plate.

These works are amongst *The Augmented Tonoscope's* main artistic

20 Developed by Al Payson and Michael Colgrass in the 1970s, a rototom head sits on a threaded metal ring. Rotation raises or lowers the tension hoop relative to the rim, which increases or decreases the pitch of the drum by increasing or decreasing the tension of the drum head.

21 On chain timpani, the tension rods are connected by a roller chain much like the one found on a bicycle. All the tension rods can then be tightened or loosened by a single handle which turns them all at once.

contemporaries - at least in terms of physical cymatic effects - yet few of these are real-time works, a pre-requisite for this project, integrating Cymatics as one stage within longer artistic production processes. While they indicated a variety of aesthetic approaches to employing Cymatics, they mainly served to point out what the cymatic outputs of this project should not look like.

However, examples of open-source creative coding modelling Cymatic effects and manifestations (references to these and other examples are listed in Appendix 6 - Cymatic Art & Creative Coding Examples) highlighted the potential of the *virtual systems* module to create engaging digital visualisations exploring Cymatics - such as:

- Falstad's (no date) *Circular/Rectangular Membrane Waves Applets*;
- Wakefield's (2009) *Chladni 2D/3D* - Max/MSP patches which simulate a Chladni plate pattern in 2D and speculate what the equivalent might be for 3D;
- and Hodgin's (2005-2011) *Flight404 blog* - elegant and refined examples of cymatic effects built in Processing.

While this project focussed on realising a virtual drum skin - even though this theoretically based model could not reflect the complexity of vibrating diaphragms in the transitions between steady vibrational states as discussed in Section 7.4 Cymatics above - this subsequently evolved into the associated artwork *Moiré Modes*. The potential of this model to effectively visualise the dynamics, pace and physicality of percussion led to a collaboration beyond the scope of this Ph.D. with the Gravity Percussion Duo - young percussionists from the Royal Northern College of Music (RNCM) - and to adapting *Moiré Modes* into a real-time visualisation of Jan Bradley's *For Timps and Tape*, an accompanied solo for five timpani, performed as part of an RNCM Spotlight Concert, 15th March 2014.

7.7 Cymatic Music

Aspects of theorising within John Telfer's (2010) *Cymatic Music* project and his attempts to *"take advantage of the creative cross-fertilisation between musical harmony and physical patterning"* (Telfer, 2010:online) have also been persuasive. His assertion that the ubiquitous 12-tone Equal Temperament musical tuning system has harmonic inconsistencies - and consequently, that a cymatic equivalence to musical harmony will be difficult to find in music based on the Equal Temperament - directed this research towards choosing music for associated artworks that might reflect a more mathematically accurate harmony based on the perfect intervals of Just Intonation. This is particularly true for *Whitney Triptych* and the J. S Bach's *Fugue in F minor BWV 881* from the *Well Tempered Clavier Book II* (Goeth, 2014), published in 1742 - and subsequent efforts to retune it to a tuning system more contemporary to that Bach would have actually used through the Young Temperament c.1799 (Rubinstein, 2000).

Telfer's *Lamdoma Matrix*, an applied outcome of his harmonicism theory based on revisiting the Pythagorean Lambdoid, has proven itself "a practical creative resource for music" (Telfer, 2010:online). By integrating the Lamdoma within the *musical interface* module of *The Augmented Tonoscope*, this research has built upon yet extended Telfer's own explorations of this perfect interval based framework (he makes acoustic musical instruments) but through an alternative and decidedly electronic/digital approach.

More significantly, the arithmetic progression within the Lamdoma aligns with Whitney's *Differential Dynamics* where the resolution of the patterns generated from his algorithms occur at those ratios defined by this more unorthodox subharmonic series (as well as the experimental evidence that suggests a strong correlation between frequency, undertones and cymatic pattern introduced in Section 5.4.3 13" Piccolo Snare). Yet the unconventional nature of subharmonics makes them difficult to appreciate.

By means of illustration, and specifically in relation to fretless stringed instruments such as the violin, the conventional harmonic series usefully defines the position of the finger on the fretboard in relation to the length of the string. A finger held down at a halfway point along the string effectively halves its length - doubling the frequency of the note produced compared to the open string by an ascending octave, a ratio of 2:1. By the same analogy, a subharmonic ratio of 1:2 requires doubling the length of the string (obviously not possible on a violin) although this would have an equivalent effect of halving the frequency of the note produced compared to the original open string by a descending octave, a ratio of 1:2. There seems to be an important correlation in this simple inversion - yet perhaps the impracticality of its application in traditional acoustic instruments at least, has resulted in tentative acknowledgement of its significance within mainstream Music Theory.

Yet this simply isn't an issue for virtual instruments where the subharmonic series is just as straightforward to implement as the harmonic series. The *Lamdoma Monome* interface - freely available through this research and usable by anyone with a monome or monome emulator - provides easy access to this alternative musical framework and to further exploration of the arithmetic progression within contemporary music production. Despite a limited personal interest in micro-tonal composition, this aspect of the research has a deep significance for ongoing practice which will certainly be implementing and refining these principles and techniques within future music and audiovisual composition.

7.8 Whitney's Differential Dynamics

As a consequence of realising the limitations of Cymatics but also through discerning a deep pedagogic connection with the creative outputs and writing of John Whitney Sr., this research has pursued an alternative approach to realising a more intimate perceptual connection and harmonic *complementarity* between music and moving image - through an active exploration of his legacy. The impact on this research of Whitney's theories, approaches and techniques to audiovisual composition is significant - as described in Sections 1.8 John Whitney Sr., 2.5 The Legacy of John Whitney Sr. and 5.5.3 John Whitney Sr.'s Differential Dynamics.

So it has been satisfying to make a modest personal contribution to Whitney's legacy, find a context within a body of work inspired by him and make personal connections with the likes of abstract animator Larry Cuba (Cuba, 1998) (the programmer for Whitney's 1973 classic *Arabesque* and currently Executive Director of The iotaCenter (no date) - a public benefit, non-profit arts organisation promoting abstract film and animation based in Los Angeles, CA) and composer, writer and video artist Bill Alves (no date) - both active collaborators with John Whitney Sr. before his death in 1995 - as well as audiovisual practitioner contemporaries such as Mick Grierson (2014) and Paul Prudence who also explore Whitney's legacy through their work.

What marks this research as being distinctive within the oeuvre, particularly in relation to works by Grierson such as *Re-Entry* (2012) "… not intended to represent perfect harmonic beauty, instead it is a deliberate piece of audiovisual noise art intended to represent an entirely different aesthetic to that normally associated with Whitney's work" (Monomatic, 2012:online video), is a focus on matching pitch to pattern (Grierson favours matching timbre to pattern), of attempting to represent the melodic contours and harmonic structures within a piece of music through the converging and diverging forms of Whitney's *Differential Dynamics*.

7.9 Perception and the Senses

An emerging interest and focus within the research on attempting to realise audiovisual work of a subtly shifted perceptual quality is perhaps the hardest area to quantify and evaluate. There had always been a suspicion that this would involve a search for something nuanced and fleeting - trying to find those particular conditions under which an audiovisual percept - a combined sonic and visual object of perception - is not just seen and heard but is instead *seenheard*.

While there are certainly markers and hints towards creative possibilities within the cognitive neuroscience research - reinforced by the new audiovisual effects of 'syncresis' and 'added value' proposed by Chion as well as the sensory-centric philosophising of O'Callaghan - there are no explicit large scale behavioural rules and only a limited analysis of the dynamics of audiovisual material which tries to employ these effects. Grierson's (2005) argument that audiovisual composition which exploits structural relationships - a synchronisation of visual and sonic events - by its nature rises out of a desire to understand these combined audiovisual effects; that *"audiovisual composition, in fact, may rely on an understanding of this 'effectiveness' and the complexity of its operation"* (Grierson, 2007: 2); and his call to consider the study of audiovisual composition as a metadiscipline in its own right - is a response to this.

Still, this research hasn't realised a definitive answer to the question of what the nature and behaviour of a 'multi-sensory object of perception' might be or whether it is possible, with artistic intent, to manipulate it. What the practice has achieved, is finding an alternative, perhaps more intimate perceptual connection between the aural and visual that is not solely dependent on a synchronisation of visual and sonic events - by creating works which integrate:

- a direct, elemental and real-time correspondence between sound and image;
- a mirroring of music's innate movement and transition within the visual domain;
- and an underlying concord or harmony between music and moving image.

Through these mechanisms and a formalist, minimal, decluttered aesthetic, the practice has tried to create an amalgam of sound and image in which there is a more literal harmony between what is heard and seen and which engages the viewer in a subtlety shifted way. This ambition is perhaps best realised in *Whitney Triptych* - discussed in Section 6.9.4 Critical Reflection. Building on, refining and extending these techniques will certainly be central to future audiovisual composition beyond the scope of this Ph.D..

7.10 An Emerging Aesthetic and Form

The slow, step-by-step, back-to-basics approach required through the strategy of building an instrument, facilitated gazing deeper at the simple interplay and elemental relationships between sound and image - to what might be understood as essential building blocks of a visual music. This resulted in several reductionist techniques employed through the research and demonstrated through the associated artworks that could only work with minimalist instrumentation. Both Cymatics and Whitney's *Differential Dynamics* require essentially solo instrumentation - monophonic parts i.e. single notes (not chords) and a purity of tonal colour. Also an essentially anti-synaesthetic position within the research

shied clear of mapping pitch to colour and in fact to barely using colour at all. This preference for pure tones and solo instrumentation, a minimalist greyscale palette and a Euclidian geometry of line and pattern runs counter to much contemporary audiovisualisation which seems to depend upon dense, multipart and complex sonic and visual palettes - such as those tools for music visualisation collated by Ricardo Silva (2010).

