The *HarmonyGrid*: Music, space and performance in Grid Music Systems

by

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Abstract

This research explores music in space, as experienced through performing and music-making with interactive systems. It explores how musical parameters may be presented spatially and displayed visually with a view to their exploration by a musician during performance. Spatial arrangements of musical components, especially pitches and harmonies, have been widely studied in the literature, but the current capabilities of interactive systems allow the improvisational exploration of these musical spaces as part of a performance practice. This research focuses on quantised spatial organisation of musical parameters that can be categorised as grid music systems (GMSs), and interactive music systems based on them. The research explores and surveys existing and historical uses of GMSs, and develops and demonstrates the use of a novel grid music system designed for whole body interaction.

Grid music systems provide plotting of spatialised input to construct patterned music on a two-dimensional grid layout. GMSs are navigated to construct a sequence of parametric steps, for example a series of pitches, rhythmic values, a chord sequence, or terraced dynamic steps. While they are conceptually simple when only controlling one musical dimension, grid systems may be layered to enable complex and satisfying musical results. These systems have proved a viable, effective, accessible and engaging means of music-making for the general user as well as the musician. GMSs have been widely used in electronic and digital music technologies, where they have generally been applied to small portable devices and software systems such as step sequencers and drum machines.

This research shows that by scaling up a grid music system, music-making and musical improvisation are enhanced, gaining several advantages:

(1) Full body location becomes the spatial input to the grid. The system becomes a partially immersive one in four related ways: spatially, graphically, sonically and musically.

(2) Detection of body location by tracking enables hands-free operation,

thereby allowing the playing of a musical instrument in addition to "playing" the grid system.

(3) Visual information regarding musical parameters may be enhanced so that the performer may fully engage with existing spatial knowledge of musical materials. The result is that existing spatial knowledge is overlaid on, and combined with, music-space.

Music-space is a new concept produced by the research, and is similar to notions of other musical spaces including soundscape, acoustic space, Smalley's "circumspace" and "immersive space" (2007, 48-52), and Lotis's "ambiophony" (2003), but is rather more textural and "alive"—and therefore very conducive to interaction. Music-space is that space occupied by music, set within normal space, which may be perceived by a person located within, or moving around in that space. Music-space has a perceivable "texture" made of tensions and relaxations, and contains spatial patterns of these formed by musical elements such as notes, harmonies, and sounds, changing over time. The music may be performed by live musicians, created electronically, or be prerecorded.

Large-scale GMSs have the capability not only to interactively display musical information as music representative space, but to allow music-space to co-exist with it. Moving around the grid, the performer may interact in real time with musical materials in music-space, as they form over squares or move in paths. Additionally he/she may sense the textural matrix of the music-space while being immersed in surround sound covering the grid.

The *HarmonyGrid* is a new computer-based interactive performance system developed during this research that provides a generative music-making system intended to accompany, or play along with, an improvising musician. This large-scale GMS employs full-body motion tracking over a projected grid. Playing with the system creates an enhanced performance employing live interactive music, along with graphical and spatial activity. Although one other experimental system provides certain aspects of immersive music-making, currently only the *HarmonyGrid* provides an environment to explore and experience music-space in a GMS.

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Statement of Originality

The work contained in this thesis has not been previously submitted to meet requirements for an award at this or any other higher education institution. To the best of my knowledge and belief, the thesis contains no material previously published or written by another person except where due reference is made. Material from Chapter 3 has appeared in a paper entitled "Improvising with Grid Music Systems" co-authored by Andrew Brown, for the Conference Proceedings for ACMC 2009.

Signature

Date

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Preface

My musical background is as a classical music performer, having trained and "soaked" in the traditions of Western classical music, its history, great works, notation and performance styles. Although trained in reproducing particular historical performance styles, my expanding appetite since the late 1980s for newer music and music of other cultures, as well as my growing interest through the 1990s in composition and music creation, has led me to explore new technologies and paradigms in order to develop a new means of personal and artistic expression. This exegesis and the accompanying creative work is the present culmination of my accumulating skills, expanding interests, and searching for new performance paradigms.

As a musician and composer I have learnt to rely, to a great extent, on my own perceptions in real time, and also in referring to recordings, and musical discussions with others. As an experimenter, designer, and researcher, I've had a history of designing, constructing and creating interactive artworks, and testing them through engagement and performance with them. Additionally I've grown up accepting feedback from audiences, feeling and gauging an audience's response, and discussing performances in detail with others. I have collaborated on many projects, including music performance, composition, and hybrid-arts works; and have had to learn the difficult job of speaking to others outside one's area of expertise, about music and composition. I've had to discuss approaches, working methods and desired outcomes. Along the way I have also discussed fantasies and done the envisioning that artists must do. As a member of the broader arts community, I have been able to continually compare and discuss perceptions of current artistic endeavour, especially that which is performed and presented in our city.

The new system developed during this research allowed me as a performing artist to broaden my domain from an instrumental performer to a media artist engaged in multimedia performance work. This provided a challenge for my creativity, to utilise space as a musical performance medium, by working within a colourful immersive environment that is both theatrical and performative. I wish to highlight the musically expressive nature of the new system for me as an artist: the ability to traverse a landscape of musical components provides stimulation and support, not to mention musical accompaniment, to improvise with. The system, as a flexible musical accompaniment, provides a wealth of opportunities to explore diverse musical terrains and to develop my musical and improvisation skills.

In presenting this preface I seek to outline my position within this research and to openly present my role, preconceptions and previous influences before the reader, so that they may evaluate my work and writings through the appropriate lens.

Chapter 1. Introduction

This chapter briefly defines and introduces grid music systems (to be termed GMS from here on), followed by a brief discussion of their usage in human history. Following this is a discussion of the conceptual ideas that initially sparked my enthusiasm for this research endeavour and that later I found informative. By assembling these threads I located my research direction, and began designing GMSs. A brief look at some uses and functions of GMSs, within the broader context of music and performance, follows. Then there is a short section outlining some of my relevant background, and personal motivations and for pursuing this research. A brief overview of my new system, the *HarmonyGrid,* is presented, followed by a listing of the research aims and questions. The chapter concludes by detailing the structure of the remaining exegesis.

1.1 What is a Grid Music System?

I am defining a GMS to be a musical system that provides a visual grid or matrix layout on a screen or physical interface as a method for the temporal structure of musical content. Moving around on the grid, like a gameboard, or pressing buttons of a grid-like matrix, provides the means to operate on, or “play” the grid. A system may be a hardware console, software application, or a combination of the two. A typical grid system uses a chequerboard-style layout with an active marker or cursor that shows current location within it. For example, a modern GMS might be a portable device covered with a matrix of buttons that are backlit when activated, with a small LCD screen, and some other controls. Typically, computer-based grid systems allow the user to perform or program a sequence of steps around the grid that produce cyclic musical patterns. Sound output from these systems is usually provided by software synthesizers, heard through a sound system. GMSs will be explored in detail later in Chapter 3.

Because grid layouts are so ubiquitous, we need also to describe some grid-related musical interfaces that are outside our current definition, because there are several other usages of terms similar to “grid music” in circulation. There is a “music grid” on Facebook, where one can create a grid of pictures of favourite album covers, listen to samples, and discuss them with others on Facebook.[1] There are various other “grids” which are collections or databases of music files, such as the In-Grid MP3 download site. In addition, a chord chart may be referred to as a harmony grid. At the time of writing, there is also a band called *The Grid*. Because of this variety of meanings, it was decided to not to name the *HarmonyGrid* “MusicGrid”, which would have been a more suitable name, covering several parameters of music as it does. The former name stuck, along with my predilection for harmonies, and the fact that most of the music emanating from the system used harmonies.

In the 1980s there was another *Harmony Grid*: Levitt's program for Macintosh (Holland 1992). Levitt's program displayed a large grid, and cells could be activated by passing the mouse over them to sound pitches and harmonies; this is the first software GMS known to the literature (see Section 6.3.1). The next significant software GMS was Simon Holland's (1992) program called *Harmony Space*, which will be discussed at length in Chapter 6.