Yet the research suggests that these limitations do not fetter artistic possibilities - and in fact validates the adage "less is more" (Phaidon, 2014). Artistic exploration pushing at the boundaries of restrictions is actually more creatively challenging and arguably more likely to reveal fresh insights. As Dr. Nick Collins noted in an email exchange following a presentation of this research at *Seeing Sound 2*, Bath Spa University, October 2011: *"Who knows where slight changes lead to big innovations?"* (Collins, 2011:email). Furthermore, there is a rich body of work to draw upon within this reductionist, minimalist tradition - for example the ouvre of minimalist and postminimalist music (Gann, Potter & ap Siôn, 2013). Yet this perspective is not a rejection of complexity within audiovisualisation per se - just a stance that it harder to glean meaningful insight through a study of complexity which naturally tends toward chaotic behaviour making it more difficult to discern pattern.

This suggests that outputs from this research may lack complexity and sophistication. Yet an understanding of basic algorithmic principles - that a few simple rules can result in generative systems with the most complex of outputs (Pearson, 2011) - argues that this is not the case. As has been demonstrated through associated artworks, the basic principles surmised through the research can always be 'scaled up', overlapped and overlaid to create more ambitious works of increasing complexity.

A main intent has been to reveal, investigate and apply underlying paradigms that could inform and guide the practice and the project overall. In this way the research might contribute something meaningful and lasting to an ongoing evolution of *Visual Music*. So this research argues that integrating the arithmetic progression and applying the principles of perfect intervals and Just Intonation in the composition and retuning of music - and subsequently in driving Whitney's *Differential Dynamics* - has gone a fair way to achieving visual equivalences to the auditory intricacies of rhythm, melody and harmony and to characterising a visual music that is as subtle, supple and dynamic as auditory music - as described within this research and demonstrated through its associated artworks.

A satisfying validation of this approach has been provided through the submission of associated artworks to the NOISE festival (NOISE, 2014) *'A national celebration of the UK's next generation of creative talent, handpicked by the best in the* business'. From over 5,000 festival submissions, *Stravinsky Rose* (v2.1) has been judged "Excellent" and *Whitney Triptych* (v1.2) "Outstanding" by NOISE curator Janey De Nordwall. The latter work will feature alongside 55 other selections as part of a *Best New Creatives: NOISE Festival 2014* outdoor exhibition, Southbank & Bankside, London, 9th September – 7th November 2014 and be showcased at a three-day exhibition of *Best New Artists of NOISE Festival 2014* at The Old Granada Studios, Manchester, 26th – 28th September 2014, as part of Buy Art Fair.

7.11 Impact of the Research on Personal Practice

This study had been conceived as a self-contained research project - a discreet area of investigation, likely realisable within the time-frame of the Ph.D. and aligned with but separate from a personal artistic practice. Yet this approach seemed at odds with many Art & Design postgraduate researcher contemporaries within the Institute - those who struggled with the nature of the relationship between their personal artistic practice and the requirements of a Ph.D. study - perhaps uncertain whether to consider themselves practising artists undertaking a Ph.D. or Ph.D. researchers who happened to be practising artists. This raised some not unhealthy self-doubt as to whether such a logical, critical thinking (perhaps left brain dominant) personal approach was appropriate for an Art & Design Practice as Research Ph.D. pathway.

Yet despite the compartmentalisation of this project within a wider practice and perhaps due in part to subsequent reservations in this approach, the Ph.D. study has in fact become far more influential on a personal artistic practice than originally envisaged. By being cognisant of an individual creative process with its own dynamic, pulse and trajectory and allowing these factors to guide the progress of a course of study iteratively and in intended rather than incidental ways, this three-year solo detour into a discreet area of investigation - atypical of a natural default of collaborative practice established over many years - has focussed, shaped and honed a personal approach to audiovisual composition that is now significantly more informed, practised and mature.

More than this, it has come close to realising the ambition for a personal audiovisual production process - a means and a method whereby audio and visual composition can occur simultaneously. By merging the usually separate strands of audio and visual (post) production into a single workflow, sounds and images can interact with, influence and shape each other from the outset and then throughout all stages of composition, arrangement and mixing. Admittedly the hybrid analogue/digital instrument envisioned through *The Augmented Tonoscope* has not been fully realised. Yet development within some of its modules has exceeded expectations and while others, despite an initial focus within the research, have remained relatively incipient, strategies for their refinement and next stage iteration

are clear. So the study has provided a unique opportunity to design, test and refine a methodology and approach to audiovisual composition that not just promises but now also demonstrates the ability to generate new visual music work of a rare and altogether different quality.

7.12 Future Trajectories

Although the longer term outcomes of this research are speculative it has opened a door to audiovisual composition based on Cymatic effects and particularly Whitney's *Differential Dynamics* which will continue to develop through collaborative arts practice beyond this investigation.

The nature of this practice as outlined in Section 6.4 Creative Output Timeline means that the process of producing work is ongoing and new collaborative works beyond the scope of this Ph.D. are currently in development. Overall the intention is to consolidate, refine and extend this body of work with a particular emphasis on live audiovisual performance:

- *Three Space*, a work with Ben Lycett performed at *Seeing Sound 3*, Bath Spa University, November 2013, began development of a visual performance system for real-time control and variation of John Whitney's and Larry Cuba's algorithms - and next stage refinements and enhancements to this software, promising unprecedented speed, fidelity and control well beyond anything realised to date, is underway. Once implemented this system will come close to providing a means and a method whereby audio and visual composition can occur simultaneously;
- Collaboration with the Gravity Percussion Duo is ongoing, including plans for a live audiovisual performance of Steve Reich's *Nagoya Marimbas* using a next stage iteration of the *Whitney Triptych* to visualise the counterpoint between the two interlocking marimba parts;
- Aaron Hunt of *Hπ Instruments* composes works in which Bach-style counterpoint and microtonal music are his specialties - and the idea of visualising one of Aaron's more contemporary classical works has already been mooted. Aaron has also been prototyping new software which makes the playback of MIDI files feel more 'human' and which could overcome the lack of musical expression and natural cadence and dynamic within MIDI files as described in Section 6.9.4 Critical Reflection - Whitney Triptych (v1.0);
- Despite a limited number of dome projection systems worldwide, there are occasional calls for submissions in this format - so a next iteration version of *Stravinsky Rose* (v2.0) is planned. Apart from implementing refinements in the credits and information section layout since realised in v2.1, the obvious perspective flaws will be corrected by shifting the Whitney figures 'centre stage' within the dome (using a similar production process to the current circular logo

animation slowly rotating at its centre as described in Section 6.8.3 Technical Realisation - Creating Assets). This will also allow the video of Fiona Cross' performance to be reduced in size and repeated at regular intervals around the bottom edge of the frame.

However a main focus will be to complete *The Augmented Tonoscope* proper:

- Fabricating more advanced tonoscopes, while certainly desirable, was beyond the scope of this Ph.D. study. So the next stage is to work with the Manchester based professional design and fabrication service 24 Design (2014) to fabricate a self-funded analogue tonoscope based on the rototom and to detail the design (as part of efforts to attract external funding) for a final version based on chain-tuned timpani. The intent is that these devices should be resolved, elegant objects d'art - both functional and aesthetically refined;
- Although development in the *sequencing and recording* module using the Ableton Live Studio 9.1 Digital Audio Workstation realised some useful techniques and tools - particularly the *Teensy Weensy Micro-tuner* - the use of Live as a recording and sequence mechanism for The Augmented Tonsocope was essentially pragmatic - a 'stand-in' for an unsuccessful attempt at building a custom-made sequencing and recording tool. Yet the conceptual strength of the nodal sequencer detailed in Section 5.7.1 Ki-No-Seq (Kinetic Nodal Sequencer) still stands and with more collaborative development and external input may still be realisable. This will allow the *Lamdoma Monome* to come into its own as a musical interface - it wasn't designed to work with Live and doesn't integrate with it that well - as well as merge other intended features - such as a Bézier curve control over pitch - which weren't possible using Live.

A modest attempt at commercialising custom-made hardware and Max 4 Live devices realised through the research may be attempted:

- The SWG, *Teensy Weensy Micro-tuner* and LED Ring Light + Controller may well be of interest to a wider community - so a first stage will be to rationalise, refine, provide full schematics, design templates and a bill of material (BOM) for these devices - but potentially develop MIY (Make It Yourself) kits and pre-built units;
- Despite the limitations of a prototype micro-tuning device detailed in Section 5.7.4 Max4Live Pitch Bend Device, Max for Live has potential. Contact has been made with the specialist Max 4 Live development team of Isontonik Studios (no date) and the specifications for both monophonic and polyphonic micro-tuning devices have been discussed in principle. The plan is to commission Isontonik to develop these M4L devices for a wider distribution.

The research has also highlighted areas for future investigation:

- Telfer (and Jenny) conclude that spheres do in fact vibrate harmonically - there is a harmonic correspondence between bubble diameter and the frequency

of the tone which induces a given bubble symmetry, all vibrational states are clearly proportionally related. This offers an alternative and more harmonically robust approach to realising visual equivalences to the auditory intricacies of rhythm, melody and harmony. A prototype virtual model of a soap bubble which integrates a mathematical derivation of spherical harmonics has already been realised and planning is underway to build a 'cymatic bubble chamber' to explore bubble symmetries empirically.