1.1.1 Grids in human history

Higgins (2009, Introduction on front flap) identifies the grid as “the most prominent visual structure in the Western culture”. She lists ten grids “that changed the world: the brick, the tablet, the gridiron city plan, the map, musical notation, the ledger, the screen, moveable type, the manufactured box, and the net.” The appearance of each grid is noted as a watershed event: “brick, tablet and city gridiron made possible sturdy housing, the standardisation of language, and urban development.” In short, the grid has been a powerful organising principle in human civilisation, its structures, and artefacts.

Higgins claims that there is little evidence for the following sequential interpretation

1 The site is available from one's own Facebook profile using “search”, so a reference web address is not meaningful.

—bricks lead to square or rectangular houses, and then to square street plans—isn't true. Rather, she suggests, “The gridiron is line-based (like mortar) as opposed to module-based (like brick), even as both make up a grid field. The gridiron begins with the plan, which is then filled in; it is the tracery, the spaces *between* the buildings. This tracery, in turn, organizes proprioception, literally tracing the human sense of where we are in space. It systematizes the relationship between the individual body and acculturated spaces of our towns and cities, not in terms of the organic forms dictated by nature, but in terms of organized social systems” (2009, 50). So the grid becomes an organising force for our use of and sense of space.

More relevantly, grids in the forms of “Maps, musical notation, financial ledgers, and moveable type promoted the organization of space, music, and time, international trade, and mass literacy” (Higgins 2009). Higgins also suggests that the “most ancient grid”, the net, provides the model for a series of networked structures eventually leading to the emergence of the universal net, the World Wide Web. Thus, grids and networks organise the recording and communication of meanings throughout society.

It is worth clarifying the difference between a grid and a net. Either may refer to an arrangement of cells or filled-in shapes, or may refer to a cross-hatching of lines formed by some means, with empty spaces between them. Generally speaking a grid is square or rectangular arrangement, whereas a net may be an arrangement of other shapes (geometrically termed edge-connected polygons), and may be flexible as in a fishing net. Nets can lead to more complex topologies, and so the simplicity of the grid is preferred in this research.

1.2 Conceptual threads

Each of the sub-sections below briefly outlines areas of human cultural or artistic activity that sparked my interest, and led to the assembly of these ideas, towards a GMS. In considering these areas, only functions or aspects relevant to the current research are reported on.

1.2.1 Games

Of the conceptual and, to some extent, historical threads that have led to the development of GMSs in recent years, perhaps the most obvious of these are games: especially board games, parlour games and, more recently, arcade, video and computer games. In these games an array of cells or a grid is often used as a gameboard, on which players move counters or game pieces. Design of the gameboard, location of other pieces, and various rules combine to allow for the paths played. Rules are applied, concerning such factors as allowable movements, proximity to other players' pieces, and specific squares or locations that, in total, create the gameplay. Common examples include Chess, Snakes and Ladders, Monopoly, Chinese Chequers, etc. Additional equipment may be in use, such as special cards and game money. Naturally, the movement of a counter or game piece from one square to another, is an analogy for moving in the real world, but has been broken down into discrete steps. In a way the gameboard becomes a small virtual world for its inhabitants; the game has actors, its own rules, and outcomes.

With the development of arcade games, moving into video games and then computer games, there has been an explosion of possible gameworlds, and ways of moving around them; accompanied by extra features not possible before, such as accompanying music, advanced score keeping, artificial intelligence running the gameplay, computer adversaries, etc. However the common analogy with moving in the real world holds, and for most games, the elements of moving along paths, constrained by various factors, and interacting with the game environment, other players and game entities, remain consistent. Additionally, and relevant to later discussion, locations have meanings (in the game world) attributed to them, and adjacent locations bear relationships to each other. Further discussion and comparison with games is to be found in Section 3.3.3.

1.2.2 Interactivity

The development of interactivity in mechanical and electronic devices, has greatly enhanced functionality of machines and games, but has also crossed over into entertainment, and artistic creations, especially in the last few decades.

Todd Winkler defines interactive music as “a music composition or improvisation where software interprets a live performance to affect music generated or modified by computers” (1998, 4). Robert Rowe defines interactive computer music systems as “those whose behaviour changes in response to musical input” (1993, 1). Coupled with the development of interactivity, is that of interfaces, and more specifically, human computer interfaces. A large part of the growth of this development has been for computer environments, both for functional applications such as word-processing, and for entertainment applications including games. The development of interactivity and interface design, and of digital technology more generally, has led to a great expansion in the current and possible applications for interactive arts, including multimedia and music.

1.2.3 Installation art

Installation art combines visual arts with elements of sculpture and other media to create environments in physical spaces that are often large enough for the viewer/participant to move around in. Installation art provides location-based art experience, in that each location provides a unique viewpoint or experience, and a particular path through the installation space provides a specific experience. Installation art may include interactivity of varying degrees of technological complexity, so that experiences “happen” or are triggered by arrival at various locations. Thus, visuals, video projections and musical events, among others, may occur, or be seen differently from various locations.[2] Many installations have involved the use of musical samples triggered by participants arriving at specific locations (for example, Mitchell, Lillios and Cornelius n.d.). In this way, a musical environment in space has been constructed, and may be explored and experienced in many ways. In common with games discussed above, installations may often have constrained paths, involve elements of location-specific experience, and embed meaning in locations.

2 Dixon (2007) provides good coverage of installation art and interactivity.

1.2.4 Movement

Movement and, more specifically, dance generally involve moving in particular ways on some kind of horizontal surface (including the ground or floor) under the constraint of gravity. For the present discussion, we will consider movement-based activities such as physical exercise, sports, games, martial arts, and dance. Commonalities among these include:-

(i) a particular surface, ground, playing field, or stage upon which participants operate
(ii) particular zones, boundaries, goal posts, props, etc.
(iii) allowing specific movements, such as dance steps, exercise movements, kicks, martial arts moves; and sequences of these combined into routines, choreographies, etc.
(iv) directions, patterns of step movements and paths of these movements, which may be facilitated or constrained by (ii) above;
(v) rules, objectives, motivations (e.g., fighting), and gameplay strategies that map the overall movements of participants.

A simple example of the grid-based game is hopscotch, which is played on a flat surface with the court or course design of numbered squares. Game rules dictate movement on a particular path, by hopping from square to square on the course. A contrasting example, in which the institutions are looser and not shaped by the grid form, is the Brazilian martial art/dance/sport of *Capoeira*, in which a circular area is selected on the ground, and participants may play musical instruments, or dance or fight ritualistically and acrobatically in the centre of the circle. There are no specific rules, strategies or gameplays; instead it involves a loose assembly or repertoire of moves and ritualistic encounters.

1.2.5 Music

Western music has gone through many revolutions in the 20th century, one of them being the breakdown or mathematical deconstruction of music into its constituent elements. An early example was Arnold Schoenberg's serialism (Simms 1996) and its twelve-tone technique of using a set of twelve pitches over and over, and in various mathematical transformations. Later, particularly in the 1950s and 1960s, compositional processes were devised where constituent elements of music were then recombined by various processes and procedures including using chance techniques (Nyman 1999). The production methods for these processes and procedures spanned a broad range, from small handwritten instructions, similar to recipes, as used by John Cage, to complex computer programs and algorithms that used extensive and complex equipment, as used by Iannis Xenakis. The use of game rules and gameplay for musical composition was explored to some degree by John Cage and Christian Wolff among others (for examples, see Cross 1999, 35-41 and Nyman 1999, 16). Most dramatically, the outcome of music was no longer the production of staged masterpieces presented in front of a seated audience, but a splintering of musical experiences into many forms, ranging from solo participant experiences (single listener), to chaotic multi-art forms such as “happenings”.

Since the 1960s, computer music has continued to develop by using processes and procedures from such diverse fields as mathematics and computer science (Xenakis 1992), engineering, and biology. Today music-making methods include algorithmic and generative techniques, interactive systems, artificial intelligence (AI) techniques, and those borrowed from biology including genetic algorithms and artificial life (Todd and Miranda 2006).

A fuller discussion of music composition and improvisation is provided in Chapter 6.

1.2.6 Computer games

Computer games have become sophisticated enough not only to present a virtual gameworld, inhabited by participants, avatars, creatures, vehicles, etc., but also to include music partially generated in real time. Movement, by the player's avatar for instance, is in and on the gameworld; which could be as simple as a grid or board-game layout or as complex as an artificial planet. Movement may be as simple as jumping from square to square, as in draughts or chequers, or as complex as flying a spaceship in a four-dimensional universe; with possible movements and methods or styles of movement being defined by the gameworld. Generally speaking, paths or routes taken have consequences on strategies, outcomes, fights etc.

Interactivity is provided firstly by the interface—mouse, joystick, steering wheels, etc., and interface screen—and, secondly, by engaging with the game logic that subsequently controls the output, typically graphics, music and sound effects. Music may be generated (usually assembled from a collection of segments) and cued by location or by action. Examples of such triggers include entering a “room”, a fight hit, or achieving a point threshold. Another view of the above scheme could be that the gameworld is an environment for having a musical experience, aided and effected by the interface and gameplay. Typically, the music is not yet sophisticated enough to satisfy this view, as it is constructed of repetitive loops that recombine in various ways. Computer games may combine all the elements of grid music systems (introduced below), but with the motivations and overall experience of a game - rather than a musical/artistic experience.

1.2.7 Collecting the threads

By collecting and combining the conceptual threads described above, one can imagine that a simple gameboard layout, like a chequerboard, could be used as a means to navigate an art-space; that is, it becomes a means to trigger interactivity between a visual space and meanings from a musical space. Moving a game piece or avatar around a geometric space can form the input of a system that becomes a means to navigate a musical terrain.

Approaching this idea from another direction: two-dimensional grid designs or tables have been used to store and compare information or data, probably as far back as records go. There are many historical examples of storing musical data in tables, including the layout of harmonies from Euler's design (see Figure 21), musical instrument tablature, or intonation systems. By transferring data to a virtual grid, it becomes a “data-scape”. Generally the data has been stored in a meaningful layout so that, when transferred to a grid, squares or cells in the grid relate to their neighbours in certain ways, usually dependent on navigational direction along the row or column. Naturally the cell relationships can be purely mathematical or they could relate to musical values such as pitches, harmonies, rhythms, etc. The means by which paths through the grid make meaningful music is a matter of some complexity, and has been explored from a variety of trajectories.

1.3 Play and performance with GMSs

Many GMSs are released for consumers as packaged products to be played and performed by the general public as well as expert users. One motivation of designers of small GMSs is to make music creation accessible and to break down the gap between experts and laypersons. A successful interface to a music system, in these terms, allows for a simple interaction to produce pleasing results, and also for users to progress to more complex output without too much difficulty. To that end, small devices like the *Tenori-On* (Iwai 2008) perform effectively (Nagle 2008).

Another example of a consumer-oriented GMS is the *Monome* (Crabtree and Cain 2008) that has been used (a) for visualisation (e.g. as a grid based “score”, with a built-in accelerometer that tilts a bitmap picture around, or to display cellular automata), and (b) as an interface. Monomes, and similar devices, are being used mostly as controllers for software programs running in the style of a step sequencer where one cell activates one musical event. This direct mapping of a grid of buttons to musical events is easy to comprehend and the technique required to use it is straightforward.

By way of contrast, large and/or complex systems, such as *Gestation* (Paine, 1999), typically require intelligent and skilled interaction over some time to produce good results, and often require complex set up. Such complex systems are less likely to be purchased and used by the layperson, and are generally installations, custom-made by an artist/designer, one-off and purpose-built. It is generally seen to be more difficult to develop an interactive installation system with which the public can interact on a casual basis, and which produces suitably interesting and engaging results, than it is to build a system for the expert user (Rainer Linz, Personal interview, May 24, 2007).

In its early development, the *HarmonyGrid* was intended for use by the general public on a casual user basis, but after advice and consideration of the difficulties described above, development of the *HarmonyGrid* was redirected toward use by a proficient, improvising musician. As such, the *HarmonyGrid* requiresthe ability to understand and operate with harmony in real time, and is therefore likely to be less rewarding for the casual user with little music-theoretic knowledge.

1.3.1 Music-making

I shall briefly define my idea of music-making in an informal way. The *HarmonyGrid*, as will be later described in detail, allows for control of compositional parameters in real time whilst the musician performs on an acoustic instrument. Therefore, for the purposes of this research I am concerned with making or creating music live, in real time, as a process that might be strictly termed improvisation. Although Lukas Foss said "improvisation is not composition" (Foss 1962, 684) in 1962, few would argue in recent times that where improvisation is successful, we may call it composition. Mandel writes: "Improvisation and composition are two sides of one coin alloyed in the medium of form. At least it's how it is in jazz" (2001), and further observes: "It's hard to conceive any creative construction that doesn't involve some degree of improvisation once substance has been chosen and intent begins to manifest." Some writers make distinctions however: " 'Composition' implies that the improvisational activity involves some degree of innovation, because it goes beyond automatically repeating a pre-existing routine" (Crossan and Sorrenti in Moorman and Miner 1998, 6).

At the very least, musicians would agree that a given improvisation would lie somewhere on a continuum between musical sketches and complete compositions. I place my idea of music-making on that continuum, but not in any defined location. It is both improvisation and composition. Perhaps the idea contains something of the craft or activity of simply making music rather than a sophisticated, culturally-determined notion of composition, which includes the concept of the masterpiece, with its rigour, integrity, and sophistication in the musical structure and materials.

1.4 Personal background and motivations for the research

A brief look at my background history will illuminate my motivations towards conducting the present research.

Moving beyond my earlier comprehensive classical training at the Queensland Conservatorium of Music, I began to explore the wider world of the musician. Initially trained as a performer, I then learnt to improvise, to explore my own styles, and to play with different types of ensembles including bands. I developed my own style of musical composition inspired by world music, and arranging skills, using traditional notation. Later I explored electronic and computer music techniques, learning to make music in the new methods with the vast range of sounds available, and developing further musical styles including dance music and world fusion. These systems also catered to exploring a range of music-making techniques, from unprepared improvisation all the way to fully worked-out composition.

In the early 1990s I completed a science degree, majoring in microelectronics and physiology – contrasting 'hard' and 'soft' sciences - and became interested in the interface between the two. This comprised the technologies that took structures and ideas from human brain functioning and applied them to computer systems, such as neural nets, connectionist networks, and artificial life. For my Honours year project I used fuzzy logic and a connectionist network to develop software for an aircraft cockpit display. It is interesting to note in hindsight that this system used graphical animations and icons, for a pilot's performative display.

Since the early 1990s I've “dabbled” in other art forms including video, set design and wearable art. I've collaborated with other artists such as poets, film-makers, theatre actors and directors, on projects including making a music and poetry CD, and creating and performing music for theatre shows. In addition, I explored the creation and presentation, or facilitation, of a variety of events and performances,

from underground art events and 'happenings' through to traditional concerts.
Overall, in reviewing the last two decades of activity, I can summarise by saying I have been a musician looking to expand my range of musical activities in two ways. At first I extended my activities in terms of styles and techniques, to include composition and arranging, and new performance styles; and then secondly to extend music by combining it with other art-forms, in varying presentation modes, to further enhance my range of performance expression.

One personal aim of the research was to design a system that I, or any proficient musician, could improvise with. To that end, the *HarmonyGrid*, introduced in the next section, is a real time, open-ended format, creating music triggered by the performer's location. Musically, the system is not sufficient unto itself, but is dependent on controller input, to create musical output. This can lead to a satisfying result on its own, but is really designed to operate in partnership with a solo performer. Additionally, I enjoy the pairing and dialogue of my acoustic instrument skills with the sounds of the new electronic instruments from today's soft synthesizers.