In the longer term, a focus for post-doctoral research may be found in the potential application of Whitney's *Differential Dynamics*, as developed through this research, to realise dynamic visual patterning which meaningfully represents the auditory intricacies of rhythm, melody and harmony. If this could be achieved then it could effect a unique approach to collaboration with deaf and hearing impaired musicians - opening a new area for a personal collaborative artistic practice exploring the sensorium (the sensory apparatus or faculties considered as a whole). This potentially reflects the growing genre of systems and on-human perceptual devices currently being developed to perform sensory substitution for sensory impairment - such as Low-fi Skin Vision (Bird, Marshall & Rogers, 2009) for the blind and sight impaired.

The strength of this approach is that offers a more delicate use of technology than those promoted through *Sensorium* - an exhibition at the MIT List Visual Arts Center summarised by Jones (2006) *"*when modernist segmentation of the senses is giving way to dramatic multisensory mixes or transpositions*"* (Jones, 2006:sleeve-notes) and certainly to the collection of abstracts, overviews, technological realisations and references of the diverse projects selected for the *Devices That Alter Perception 2010 Workshop* (Reynolds, 2010).

While investigations such as these show a growing interest in the design and critique of systems whose explicit purpose is altered human percepts and shaping perceptual phenomena - they seem to lack an engagement with subtlety, an accent on nuance or an interest in the fleeting which underpin [this researcher's] thinking to date. Perhaps ironically, an extract from James Auger's keynote for *Designing Devices that Alter Perception*, seems to warn of these dangers:

> A common approach in techno-centric domains is the focus predominantly on application and function for enhancement purposes, ignoring the contextual factors and implications. If we remove the connection to everyday life when researching a technology, the experiences or the effects facilitated by the device risk being purely a showcase; a kind of fairground ride where the aesthetic experience, however striking, is simply a temporary alteration of reality. This can create intrigue, thrill and fascination but the effect is rarely enduring, existing like a one-line gag (Reynolds, 2010: 1).

This new area of research could find an academic context in the agendas of institutions such as Sensorium - "an ambitious new research centre based in the Faculty of Fine Arts at York University that supports cross-disciplinary work in application and content creation, artistic and scientific inquiry, policy development and critical discourse in digital media arts" (York University, no date:online). Research outcomes may well offer wider benefits within music training, education and therapy amongst the deaf and hard of hearing since "the perception of music is often more accessible to the hearing impaired than the complexities of the speech signal" (Music Therapy Association of British Columbia, [online]).

So it would be fascinating to explore philosophical accounts of perception and its relationship to tools and devices and determine criteria which would help push this design concept forward "beyond an ever-growing, rich, yet straggled collection of ideas to a coherent forward thinking, and evolving body of knowledge" (Reynolds, 2010:41) - and perhaps to realising a more definitive answer to the question of what the nature and behaviour of a 'multi-sensory object of perception' might be and whether it is possible, with artistic intent, to manipulate it.

Appendices

Appendix 1 A Visual Music Manifesto
Appendix 2 Automating Portamento
Appendix 3 Comparative Tests of Drum Based Analogue Tonoscopes to Virtual Drum Skin
Appendix 4 Adapting John Whitney Sr.'s Differential Dynamics
Appendix 5 Analysis of the Lamdoma Monome
Appendix 6 Cymatic Art & Creative Coding Examples
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A Visual Music Manifesto

The Augmented Tonoscope by Lewis Sykes

http://www.augmentedtonoscope.net

I acted on Dr Felicity Colman's suggestion to develop a personal artistic manifesto that answered the question "Why am I doing this?"

So I looked to early examples of C20th art manifestos - *The Founding and Manifesto of Futurism* by F. T. Marinetti, 1909 and the *Dada Manifesto* by Tristan Tzara, 1918 - for inspiration.

I subsequently came across Lee Scrivner's (2006) *How to Write an Avant-Garde Manifesto (a Manifesto)*, *"An avant-garde manifesto that reviews avant-garde manifestos of the past hundred years, it was taped to the front door of the Institute of Contemporary Arts in London in April 2006. It was later published online by ICA residents, the London Consortium."* Scrivner's citation from Tristan Tzara seemed suitable advice.

So I started to develop my own modest manifesto for Understanding Visual Music 11 but presented it for the first time to an audience at Seeing Sound 2, Bath Spa University, UK on 29th and 30th October 2011. Somewhat to my surprise I received a round of applause after my fulmination!

In order to crystallise and communicate the 'Why' of my postgraduate research project, my imaginary comrades and I have been up quite late drafting an artistic manifesto, inspired by the sentiments of Tristan Tzara - one of the founders and central figures of the Dada movement.

"To launch a manifesto you have to want: A. B. C., and fulminate against 1,2, & 3."
Tristan Tzara, Dadaist Manifesto, 1918

I declare that the greater part of contemporary audiovisual culture is in a tired and sorry state. Caught in a swirling morass of audiovisual static fed incessantly by: the crass product placement and pouting lips/thrusting hips of MTV music videos; the endless conveyer belt of up-to-the-minute imaging methods and earworm soundtracks sponsored by TV and film advertisers misguidedly pursuing the novel; the anti-aesthetic iVideotics of Youtube; the bland visual wallpapering of countless clubs worldwide by bored, underpaid VJs (video jockeys) with too much time to fill and too little material/skill to do it; and overly earnest, audiovisual artworks that celebrate form over content through a techno-fetishism of 'cutting-edge' audiovisual techniques and technologies.

What we deserve is thoughtful and inventive exploration of the interplay between sound and image.

A re-capturing of the imagination, a re-inspiring of awe and wonder and a re-engagement in deep and significant ways.

We should strive to make Visual Music that transcends the background noise and offers unique and profound insights into the relationship between things and the nature of the world around us.

So I want to design, test and refine a methodology and approach that generates new Visual Music of a rare and altogether different quality.

I want the relationship between the audio and the visual to be direct and elementary - analogs of each other in aural and visual form - and to occur in real-time.

Through the instrumentation of the Augmented Tonoscope, I want to create a means and a process whereby audio and visual composition occurs simultaneously. By merging the usually separate strands of audio and visual (post) production into a single workflow I hope that sounds and images will interact with, influence and shape each other from the outset and then throughout all stages of composition, arrangement and mixing.

I want to find an amalgam of sound and image that engages the viewer in a subtlety shifted way - a synchronisation between the senses of sight and hearing that results in a 'co-sensing' of a 'co-expressiveness' - where the mind is not doing two separate things, it's doing the same thing in two ways. Akin to that by which Moritz (1976) critiques Oskar Fischinger's synthetic sound production experiments, *"Ah, but those visuals contain formulas and gestures that communicate with us subconsciously, directly, without being appreciated or evaluated."*

I expect this will be a hard thing to do… but then I'm not doing this because it is easy.

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Scrivner L. (2006), *How to Write an Avant-Garde Manifesto (a Manifesto)*, http://en.wikipedia.org/wiki/Art_manifesto (downloadable as a PDF from) http://www.londonconsortium.com/wp-content/uploads/2007/02/scrivneripmessay.pdf [accessed 16 August 2011]

Appendix 2 - Automating Portamento

Development within the SWG v3.0 focussed on extending the automation of portamento - controlling the way the SWG moved between two frequencies. This was realised initially via Andy Brown's *Easing* library (Brown, 2010), a port to Arduino of Robert Penner's tweening functions (Penner, 2002) - essentially a family of mathematical formulae determining position over time - commonly used to create more natural looking movement within computer-based animation.

Could these ubiquitous motion graphic tools also be applied to sound and provide a more precise and natural control over the transition between musical tones? How would shaping the movement between audio frequencies using these various functions affect the transitions between cymatic patterns?

While experiments confirmed that the various 'tweens' generated not just a series of distinctly different portamentos to the ear, but also a visible difference in the transitions between cymatic patterns, they also demonstrated that Penner's tweening functions, despite his efforts to *"*provide meaningful and predictable relationships between position and time*"* (Penner, 2002:194) are essentially presets - with minimal control over the hand-on shaping of the transition.