Another personal aim, is to provide a spatial component to musical performance, becoming part of the theatrical presentation of performance. The spatial component may be part of both input and output of the system. As a controlling input to the musical system, it needs to be seen and the results heard, for the system to be intelligible to an audience. In alignment with Rainier Linz, Gordon Munro and many other practitioners, I consider that at least some, if not most, of the controlling actions need to be observable as such, that is to seen and heard, even if the specific outcomes are not obvious, but rather are appreciated in a general way.

I have used spatial location, within a simple two-dimensional grid, as the most obvious controlling factor by the performer. In addition, the performer wears a control box of knobs and switches, functioning mostly to start and stop sub-systems within the system. Spatial location has been used for gestural control in many systems, and has been accomplished by varied technological means including sonar, infra-red, radio location, and camera-tracking as I have used. I decided to engage with rather simple data, using quantised spatial location in order to trigger harmonies; as opposed to quite complex positional and gestural data used in some systems, such as *Gestation* (Paine 1999). The pace of harmonies in traditional European and Western popular music tends to be at least as slow as the beats, so *HarmonyGrid* provides for a harmonic speed from few hundred milliseconds up to 3.5 seconds, but generally using equivalent crotchet tempi of 60-120 b.p.m. I then extend the system so that grid positions and pathways control other musical parameters.

A further interest has involved controlling musical instruments, and developing an instrument-system. This could be seen as an extended instrument (see Section 6.6.2.1). I enjoy controllers, and look for instrument control on electronic/computer instruments that go some way towards the kind of control I have on my acoustic violin.

Additionally, I've enjoyed designing a somewhat theatrical presentation, where the performer moves on top of a design of projected colours with moving components. The effect is like augmented reality, with the performer on top of a computer environment, perhaps heightened by the 'retro' style of the design.

1.5 Overview of the HarmonyGrid

The *HarmonyGrid* (see Figure 1) uses a simple 4x4 grid of squares which is projected vertically down onto a performance area, so that it forms an area 2 metres square. The user, a performing musician, walks on and around the grid. The performer's location on the grid is detected by a webcam placed overhead near the projector and the corresponding square, or cell, is thus activated or selected. Software developed in the PureData (*Pd*) environment with the GEM graphic library extension, drives both the grid graphics (which are somewhat animated) and the generated music. Changes to the music can be triggered by the performer's location on the grid. The grid operates in four modes, aligned to the musical parameters of volume, rhythm, timbre, and pitch (or harmony as the combination of pitches). Moving on the grid in one of these modes alters the current parameter for the particular square, or cell, currently activated. Musical output runs continually, and is generated in real time and interaction is "live" so that, for example, in "harmony" mode arpeggios based on the currently triggered chord continue to sound until a new square is triggered. Musical output is produced via software synthesizers and sounds quadrophonically over the performance area. The performer's role is to improvise over the system's musical output with a portable musical instrument whilst managing changes to the generated output by moving around the grid and by operating a wireless controller box (see Section 5.3).

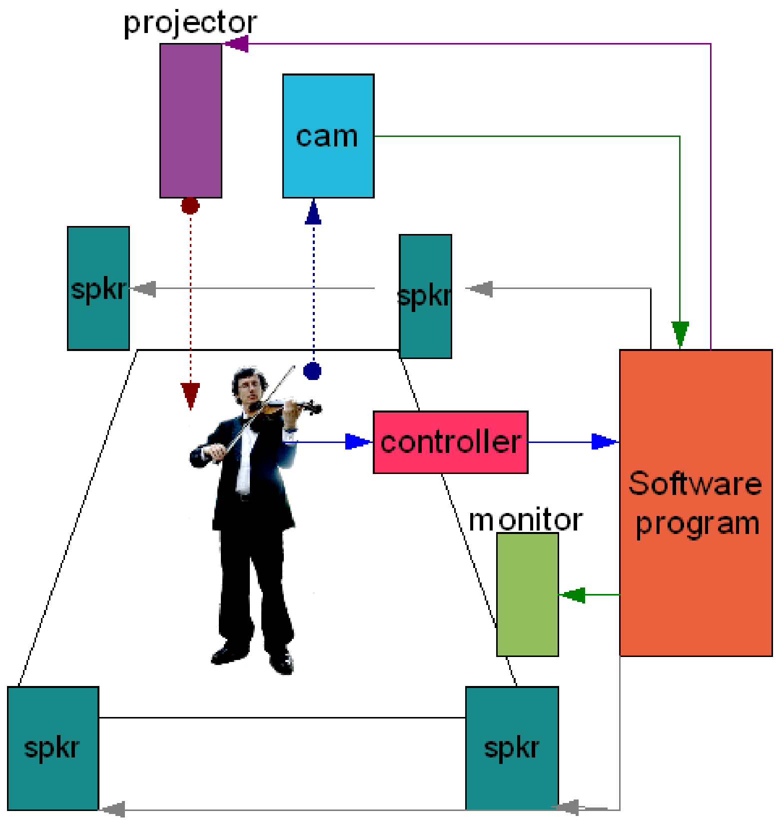

Figure 1. Information flow in *HarmonyGrid*.

The *HarmonyGrid* appears to combine a unique set of features, in that it is a (relatively) large-scale grid on which the user moves their whole body around to produce music while performing on a mobile instrument. Dance games, such as

Dance Dance Revolution (Konami Corporation 1998), provide somewhat similar systems, in that they involve moving on a special surface (e.g. the dance-pad). However, in these games the motivation for engaging is dancing and scoring for dance accuracy, and the scoring forms part of the graphical output rather than the creation and control of a musical score. Other similar systems where musical control is at least part of the result include interactive installations where sound samples and soundscapes are triggered by a user's location, and a few motion tracking systems for installation or dance performance.

The *HarmonyGrid* differs from typical installations where participants may move around the space within the constraints of objects and artworks. In these cases space is typically treated as continuous and free-form, and bears no relation to simple geometric schemes or grid systems, which are explicitly visible and operated upon. Also, it is often the case that the musical outputs of these installations are somewhat indeterminate, given their temporal and spatial inputs, and resemble soundscapes. In contrast, grid systems lend themselves to specific and discrete states that are typically quantised and synchronised precisely.

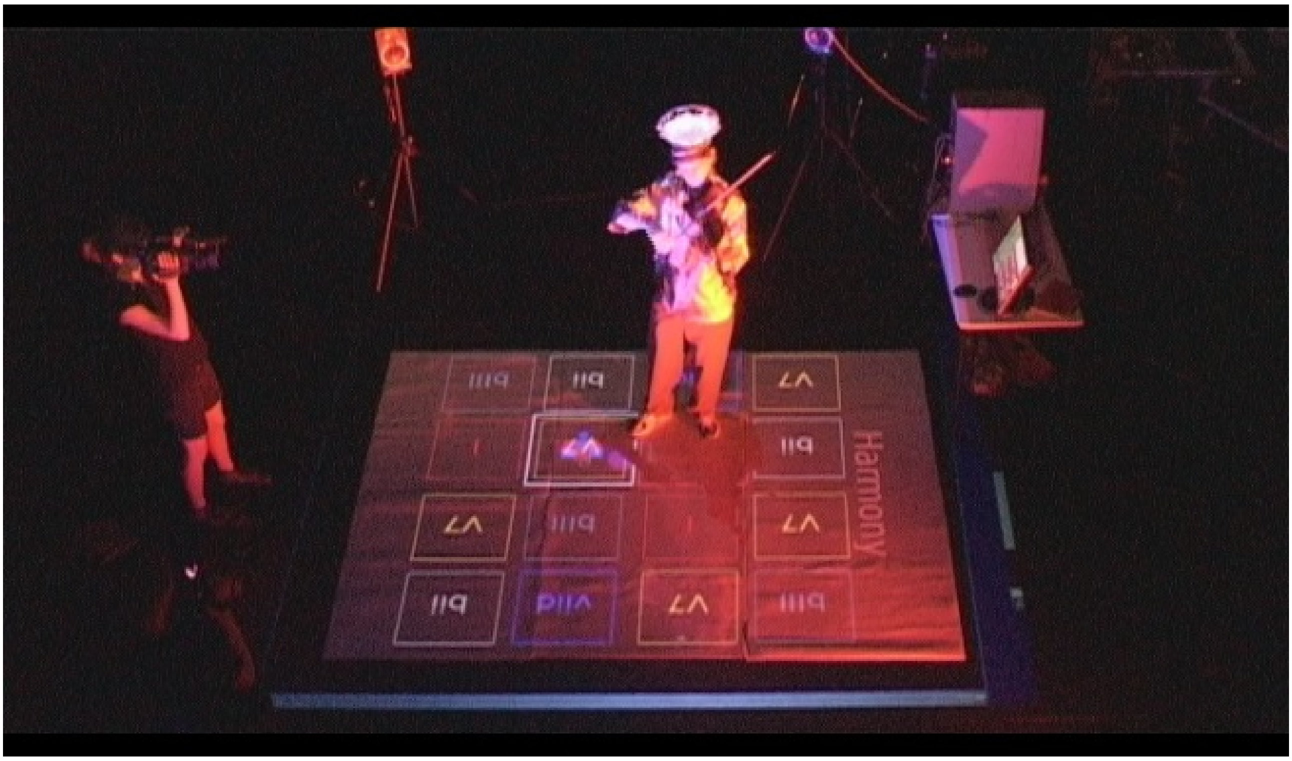

Figure 2. Performance with the *HarmonyGrid*, still from Video 5.

Many motion tracking installation systems that track full-body motion, such as Garth Paine's *Gestation*, allow one or many users to trigger quite complex musical processes. Tracking in Paine's systems, as in most, is continuous across the space. Some exceptions to this rule are the discrete dance-based motion tracking used in *dis-patch* (Parrot and Mustard, 2004), where quantised inputs—the locations of limbs—wer used to inform a complex music-making computer program. In these dance systems there is no obvious (visible) geometrical system constraining the input, to inform the output; and as such, the process is obscure to the observer. Other exceptions are systems that used the Buchla *Lighting* infra-red controller that, most likely due to technical feasibility at the time, divided space into a grid.

Further discussion of motion tracking approaches appears in Section 3.3.1.1. Chapters 5, 6 and 7 provide extensive description and discussions of the *HarmonyGrid*, and extra technical details are provided in Appendix 1.

1.6 Aims and outcomes of the Research

1.6.1 The Research questions

This research presents an original investigation into spatial music systems, undertaken in order to gain new knowledge about interacting with music and space. This new knowledge is explicated through exegetical writing and creative product.

The research process proceeded as a creative exploration with a performance outcome in mind, with the spatial component of the musical experience as a core interest. A personal and aesthetic choice was made to use music and graphical components with a discreet set of values—a square grid in graphics and tonal music and metrical rhythms. Another preferential constraint was the use of direct real time interaction enabling direct engagement in music-making typical of live performance.

The decision to focus on the GMS as an interface for music-space generated a number of specific research questions, including:

1. how can a musician spatially engage and control an immersive GMS?
2. how might one implement a computer system as an interactive system for music and graphics?
3. how can a GMS operate as a musical system to improvise with?
4. what spatial presentations will allow effective organisation and selection of musical elements on a grid?
5. how might one best engage in music-making with a GMS in a way that meets the targeted aesthetic aspirations?
6. how can an experience of immersion[3] in space, graphics, sound and music, be facilitated using existing multimedia equipment, with some adaptation?[4]
7. what are the issues in designing a performance practice for an immersive GMS?

1.6.2 Design of the research

Commencing as a very open-ended exploration, this practice-based research proceeded through three discernible phases:

1. locating and homing in on the subject area, literature review, and early experimentation
2. finding a suitable environment and development strategy for the *HarmonyGrid*; further literature reviews, experimentation and development work
3. constructing and using the *HarmonyGrid*, analysing and comparing with other work.

Each phase of the practice-based research was accompanied by creative development and experimentation as well as literature reviews. The last phase included iterative cycles of development and testing, common in engineering product development, along with artistic performance testing. The methodology is fully explained in Chapter 2.

3 Immersion is defined and discussed in Section 4.4.1.2.
4 Naturally one would prefer to build using a three-dimensional Holographic system!

1.6.3 Research outcomes

The outcome of this Ph.D. research is proposed as a 40% - 60% weighting between the creative product and the theoretical component. The research outcomes are:

1. this written exegesis
2. creative product – a new GMS, the *HarmonyGrid* ; documented as a DVD with surround sound, showing video excerpts of the performance testing, along with software screenshots, code examples, and analysis in the exegesis Appendices

The DVD documents the *HarmonyGrid*, a new interactive spatial music performance system on a grid. It documents performance testing, demonstrates pertinent aspects of GMSs as discussed in this exegesis, and displays a system that is a unique product with distinctive interaction design, appearance and music generating capacity.

The claim of originality and contribution to knowledge is demonstrated in both the exegesis as well as the creative work. The *HarmonyGrid* demonstrates originality by being a large-scale GMS that combines these properties:

1. it provides a generative music-making process to improvise with
2. the musician controls the music-making process whilst moving in the space which he or she makes (or *produces*[5])
3. it provides a partially immersive environment - spatially, graphically, sonically and musically
4. it combines music representative space with music-space.

These points are expanded upon and discussed comprehensively in Chapter 6. The *HarmonyGrid* currently appears to be the only large-scale GMS incorporating the properties listed above, that this author has been able to locate during the present

5 after Lefebvre – see Section 4.4.1.1

research.

The exegesis explores and discusses:

1. music composition and performance, by accessing multiple musical parameters, to create paths and loops to combine and form musical textures
2. using the structures of a GMS to build a new large-scale immersive system
3. spatial access and arrangement of musical parameters, and their embedded knowledge
4. the experience of music in space, and the composition, facilitation and performance of music in space
5. the overlay of music representative space with music-space.

1.7 Structure of the Exegesis

Chapter 1 has introduced the research with a definition of GMSs, distinguishing the term from other similar ones. It has traced the conceptual and experiential threads that led to my assembly of the idea and reality of GMSs. After some discussion of play and performance with GMSs, and music-making, I examine my personal motivations and skills that have lead to undertaking this research. A brief introduction to the *HarmonyGrid* follows, with an information flow diagram and photo of the system in performance. The previous section to this present one described the research aims and outcomes.

Chapter 2 discusses the methodologies used. The overall methodology was a form of practice-based research, drawing on aspects of grounded theory, design methodology and auto-ethnography. The process of the research is then traced, showing how it shifted from a framework based on external space to virtual space, and then to a combination of both the spaces.

Chapter 3 introduces GMSs in more detail, with a simple taxonomic breakdown of system functions and components. This becomes a framework for introducing various GMS devices and software products. Other systems are then discussed, including block systems, touchpad and touchscreen systems, and "light table" systems which provide further context for GMSs. Topics associated with GMSs such as movement, visuals and gameplay are considered, before the chapter concludes with a broad placement of GMSs amongst intelligent and interactive systems.

Chapter 4 discusses space, commencing with general concepts and perception of music and space, and moving on to more specific examples of musical spaces, such as soundscape, acoustic space and some traditional perspectives. It presents structured spaces for music and sound including virtual spaces and music representative space, detailing the theories underlying these. The discussion then moves toward experiential music space, and presents my own concept of music-space. Finally, the combining of music representative space with music-space is discussed.

Chapter 5 presents a full description and analysis of the *HarmonyGrid,* starting with the terminology used and a listing of system components. This is followed by a detailed description of the system in the taxonomic terms introduced in Chapter 3. Music production via the system is covered by presenting the various grid modes using the musical parameters of Volume, Rhythm, Timbre and Pitch or Harmony. Section 5.3 covers control of the system spatiality by performance, and via the electronic controller, and the final section discusses design considerations for interactive systems.