However, Bret Battey's research into how computers can effectively and convincingly render expressive melodic forms inspired by pitch continuum traditions, such as South Indian vocal performances showed more promising potential. His technique of Bézier curve modelling - of combining an identification of critical tonal points in the performance with an intuitive designation of the curve

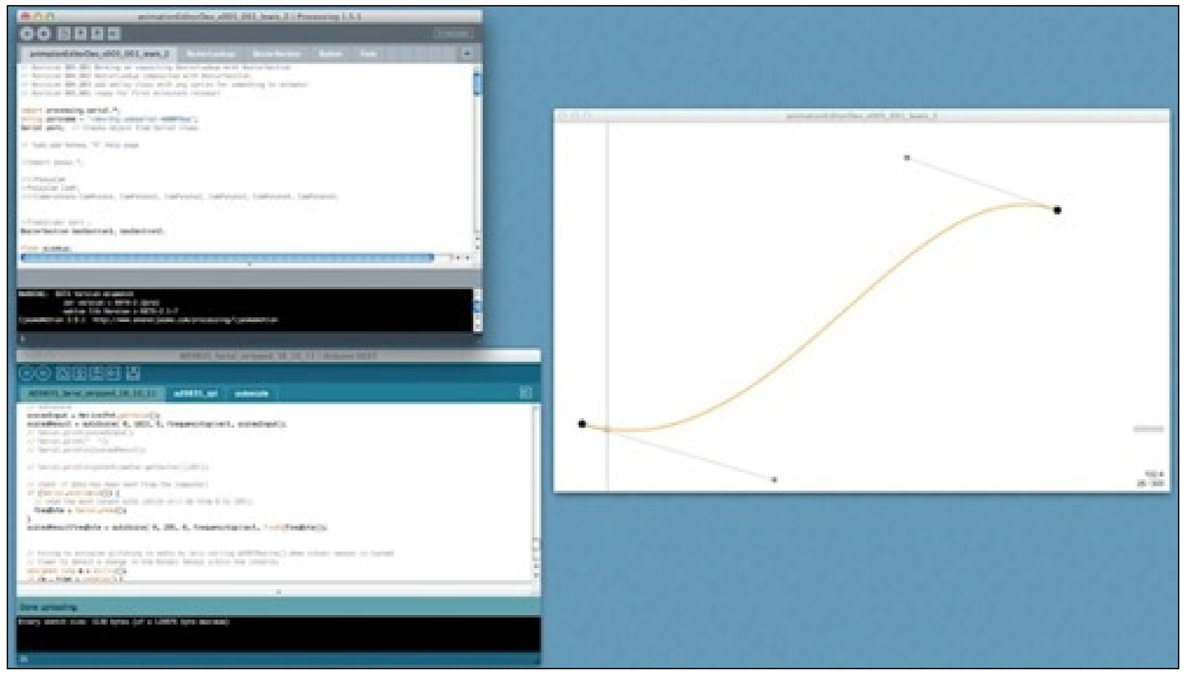

Figure 45 - Bézier curve controller - with the associated Processing and Arduino IDE windows

between those points - suggested a means to realise more controllable transitions between pitch. While Battey's software was designed to analyse music recordings it inspired development of a prototype real-time Bézier curve controller (Figure 45). A found Processing sketch was adapted to draw a Bézier curve and make a point follow its path as a timeline ran from left to right. By moving the end points and handles of the curve via a 22" touchscreen or mouse it was possible to subtly adjust the time and shape of the movement between frequencies and send this data from the MacBook Pro to the SWG in real-time via Serial over USB.

These experiments suggested not only the subtleties and nuances *The Augmented Tonoscope* might effect, but that this technique should be integrated into the nodal sequencer prototype for the *recording and sequencing* module detailed in Section 5.7.1 Ki-No-Seq (Kinetic Nodal Sequencer). It is also worth noting that the pursuit of this functionality is a fitting illustration of how an idea sparked through the literature could be tested through the practice - and how the 'starting from scratch' approach to building the instrument encouraged and enabled this process to happen.

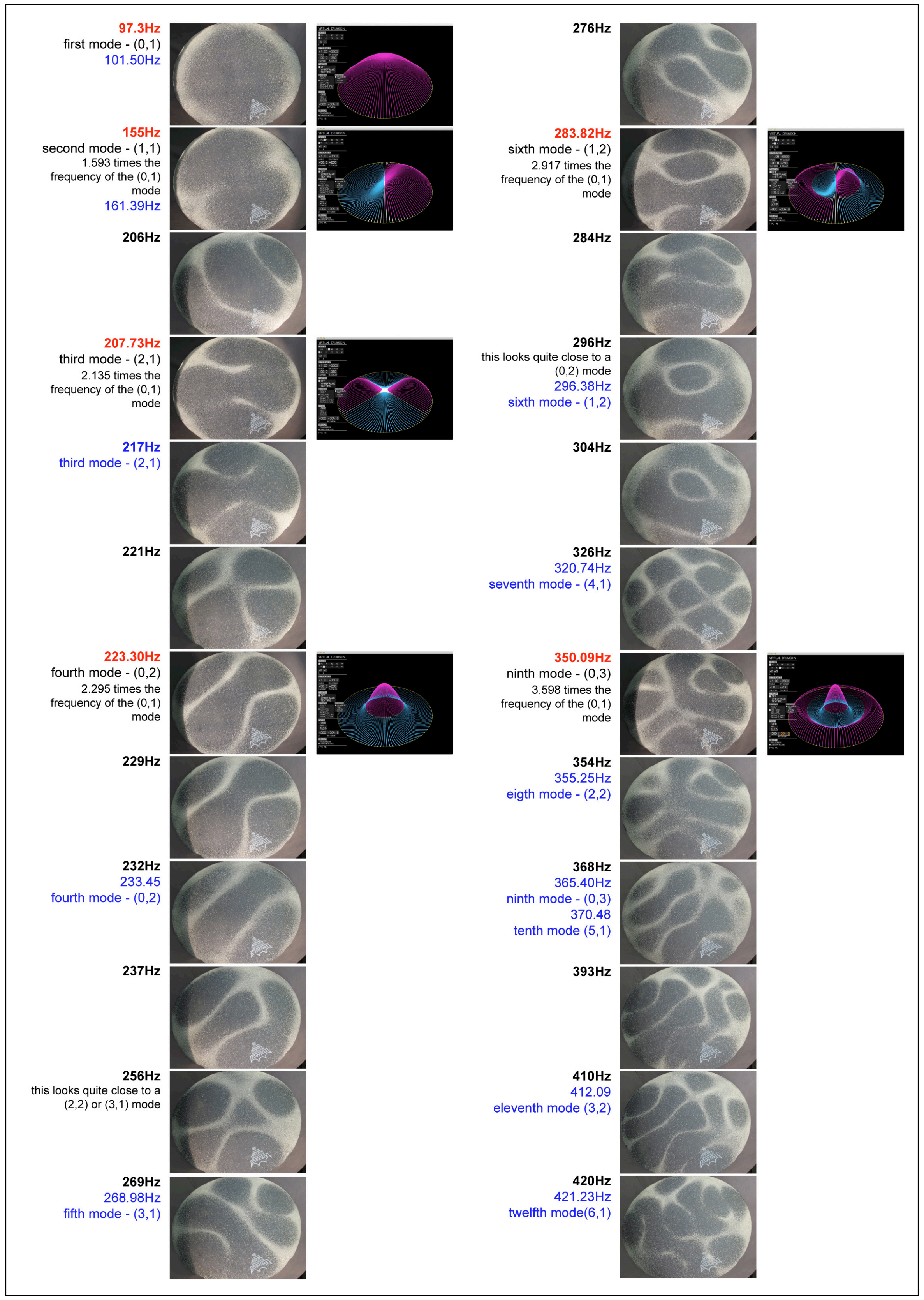

Figure 46 - Frequencies at which distinct stationary waves patterns appeared on the drum skin of the 13" piccolo snare tonoscope

Notes:

a. The comparisons to ideal modes - the additional computer model illustrations above - use a calculation of these ideal frequencies (in red) based on the 155Hz frequency of the second mode (1,1) settled upon experimentally. While these frequencies do generate patterns, a more accurate comparison could have been made using the 217Hz of the more distinct third mode (2,1). So this set of predicted modes

Appendix 3 - Comparative Tests of Drum Based Analogue Tonoscopes to Virtual Drum Skin

Having coded a mathematically ideal drum-skin model as part of *virtual systems* it made sense to test how well these analogue tonoscopes actually behaved - how many discreet standing wave patterns they generated and how closely these correlated to the ideal.

13" piccolo snare drum

The drum and model correlate reasonably for earlier modes (Figure 46), but as the frequency rises the correlation breaks down - although the ideal mode frequencies (in red) do still generate a discrete pattern on the snare. Still, the adapted second hand Pearl 13" piccolo snare is clearly a far from ideal diaphragm. This isn't surprising considering the 'tiredness' of its tuning rods and the resulting unevenness of the tension in the drum-skin (relatively small changes in tunings result in dramatically different patterns) as well as a host of other real-world factors such as:

- the performance of the speaker and amplifier;
- the non-optimised volume of air in the speaker enclosure of the 13" tom shell;
- the short distance of the speaker from the drum skin;
- the output quality of the Maximilian synth sound source;
- the irregularities in the material properties of the Remo drum-skin itself;
- humidity, temperature and atmospheric pressure etc.

So while the correlation is limited it is gratifying there's any at all.

Notes (cont.):

and frequencies are also included (in blue). These correlate relatively well to the experimental frequencies and also show a stronger correlation of cymatic pattern to ideal form - e.g. fifth mode (3,1) at 269Hz.

b. Although patterns do appear at frequencies between these vaues they are transitional patterns which frequently pulsate.

c. There may be some inaccuracies (having lost track of what frequency is what image).

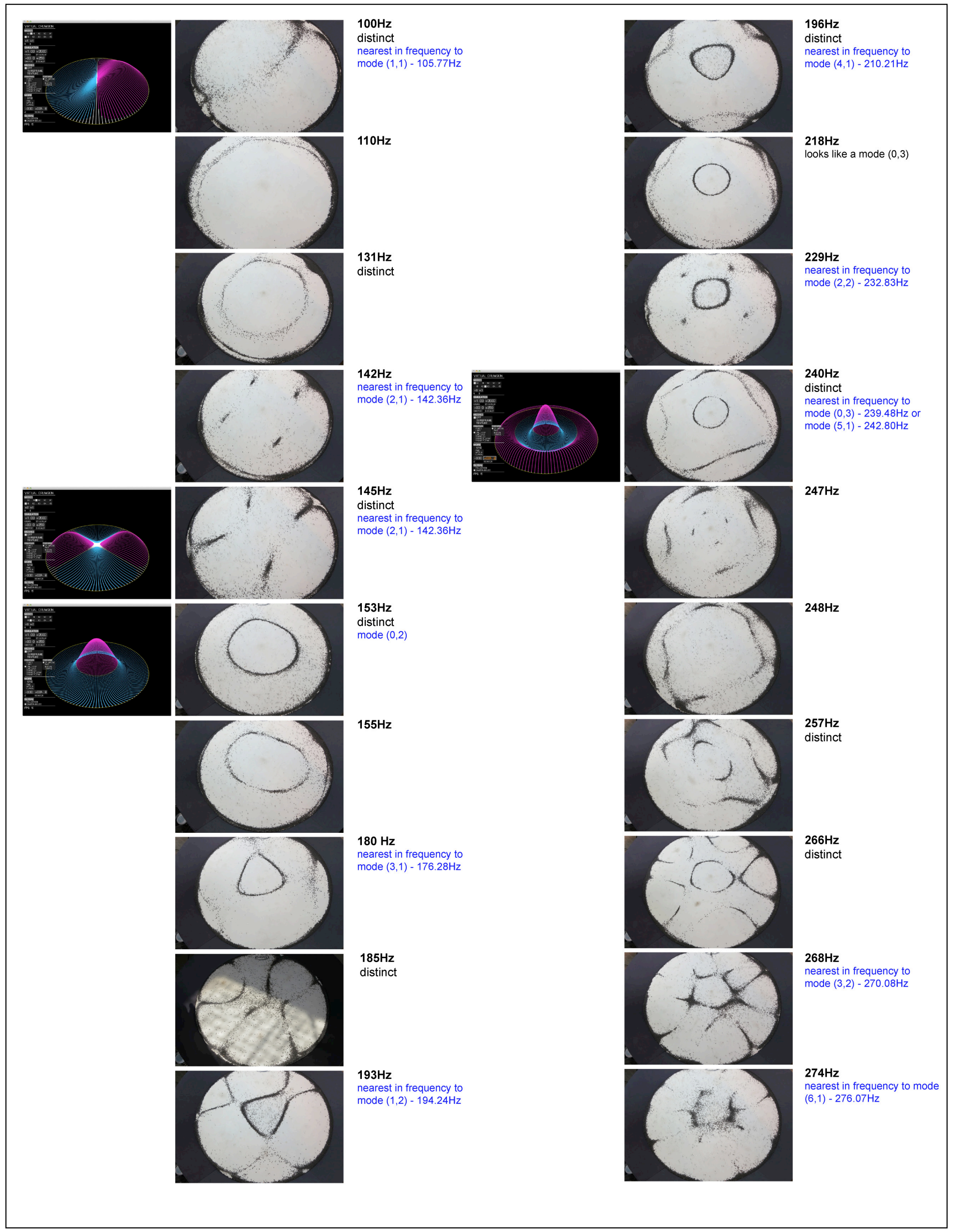

Figure 47 - Frequencies at which distinct stationary waves patterns appeared on the drum skin of the 16” floor tom tonoscope - 100Hz - 274Hz

Notes:

a. The comparisons to ideal modes - the additional computer model illustrations above and the theoretical frequencies (in blue) are based on the 153Hz frequency of the fourth mode (0,2) settled upon experimentally as the most pronounced of experimental modes that matched the theoretical modes;
b. Particularly stable patterns are marked as ‘distinct’.

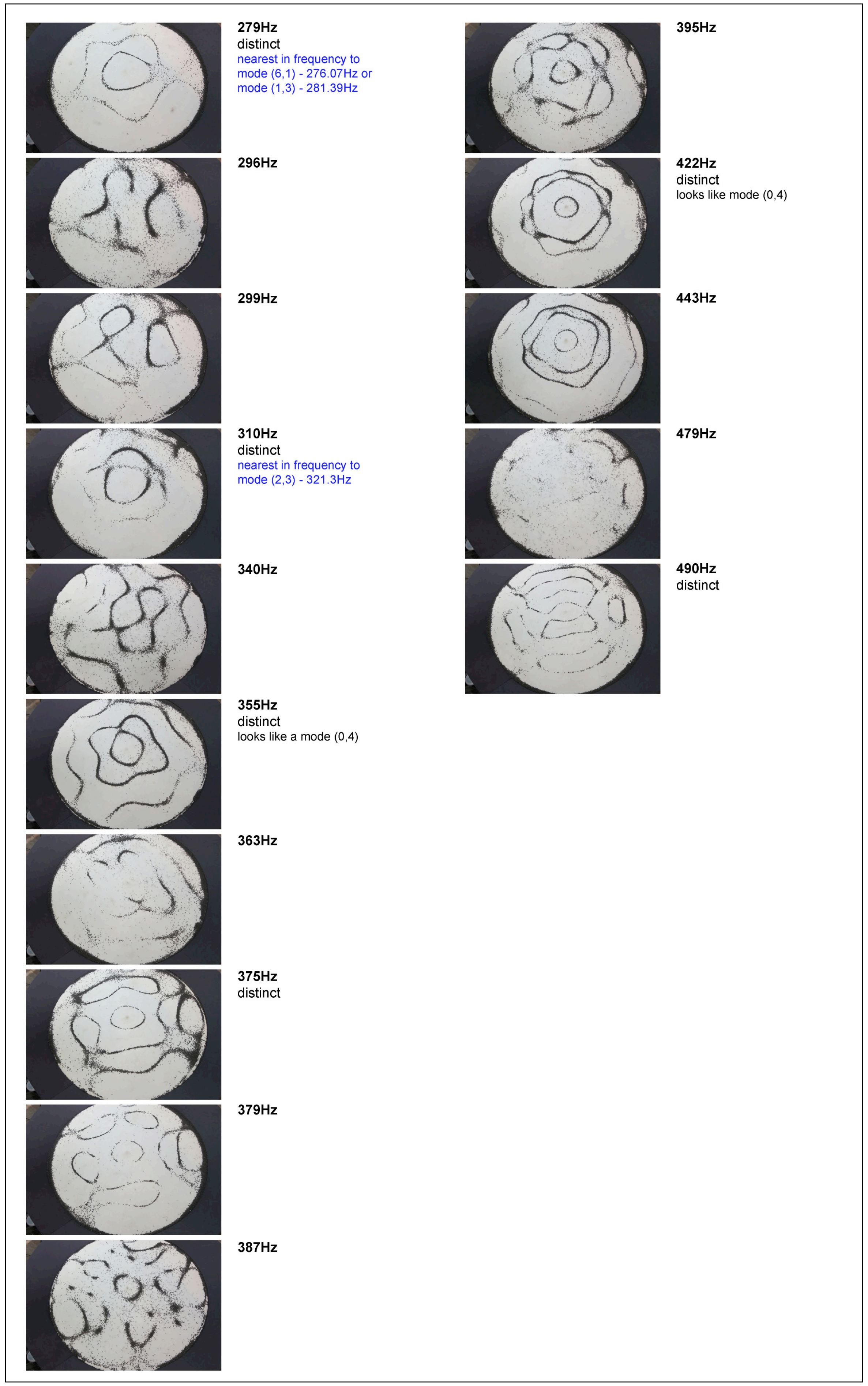

Figure 48 - Frequencies at which distinct stationary waves patterns appeared on the drum skin of the 16” floor tom tonoscope - 279Hz - 490Hz

16” floor tom

The adapted second hand 16” floor tom doesn’t behave particularly ideally and though some idealised modal patterns are present (Figure 3) - four out of the first nine modes (the first two are diametric and not particularly distinct though the last two are radial only and are decidedly distinct) there are many that are not (Figures 47 & 48). Still, as a device to visualise discrete cymatic patterns for frequencies it behaves well - 35 patterns were noted - 15 of which are distinct - the others seem to be transitional states. The patterns in Figure 47 occur consistently and repeatably, over a range of 100Hz ~G2 (98.00 Hz) to 490Hz ~B4 (493.88Hz) (and possibly higher - but the noise became unbearable) - a 28 note 12-ET range.

Despite being an earlier prototype, the 16” floor tom had a wider range, produced patterns more consistently and included more ideal stationary wave patterns than the 13” piccolo snare. Perhaps this was because it had a newer and better full range speaker and larger volume of air between speaker and drum skin. It is also possible that its larger size, generally lower tension and fewer tuning rods - five as opposed to six on the snare - results in less localised variations in drumhead tension - although there are certain patterns (around 266Hz) that exhibit a five-fold symmetry that can only be explained as a result of the number of its tuning rods.

Sometimes the patterns are unstable - very minor increases and decreases in frequency knock the drum-skin into a violent vibratory state either side. Sometimes they are extremely stable - settling almost instantaneously into a pattern and frequently after violent vibrations for a range of frequencies immediately before - and remaining present but with an increasing degradation of the form over a relatively wide frequency range after. Some of the patterns appear to be transitional states between these particularly stable forms.