Chapter 6 provides a extensive discussion on how the new scaled-up GMS, the *HarmonyGrid*, informs the research questions explored in this exegesis. The chapter begins with a discussion on music-making with the *HarmonyGrid*, looking firstly at the mapping between the grid, physical and musical spaces, and then at the grid itself and paths. Music-making is further discussed in relation to composing for the grid, space, music-space and immersion, music as an interface, and performance with the grid. The final section compares the *HarmonyGrid* with other systems, also using the categorisation of Chapter 3.

Chapter 7 sums up the research findings within each research area, and points to future directions for system development and potential applications across various fields. It concludes the exegesis by outlining some ideas for future research.

Appendix 1 addresses the equipment, components and software of the *HarmonyGrid* system. Section 1.1 details the system components, setting up the system, difficulties and known faults, and specific details of the equipment. Section 1.2 examines the software and program flow, and the controller and how it interacts with its display screens. Section 1.3 covers improvements to be made in the future.

Appendix 2 addresses the videos on the accompanying DVD. Section 2.1 presents a listing of events on the videos, to be noted when watching the videos, and may be used as a guide to locate examples of particular aspects or functions of the system. Section 2.2 provides an analysis of the videos via an extended listing in table form, with commentaries and concluding discussion.

Chapter 2. Methodology

This chapter details the methodology employed during this research, including its general approach, phases of activity, reflective practices and literature reviews. The chapter considers how the research took shape over the research period, and details its history from three perspectives on space. A final section sums up the process, including key ingredients and difficulties.

2.1 Approach

The methodology of the research has been practice-based. It included a critical investigation into GMSs through the development of a novel, immersive performance system which expresses, along with this exegesis, new knowledge about the relations between music and space The practical outcome of the creative process is documented in the form of a DVD showing the operation of a new music performance system. The claim of originality and contribution to knowledge is demonstrated by the exegesis as well as the creative work.

The research process has been largely one of exploration: of music, space and, to a lesser degree, movement. This open-ended exploration was driven also by personal experiences and interests (see Section 1.4), which motivated certain choices. These choices, for instance to discontinue a line of investigation and start somewhere else, were informed partly by intuition, and partly by triangulation of theoretical insight, experience using the system, and inspiration from the ongoing contextual review. They continually refined the investigation in order to home in on the core issues at stake in the research.

By practice-based research, I mean that the act of pursing a performance practice based on GMSs was deliberately designed to shed light on the issues of music and space. Creativity and Cognition Studios' Research Guide (2009) distinguishes between practice-based research and practice-led research. Concerning postgraduate research, it suggests that if new knowledge is sought by means of practice and the outcomes of that practice, and is demonstrated via creative product, it is practice-based research, and a full understanding of the knowledge obtained is only available through both written work and creative work. In contrast, practice-led research is "concerned with the nature of practice" and aims to generate new knowledge that has "operational significance for that practice", and is able to be fully delivered via text (CCS 2009). In line with this definition, this research uses both text and examples of the practice as vehicles for articulating the understandings developed during this research.

The methods used in the research, including personal creative practice, are all qualitative. Qualitative research utilises a pluralist approach and a range of methodologies (Denzin and Lincoln 2000). Although largely practice-based, as described above, various phases of this research drew on other qualitative methodologies. For example, the final phase took from design methodology, using an iterative cycle of development and testing of the creative product. Much of the research incorporated aspects of grounded theory. This approach calls for cyclic activity of "continuous interplay between analysis and data collection" (Strauss and Corbin 1998, 158), where data collection in this research involves testing, observation, and demonstrations of the creative product, and discussion with peers and experts. Grounded theory calls for the gathering of data and evidence prior to producing hypotheses and/or questions to locate the main concern of the researcher. The artist needs to locate in, occupy and move around in the artistic materials of his/her practice, in order to absorb the "data", get it in motion, and stimulate the rise of questions and hypotheses that lead to theory.

Additionally there was a component of auto-ethnography, a qualitative research method that in this case draws on the artist's inner experience. According to this approach, personal subjectivity can be seen as a strength, rather than merely as a cause of bias; it forms an additional source of data and a basis from which to develop and create new understandings. As with grounded theory, auto-ethnography involves iterative reflections on "data"—personal experiences and perception. Ellis and

Bochner defined auto-ethnography as “an autobiographical genre of writing and research that displays multiple layers of consciousness, connecting the personal to the cultural” (Denzin and Lincoln 2000, 739). In the preface I stated my position and my background, mentioned previous influences thereby hinting at possible areas in which preconceptions play a part. I discussed my familiarity with using my own perceptions of my work, along with those of colleagues, collaborators and audience members. In this research I have drawn on my own perceptions and experiences to document, study and evaluate the research—in particular, the practical creative work—and to do so in real time while performing and controlling the system. Additionally I have absorbed the perceptions and critical comments of others. Auto-ethnographic methods used included journalling, and examining archival material of my own actions, in this case video and audio recordings of performances and experiments, notated compositions, and software.

2.2 Research process and documentation

The cycles of data collection and analysis in the research were paralleled by cycles of creative practice and theoretical inquiry. Research methods included literature reviews, data analysis including content analysis, and reflection, software development, composition, music-making and performance.

There were three discernible phases of research work:

1. locating and homing in on the subject area, literature review, and early experimentation
2. having located the subject area, finding a suitable environment and development strategy for the practical creative work; further literature reviews, experimentation and development work
3. constructing and refining the creative work, and assessing it in comparison with other work

These three phases were informed by, and overlapped with, investigations into different categories of space; external space, virtual space, and combined external and virtual space.

Externalised evidence of the reflective practices in the research included the following:

1. Documentation of studio practice: a journal was kept, copious notes, short and longer papers, fragments of creative work, including audio and video files, computer programs; completed or partially completed works, performance/demonstrations and performances.
2. Presentations of creative work in process, and ideas, in the format of talks, lectures, and consultations both formal and casual. This led to interrogation and review by peers, supervisors, and visiting experts in the field.
3. Literature reviews commenced at the listed dates below.

The literature reviews covered a range of theoretical and practical material relevant to my ongoing creative process, reflections and discussion, including:

1. A very broad review of music, art and games-based works, either sited on computers, or involving computer technologies, involving music and graphics or visuals, generally in a performance or interactive technology (October 2005 and ongoing)
2. Music visualisation and animation: computer-based works (October 2005)
3. spreadsheets on comparative art forms (October 2006)
4. A small review of musical notation relating to graphical presentation, and possible technological access (November 2006)
5. Music Animation (November 2006)
6. Space (July 2008)
7. Grid music systems and related systems (April 2009).

2.3 The creative process

I have sectionalised my research progress over the research period, by considering three aspects of space in turn: external space, virtual space, and combined (external and virtual) space. External space refers to external physical space, and virtual space refers an artificially constructed space within a computer environment (see Section 4.2.3).

2.3.1 External space

The starting point was to examine ritual and music theatre because this placed elements of musical performance, within a designated space, and was located in hybrid art, my domain of choice. Starting this exploration within my skills base, I composed a violin piece entitled "Ritual Exercise no.1" (2005), firstly as traditionally notated score, and then reworked as a recorded audio file. Both versions were workshopped, at the "WhereMusicMeets" workshops.[6] Approximately ten participants improvised movements to the music, which was both performed live and presented via a recording. I had attempted to formally structure the musical composition emulating that of a ritual. However, though the experience was enjoyable, it was unclear how successful it was in achieving a sense of ritual. An extended composition, "Tromgroove" (2005), was commissioned for a concert[7] and provided an opportunity to blend cultural components, to include improvisation, and to fuse acoustic and electronic music styles and equipment. Experience was gained in performance, improvisation, interweaving and controlling electronic components whilst playing acoustically.