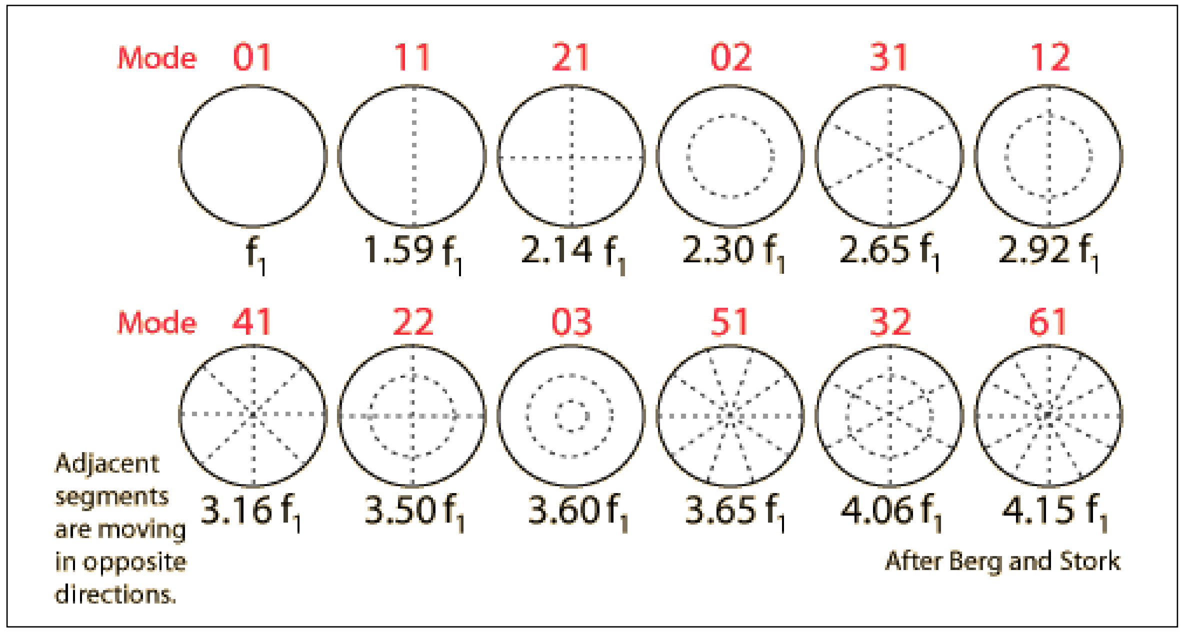

Figure 3 - Modes of vibration of a circular membrane, showing nodal lines (Figure from D. Livelybrooks, Univ. of Oregon) - reproduced for easier reference

Appendix 4 - Adapting John Whitney Sr.’s Differential Dynamics

This research has also looked for a correspondence between musical pitch and the convergence of the patterns in Whitney’s algorithms by testing several speculative criteria in applying Whitney’s techniques alongside more conventional animation tools.

First, the symmetrical resolutions of these patterns occur at those small whole number ratios defined by the arithmetic progression or subharmonic series - e.g. at a ratio of 1/2 the pattern displays bifold symmetry; at a ratio of 1/3 the pattern displays trifold symmetry and so on. So selecting a root frequency and applying the same ratio to the audio produces an associated pitch for a given pattern - e.g. for a root of A4 (440Hz), a ratio of 1/2 produces a frequency of 440/2 i.e. 220Hz or A3 (one octave down) while the pattern displays bifold symmetry; a ratio of 1/3 produces a frequency of 440/3 i.e. 146.67Hz (close to a 12-ET tuned D3 at 146.83Hz) while the pattern displays trifold symmetry and so on. Yet inverting this approach produces an associated pattern for a given pitch - compare the frequency of an incoming note to the root frequency to determine a ratio - then apply that ratio to the algorithm to generate a pattern.

Second, these algorithms can be conceived as progressive sequences along a timeline - albeit that the movement from start to end at a normal speed can take from minutes to hours depending on the nature of the function. Akin to the harmonics of a string, a ratio of 1/2 where the pattern displays bifold symmetry, is half way along this timeline. So it is possible to jump or ‘jog’ up and down to points along it in a manner very akin to video editing - essentially ‘scrubbing’ the algorithm. Using a ubiquitous animation technique, the ‘tweening’ function - a scalar interpolation from one position to another that determines position as a function of time - the algorithm can be ‘fast forwarded’ ahead or ‘fast reversed’ back to a specific point along its timeline that corresponds to a given ratio. ‘Easing’ at the start and end of this movement simulates an acceleration, a change in speed or velocity, making the transition from point to point more naturalistic. Yet these algorithms also exhibit a periodic nature - they repeat. By considering them cyclic rather than linear, their end point at a ratio of 1.0 is also their start point at a ratio of 0.0. So it is possible to loop the sequence within the code - when it reaches a ratio of 1.0 it automatically restarts at a ratio of 0.0.

Third, and not implemented until later in the research, to maintain a more consistent relationship between frequency and pattern, the ratios determined by notes that are higher in pitch than the root frequency are inverted within the visualisation - e.g. a perfect ascending fifth, 3/2 the ratio of a root frequency of A4 (440Hz) is 440*3/2 = 660Hz or a just intonation E5 (close to the 12-ET E5 of 659.26Hz). This ratio of 3/2 or 1.5 is then inverted within the code to a ratio of

2/3 or 1/1.5 = 0.667 - to generate a pattern in the algorithm that is the same as a perfect descending fifth, 2/3 the ratio of the root, 440*2/3 = 293.33Hz or D4 (close to the 12-ET D4 of 293.66Hz). This creates a ‘plane of symmetry’ for patterns around the root or fundamental frequency, otherwise known as the tonic. Notes with a similar harmonic relationship to the tonic - e.g. a perfect fifth up or down, now produced the same pattern.

These criteria and techniques go a fair way towards realising the essential requirement of agency within virtual systems - of producing a predictable output for a given input - even if the relationship between pitch and pattern is based on the unorthodox undertone series of the arithmetic progression rather than the more conventional overtone series of the harmonic progression.

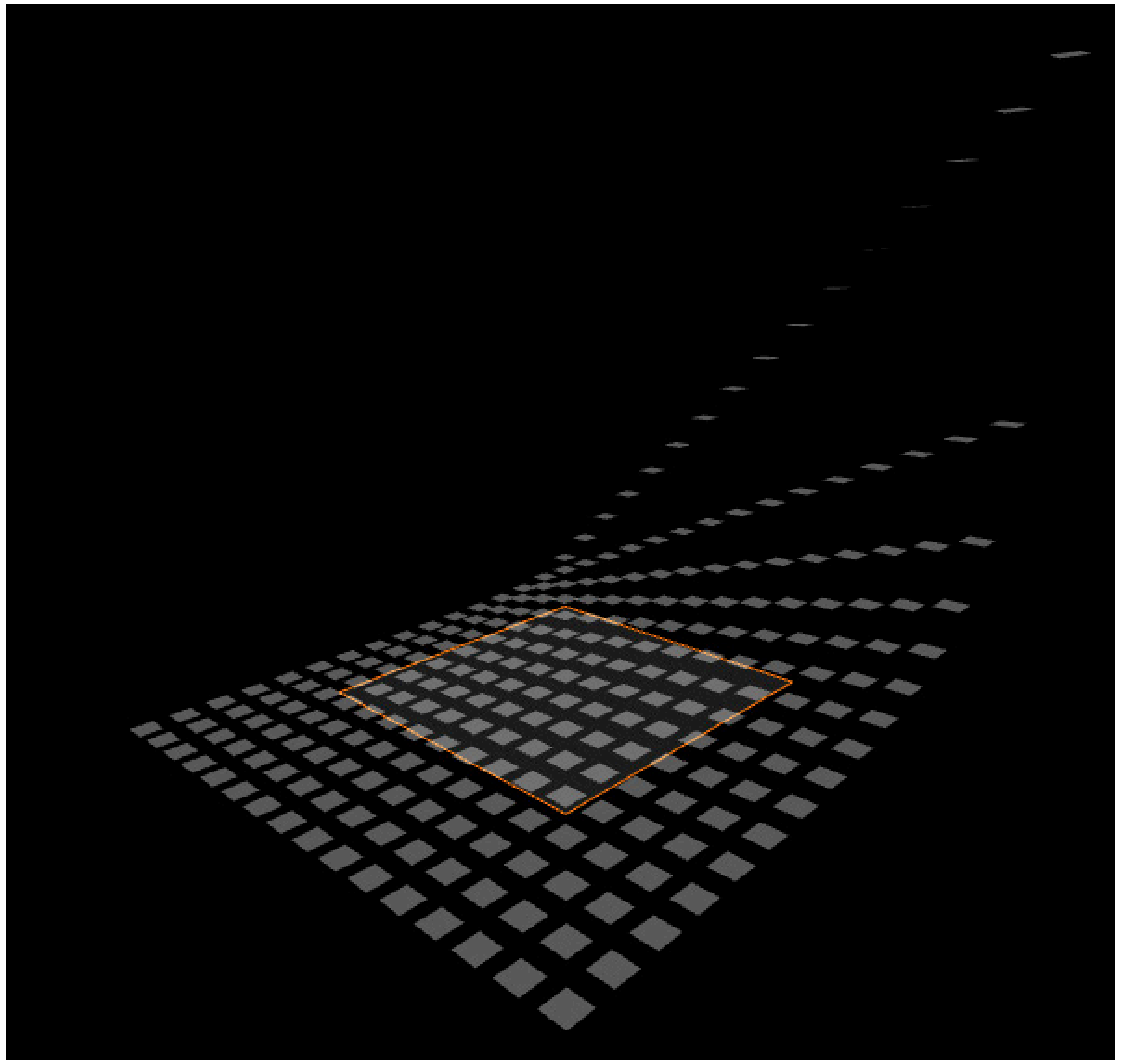

Figure 49 - Cells in the *Lamdoma Monome* translated in the Z-axis according to their ratio

Appendix 5 - Analysis of the Lamdoma Monome

Almost every modern piano has 52 white keys and 36 black keys for a total of 88 keys (seven octaves plus a minor third, from A0 to C8). A 16-limit version of the Lamdoma, a 16x16 grid, has 256 individual cells, albeit that there’s a fair degree of duplication of ratios and therefore frequencies within the matrix. However, this still results in an estimated 156 unique frequencies - almost twice that of a piano - over an eight octave range of A0 to A8 - when the unity, 1/1, root frequency is set close to a concert pitch of A4 (440.0Hz).

Yet while the 12-ET tuning of the linear, 1D piano keyboard means that all adjacent keys increase or decrease in pitch with an interval that has an identical frequency ratio - calculated by dividing the octave into 12 parts, all of which are equal on a logarithmic scale - the Lamdoma Monome creates what is essentially a 2D keyboard with a more complex, and immediately less intuitive relationship between adjacent buttons. Since its 156 discreet frequencies are defined by small whole number ratios, successive ‘notes’ across its range have irregular intervals between them - sometimes close to the 12-ET tunings but more often than not part way between. This means that the Lamdoma generates micro-tuned frequencies that no piano could play. Also these distinct tones, unlike the linear piano, are not sequentially distributed across the 2D grid, but arranged in complex patterns that while discernible, are not instantly obvious. Moreover, these frequencies aren’t evenly distributed across its eight octave range, there is a distinct thinning out of frequencies in the higher register - demonstrated by applying a translation in the Z-axis to each cell in the grid based on its ratio - revealing an underlying curved plane of frequency distributions within the grid.

This translation in the Z-axis (Figure 49) also helps to understand some of the general structure within the Lamdoma. The matrix is lower in pitch on the left hand side and higher in pitch on the right - so playing across a horizontal line of buttons from left to right always produces an increase in pitch. Accounting for the grid being turned 45 degrees clockwise, playing down a (now diagonal) column always produces a decrease in pitch, across from the left of a (now diagonal) row always produces an increase in pitch. However, the matrix is divided vertically by a central unity line - the 1/1, 2/2, 3/3… to 16/16 cells - where all ratios are 1.0 and so the frequency is always equal to the root (the central white line in Figure 10 - Telfer’s 16-limit Lamdoma Matrix). Playing from top to bottom down a vertical line of buttons other than the unity line produces an increase in pitch on its left hand side but a decrease in pitch on its right. However, the increments between frequencies from top to bottom always become successively smaller - and additionally, this effect becomes more marked the nearer the vertical lines is to the central unity line.

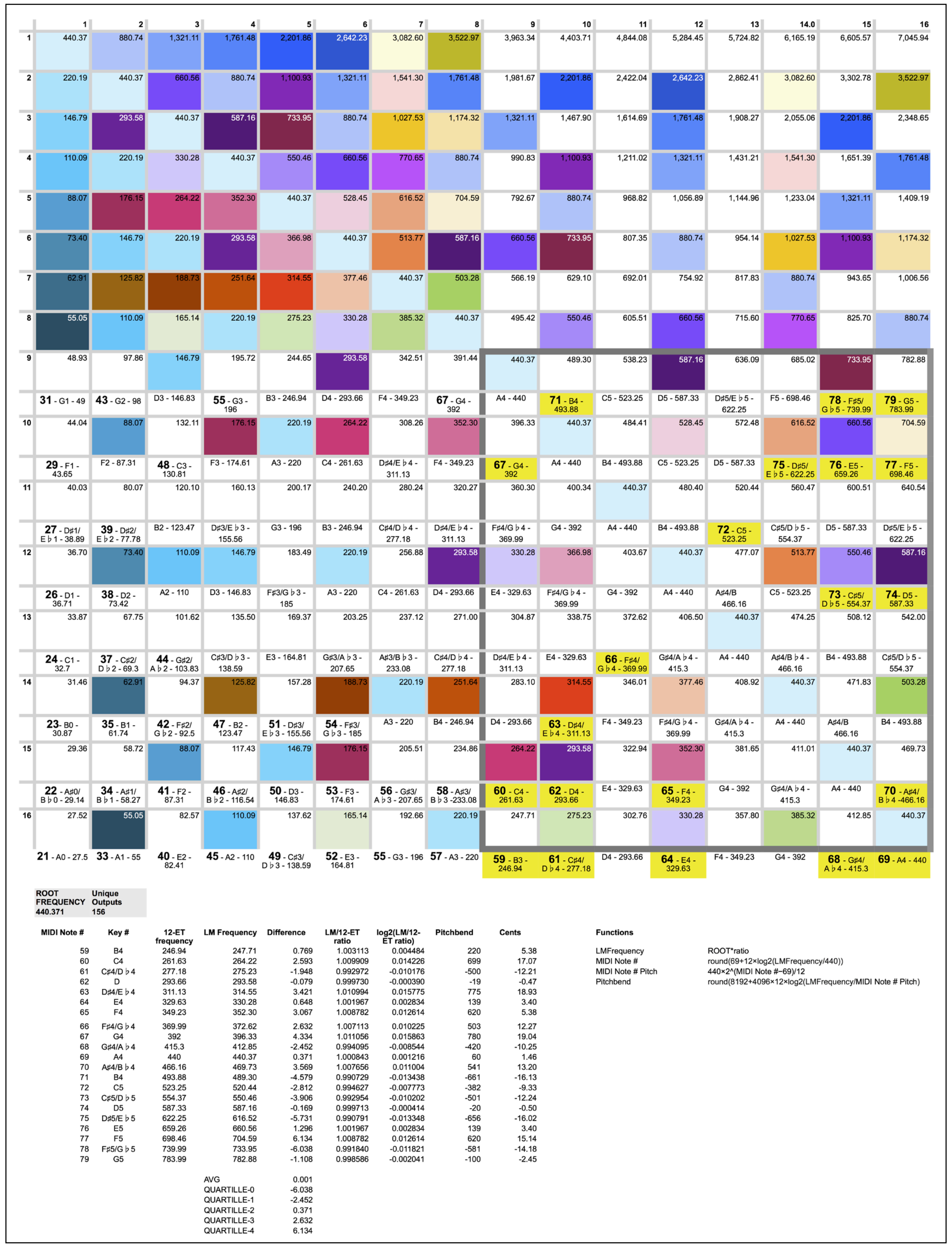

Figure 50 - Numbers spreadsheet showing analysis of the Lamdoma

The 8x8 monome64 ‘window’, despite being positionable to any area of the matrix, also helps to perceive the 16x16 Lamdoma as having four general 8x8 quadrants - top, left, right and bottom.

The top quadrant - defined by 1/1 to 8/1 on the (harmonic series) columns and 1/1 to 1/8 on the (subharmonic series) rows - is generally the most consonant, being defined by ratios of small whole numbers which are never greater than 8. Only the 7th column/row and to a lesser extent the 5th column/row introduce dissonance. It has an estimated 44 discreet notes spanning a 6 octave, 72 note 12-ET range from A1 (55Hz) to A7 (3,520Hz). So while it is not possible to play a full 12-tone scale it is feasible to discover regular patterns on the grid which produce sequences of notes with a marked consonance.

The left quadrant - defined by 1/1 to 8/1 on the columns and 1/9 to 1/16 on the rows - is of lower register, specifically from A0 to close to a 12-ET G4 (392Hz) - a 46 note 12-ET range. It is also more dissonant overall with small whole number ratios featuring denominators which include the prime 11 and 13 and somewhat less discordant 9 and 15. However, it is possible to progress through its range playing close to a full 12-tone scale - although the frequencies generated by the Lamdoma do not quite match their nearest 12-ET tuned equivalent.

The right quadrant - defined by 9/1 to 16/1 on the columns and 1/1 to 1/8 on the rows - is of higher register, specifically from close to a 12-ET B4 (493.88Hz) to A7 - a 34 note 12-ET range. It mirrors the left quadrant in structure and is likewise more dissonant overall. It is possible to progress through the lower part of its range playing a full 12-tone scale - there are more frequencies part-way between 12-ET tunings here - though as previously indicated, there is a distinct thinning out of frequencies towards the top of its range.

The bottom quadrant - defined by 9/1 to 16/1 on the columns and 1/9 to 1/16 on the rows - is generally of a middle register, specifically from close to a 12-ET B3 (246.94Hz) to close to a G5 (783.99Hz) - a 20 note 12-ET range. It is likewise more dissonant overall. Yet it is also the quadrant which comes closest to a full 12-tone scale - and interestingly, with a distinct symmetrical pattern defining the progression from the B3 to the G5.

This has been illustrated by creating the Lamdoma in spreadsheet software, specifically Apple’s Numbers (Figure 50). Using the inbuilt functions made it straightforward to calculate the frequencies within the Lamdoma and compare how changes to the root frequency was reflected throughout the matrix. It also made it possible to compare Lamdoma frequencies to 12-ET tunings - calculating the degree of deviation using Numbers in-built statistical functions by making minute adjustments to the base frequency to minimise this deviation and then calculating the required pitch bend values and cent adjustments to recreate these frequencies based on 12-ET tuning. This identified 440.371Hz as that base frequency (close to the concert pitch A4 (440Hz)) which produced the least average deviation from 12-ET tuning across a 12-note scale, with a maximum +19.04 cent adjustment required for G4 - less than a 1/5th of a conventional semitone.