The need to investigate the visual and constructed environment arose, as it was felt, even at this stage, that something would be created, including physical elements, eventually. Early experiments with a video camera explored the basics of combining movement to music, and the mapping of one onto another. Also considered was the effect of various musics on perception of movement. During this period, original

6 Led by Jody Kingston, at Creative Industries, Music and Sound.
7 Brisbane City Council 'Midday' concert, June 2005, with Angel Strings quartet, and David Williams (didjeridu and trombone), and MIDI backing tracks.

music was nearly always constructed[8] or composed to accompany these experiments. Occasionally repertoire pieces were combined with clips. Beyond simple one-to-one mappings, it was unclear how to proceed further to understand these effects. After making a four minute video clip, consisting of a montage of explored effects, each with original music, I felt that further progress in understanding the combination of music and visuals, was likely to remain slow and difficult by these activities. The direction was abandoned. However, basic video techniques had been learnt, including the tactics, skills and aesthetics of combining audio and video, and basic editing.

Feeling the urge to physically move within a structured space or environment, I began investigating games scenarios; in particular the game of snakes and ladders appealed. A large floor version was made which I could walk on and some short musical segments were selected to be played or triggered (manually) upon arrival at particular squares. Functionally this was quite ungainly. However, the structure of paths on a grid as a topic had been made physical, along with switching points or decision points, movement in space, and spatial control.

2.3.2 Virtual space

In an effort to generate a more sophisticated relationship between movement and music, and to enable a triggering mechanism, I gravitated towards the computer as a medium. At first the possibilities of triggering sections of my own compositions appealed, in addition to ordering them as I pleased at the time. I was exploring and creating rather jolly, jaunty musical segments suitable for game playing at the time, using styles like that of Michael Nyman and the neo-baroque. The direction was toward a mosaic-like formal structure of the music that could be ordered as one pleased to make an extended composition. This somewhat replicates the technique of computer game music that generates in real time via the selection of "loops" determined by the game action or location. In this way, the nexus between composition, improvisation and movement was first articulated.

Part of the appeal of using a computer to activate components of a composition was

8 By "constructed" I mean more of a process of assembly from segments, in contrast to note-by-note composition.

that graphical programming environments, like Max-MSP, enabled graphical areas onscreen to trigger musical events. At first, in Max-MSP, I triggered music samples of my own compositions,via a mosaic of graphic zones. This was development work towards an idea of a visual/music/space environment; and an exploration of an extended music composition, through space. Some simple animations in Flash were constructed, but it was found that the available control of music samples was far too restrictive in this environment. However, the idea of animation as a tool for interactivity was introduced.

At this time, and coming up to the Confirmation Seminar,[9] I conjured up or imagined a computer game-like environment as the major practical work for my research, which incorporated a large virtual graphical environment in which one could move around, facilitated by a musical interface. The idea of a musical interface was that movement onscreen is to be determined by the input of (MIDI) music, improvised at the time, in front of the screen. At this time the Ph.D. research title became "The Creation of a Musical Interface and Compositions, for Graphical and Virtual Environments". The virtual environment was to have a shape somewhat like a space station, with nodes featuring custom-designed graphics and music to be experienced at those locations. It was anticipated that the system was to be set up as an interactive installation for musicians and the general public to play with.

Towards this idea, the *Torque* game engine[10] was purchased, and I began building structures (buildings) in Quark, and importing them into the Torque environment, and placing musical segments at various locations within these structures. Torque has a facility which shows graphically the (spherical or conical) emanation of the music from an object in the three-dimensional world.

A literature review was carried out to look at music and graphics, animation, and interactive environments, and small online programs such as Flash animations. Particularly striking was the work of Gerhardt Eckel (1997) and his "virtual

9 A step in the Ph.D. Process, after approximately one year, at Queensland University of Technology.
10 GarageGames, 2007.

architecture”, which became a key reference work in the Confirmation document and related presentations. Also the *GROTRIAN Pianos* (GROTRIAN Pianos n.d.) interactive animation was identified as interesting and highly relevant. Surveys were compiled into documents and included a general survey, a survey about music and animation, and one about music visualisation. Spreadsheets cataloguing these items were collated with regard to mapping, inputs, and basic parameters of music and graphics. Quite some effort went into examining mappings between music and graphics (or visuals), to locate a fundamental selection of them. A typology had commenced. The anticipated direction at the time was to insert the fundamental mappings into a created computer application that either transformed harmonic material, or provided a toolbox to make new works utilising musical mappings.

I was advised by Richard Vella to consider analogy and metaphor as potential underlying mechanisms (Personal interview, August 11, 2006). For instance, mapping and modelling architecture and music together require analogical conceptualisation of many possible indirect relationships, as there are only a few direct ones, and some deliberate relationships needed to be contrived. I struggled to find suitable direct relationships. By correlating sound wavelength with physical length I proceeded to model a virtual building based on lengths of material specified by wavelengths related to pitches of a melody. This path was not fruitful; another path was selected.

At the outset, (real) external space and performance space were important to the investigation, but once the move to the computer had occurred, I was exploring music and graphics at a simple level or via simple animations. It was only towards the latter third of my research journey that I returned to my original ideas and re-framed the exploration in terms of space rather than graphics. Graphics have become the means to delineate and illustrate space, for the purpose of mapping music to it, via a simple geometric scheme.

In searching for a suitable software development environment, and after discussions at a computer music seminar, the media arts programming environment *Processing*[11] was suggested. It is a text-based computer language that is highly suited to graphics experimentation. At first I constructed many simple programs that explored the interaction between music and graphics, with first music and then graphics forming the input. Some attempts at building pathway structures were made, where path segments triggered audio segments to play. One program, entitled "Frogs", used a grid of 15 x 15 squares, each triggering pitches when two frog icons hopped from square to square (see Figure 3). The frogs could be steered by the arrow keys, whilst playing the melodic fragments distributed around the grid. A small separate grid provided a bass line and its own icon. Grid squares used Scriabin's scale of colours assigned to pitches, which I continued to use from then on (Wells 1980, 103). This was my first grid music program, complete with active icons, steerable paths, and three lines of music.

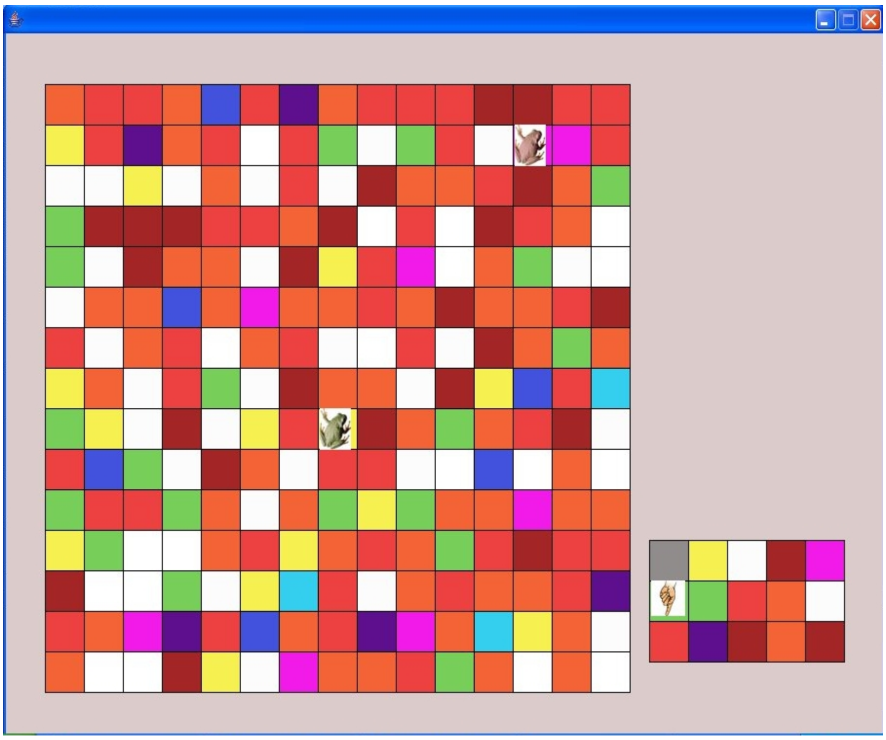

Figure 3. "Frogs" program, built in Processing.