Unlike Telfer's Lamdoma Matrix, this rather garish colour scheme serves only to identify cells of duplicate ratio - though this does highlight how these radiate out as distinct lines from the unity 1/1 cell. The bottom half of this Lamdoma has additional rows which show the nearest equivalent 12-ET note and its frequency. Those with a large prefix MIDI note number, indicates a particular frequency within the Lamdoma that has been selected as closest to the 12-ET value (there are often several that are not far off). The bottom right quadrant (the bottom quadrant described above) additionally highlights these in yellow - revealing the distinct symmetrical pattern that defines the progression from the B3 to the G5. The table below this compares the selected Lamdoma frequencies in this range to the equivalent 12-ET values - and then uses the various functions listed to the right and found through the research to calculate the relevant pitch bend and cent adjustments to recreate these Lamdoma frequencies via 12-ET tuned General MIDI.

Appendix 6 - Cymatic Art & Creative Coding Examples

There's inspiration and insights to be gleaned from the realisation, process and methodology of wide range of contemporary artistic output exploring Cymatics:

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As well as software and open source creative coding modelling its effects and manifestations:

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Appendix 7 - Glossary of Terms

Visual Music

A definition by Keefer and Ox (2008) of the Center for Visual Music:

- A visualization of music which is the translation of a specific musical composition (or sound) into a visual language, with the original syntax being emulated in the new visual rendition. This can be done with or without a computer. This can also be defined as intermedia.
- A time based narrative visual structure that is similar to the structure of a kind or style of music. It is a new composition created visually but as if it were an aural piece. This can have sound, or exist silent. Theorist/inventor Adrian Klein wrote in 1930: "…somehow or other, we have got to treat light, form and movement, as sound has already been treated. A satisfactory unity will never be found between these expressive media until they are reduced to the same terms." [Klein, A. B. (1930) Colour-Music: The Art of Light. London: The Technical Press Ltd.,. Second edition, p. 37.]
- A direct translation of image to sound or music, as images photographed, drawn or scratched onto a film's soundtrack are directly converted to sound when the film is projected. Often these images are simultaneously shown visually. Literally, what you see is also what you hear. (An early example is filmmaker Oskar Fischinger's Ornament Sound experiments c. 1932). There are many examples in Visual Music film of this process, e.g. McLaren, Spinello, Damonte and other contemporary filmmakers, including sections of Pengilly's work in this show. This method has been called a "pure" type of Visual Music.
- A visual composition that is not done in a linear, time-based manner, but rather something more static like a 7' x 8' canvas. However, as in Klee, the movement of the painted elements can and have achieved a kind of Visual Music, serving as an artist's visual interpretation of specific music. (Keefer & Ox, 2008:online)

An alternative, relatively concise, production focussed (albeit less academic definition) can be found in a summation of the "Visual music" entry on Wikipedia:

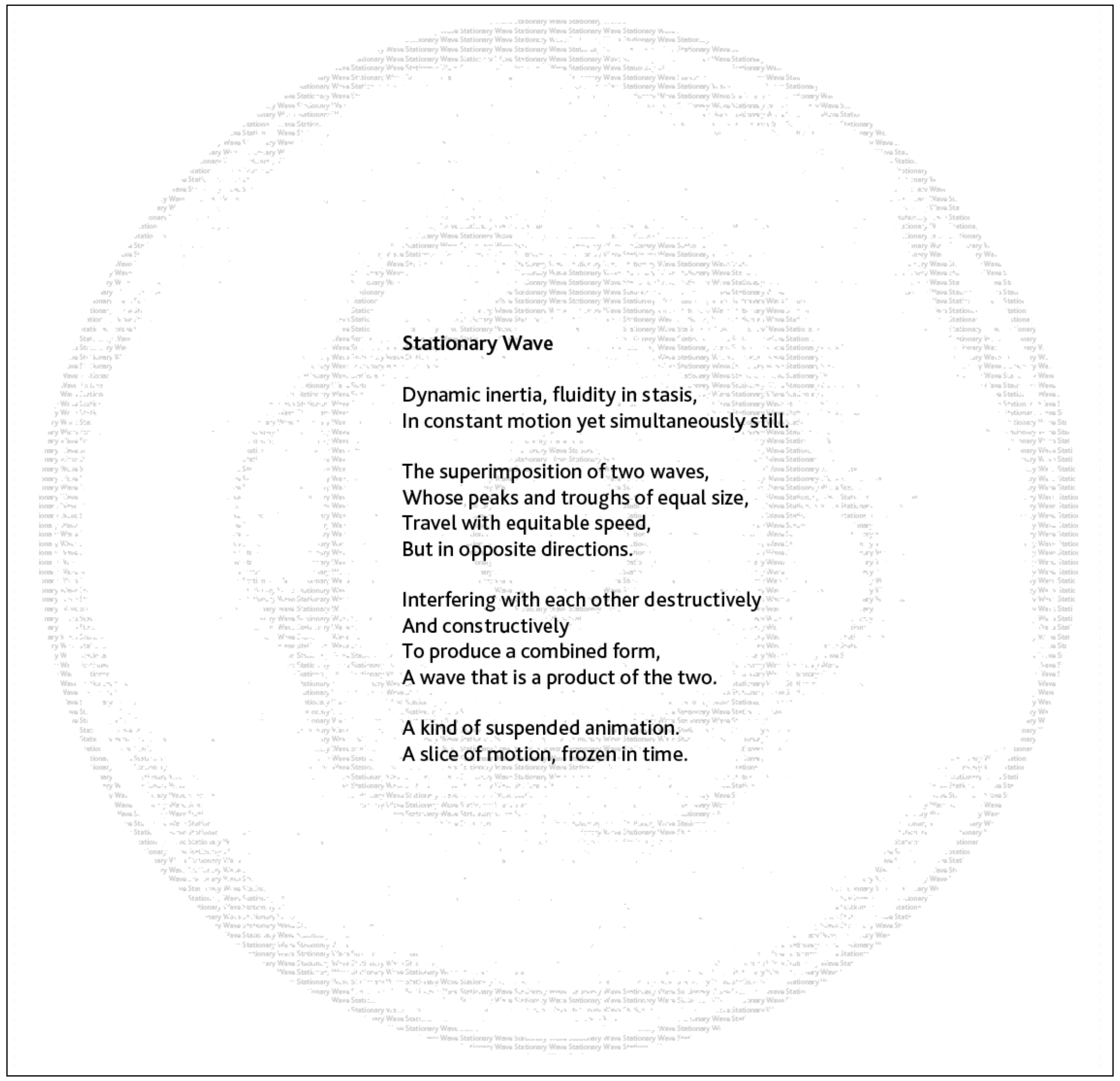
- methods or devices which translate sounds or music into a related visual presentation - possibly including the translation of music to painting;
- the use of musical structures in visual imagery;
- systems which convert music or sound directly into visual forms (and vice versa) by means of a mechanical instrument, an artist's interpretation, or a computer.

Portamento & Glissando

Surprisingly, there are a limited number of established terms and techniques within Western Music that describe the shift from pitch to pitch - and these seem to lack nuance and detail in the specific implementation of the effect:

- *"*Portamento [It.]. A continuous movement from one pitch to another through all of the intervening pitches, without, however, sounding these directly. It is principally an effect in singing and string playing, though for the latter and for other instruments capable of such an effect, the term glissando is often used*"* (Randel, 1998:673).
- "Glissando [It., abbr. bliss.; fr. Fr. glosser, to slide]. A continuous or sliding movement from one pitch to another. On the piano, the nail of thumb or of the 3rd finger or the side of the index finger is drawn, usually rapidly, over the white keys or the black keys, thus producing a rapid scale… On stringed instruments such as the violin, wind instruments (particularly, though not exclusively, the slide trombone), and on the pedal kettle drum, the sliding movement may produce a continuous variation in pitch rather than a rapid succession of discrete pitches… Some writers have preferred to restrict the meaning of glissando to the motion in which discrete pictures are heard, reserving portamento for continuous variation in pitch, but musical practice is not consistent in this respect ..." (Randel, 1998:353).

Appendix 8 - Stationary Wave



Written by the author as part of a *The Writer as Designer/Designer as Writer* course - two seminars and a 5-day Arvon Foundation workshop on offer to postgraduate and early career researchers from May 2014.

Background image *The vowel A in sand* produced by Cymatics researcher Hans Jenny using a sound visualisation device of his own design - the tonoscope.

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Although a somewhat unconventional format it seems appropriate to organise this bibliography by type:

- books, theses, articles, papers, newspapers, webpages, personal communications;
- artworks, artists/researchers, creative developers, creative agencies, academic institutions/projects;
- software, hardware, libraries, creative code, plug-ins, MIDI, protocols

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Figures:

Figure 2 - Richards G. (2008) *Illustration of harmonic overtones on the wave set up along a string when it is held steady in certain places, as when a guitar string is plucked while lightly held exactly half way along its length*. Released into the public domain by its author. [Online] [Accessed on 13th September 2014]http://commons.wikimedia.org/wiki/File:Harmonic_partials_on_strings.svg

Created by a specially written program in the Lua programming language. To recreate the image just run the program, and it will write the SVG into a file. There are various parameters that can be adjusted at the start of the code. The sine-wave approximation using Bezier curves is derived from Bezier curve sinewave approximation (PDF) by Jim Fitzsimmons.

Figure 3 - "Modes of vibration of a circular membrane, showing nodal lines." (Figure from D. Livelybrooks, Univ. of Oregon). *In* Simpson, D. G. *Introductory Physics II: Waves, Acoustics, Electromagnetism, Optics, and Modern Physics,* (updated May 4, 2014) [Online] [Accessed on 10th September 2014] http://www.pgccphy.net/1020/phy1020.pdf