The original program that went on to form *HarmonyGrid* was entitled "Lattice" and

11 *Processing* was founded by Ben Fry and Casey Reas in 2001 at the MIT Media Lab.

the graphics screen showed small squares representing nodes on a diagonal lattice, that triggered harmonies. These, at first, were sampled arpeggios from a synthesizer, with additional percussion samples added later. The lattice could be navigated using the arrow keys, with the current active node lighting up. After some months, it was found that the available music libraries for *Processing* at the time couldn't play two or more audio selections simultaneously, and that there were inherent timing control faults from within the base language of *Java* itself.[12] Although OpenSoundControl (OSC)[13] could compensate for the former, the later problem rendered *Processing* quite unsuitable as a platform, as regular rhythmic music was always my preferred option. This lead to the selection of *Pd* as a likely environment for music and graphics experimentation, although the GEM graphics associated with *Pd* are somewhat clumsy to program, and operated from a base of OpenGL which was a different paradigm from bit-mapped graphics programming I had experience with.

2.3.3 Combined Space

Finding a library function for video tracking of objects or people in *Pd* was the catalyst and moment of inspiration to relocate the functional space outside of the computer. A video camera was used at first, and it was quickly realised that this was a strong move towards a performative direction, by way of a very usable triggering mechanism. It was also strongly suggested that I could capitalise on my performance skill with the violin while operating within the performance space. Eventually, with the completed *HarmonyGrid* system, the computer's virtual space was projected onto the performance area making a partial augmented reality setup (see Sections 3.4 and 4.2.3), with the remaining screen space showing control displays. As the performer, I felt that I should be immersed within, or at least located on, the projected graphical environment and that this would, additionally, make for a strong visual and theatrical presentation. Aside from moving positions on the grid, gestural movement had been considered at various stages in the research but, after some experiments, was rejected as too complex, not only for technical reasons of motion tracking, but also for interpretation and mapping. The video tracking of simple bodily movement through

12 *Processsing* as of October 2006 was based on a Sun Java version that contained inherent timing control faults.

13 *A* protocol for communication between computers, music and multi-media equipment. Here it was used to simply trigger the playing of music tracks in *Pd*, from *Processing*.

space provided sufficient data to work with. However, further gestural processes may be involved at a future date.

The use of a grid was a simplification of the various geometrical schemes tried earlier, and was originally meant as a temporary experimental test bed, until something more enticing was created. Many people have suggested various “improvements” to the spatial plan, including much less rigid geometries, but I intuitively felt that the rigidity and simplicity aided explicit mathematical and musical relations that were to become visually perceivable in the final performance system. The resulting direction revealed a personally appealing “retro” aesthetic reminiscent of board games, arcade video games of the 1970s and Atari computer games of the mid 1980s.

2.4 Summing up the research process

The research began as a relatively open-ended process, with a trajectory towards an unknown final subject matter. Practice-based research methods, combined with other methods including grounded theory, reflective practice, and elements of auto-ethnography, provided strategies to explore and develop concepts of performative musical space. Cycles of practice and reflection followed one another, with much experimentation and continual redesign. Key ingredients included plenty of time, non-restrictive exploration periods, and a multi-directional spiralling towards the final conceptual clarifications and creative product. The spirals became more contained as the process went on, homing in on the final research outcome.

Although some informal audience feedback is reported on in Section 6.6.1, this exegesis does not extend to an analysis of responses from audiences or other performers; the acquisition and processing of such quantitative data would have entailed a significant expansion in the scope of the project. Therefore, this practice-based enquiry, located in the reflective practice of a performance-maker, was not focussed on the responses and reception by others, but on my personal process as a composer and performer.

Many difficulties were encountered during the research, aside from the intellectual quest and the unknowing at the outset. These included the acquisition of a significant array of technical skills, and it was evident early on that I was to come across many barriers. It seemed that one could prevail either by possessing a vast array of skills or by patiently and skilfully adding and developing the appropriate skills where needed. Although not highly trained in computer programming, my desire to bring together music, computer technology, electronic controls and theatrical performance proved to be a sufficient and enduring motivation to overcome the many difficulties, and move towards a successful outcome.

Chapter 3. Grid Music Systems

Grid Music Systems (GMSs) lie at the heart of the technological solution to spatialised music performance. The *HarmonyGrid* extends the general concept of GMSs by adding image projection, motion tracking, and surround sound to provide the immersive components of the performance system. However, the central features of the music-making system remain similar.

The first section of this chapter describes GMSs in a general way, using an evolving categorisation that comes from an engineering perspective and includes input and output, activation, and detection criteria. In the second section, related systems are described to provide a larger context. This review starts with block systems, touchpad and touchscreen systems, and ends with a brief description of cellular automata (CA) processes which are at the far end of the range of related systems. The final section places GMSs in the broader context of general interactive and intelligent systems.

3.1 Description of Grid Music Systems (GMSs)

Grid music systems may be constructed in hardware or software (or both). They generally consist of a matrix, or a grid, of cells containing squares,[14] buttons, or icons. These may be presented graphically, as on a computer screen or iPhone, or as a dedicated piece of hardware equipment, such as a single console, or as an installed system comprising a variety of equipment. Generally, the user activates the grid cells directly by pushing buttons or squares on a touch screen. In some systems the user may place their feet on the cells, or be otherwise detected bodily in some way.

Typically, the systems are controlled directly from the cell activation, often like a simple arpeggiator or sequencer, that reiterates or loops the sequence. Complexity

14 This exegesis shall use the term *cells* for general systems, and *squares* as appropriate to the *HarmonyGrid*.

may be layered up and accumulated, using multiple sequences, to produce seemingly complex music. A few systems provide their own sound output but most require additional hardware, such as a computer or MIDI instruments, to sound.

The description of GMSs proceeds by a categorisation, including the areas of topologies, activation, interface, detection, outputs, grid cells, paths and modes of operation. This will be referred to again in Section 6.8.2 where these systems are compared in detail to the *HarmonyGrid*.

3.1.1 Topologies

I shall restrict the investigation to those systems using square grids as the layout for placement and movement of components, in two dimensions. Naturally, other topologies are possible, with some devices having a hexagonal layout such as the *ReacTogon* (Burton 2008), or a free network structure as with *Nodal* software (McIlwain et al. 2006). Structures in many dimensions are also possible, but most systems use two-dimensional grids, as these provide sufficient complexity to manage several parameters in real time (e.g. time and pitch are common). As mentioned in Section 1.1.1, grids may be constructed of an arrangement of lines, with spaces in between, or comprise an array of cells. The grids may be defined by lines bordering the active spaces, such as a simple grid of squares, or be constructed of a matrix of squares, circles, discs, buttons, or locations marked in some way. For example, hardware grids such as *Tenori-On* (Figure 4) have a 16x16 array of circular buttons.

Figure 4. The *Tenori-On* designed by Iwai for Yamaha.

The grids are often constrained to a small area, as with portable hardware grids, or expandable to user requirements, as with *Nodal*, which provides an expandable 'graph-paper' style grid to write to. The grid size is determined by both the cell size and the cell number. Cell numbers range from quite small – 4x4 cells, to much larger — up to 100 cells.

Physically, grids range from software screens of a grid of icons, to portable hardware machines with an array of buttons, to installed systems (using a collection of equipment) where the grid may be projected (*HarmonyGrid*), or may be a dance mat with touch pads, or a constructed surface with screen display. The variations in size have occurred partly because there are roughly three physical methods of using these systems: by fingers or fingertips, hand or arm movements (perhaps moving counters or blocks on the cells), and whole body movement. Small portable devices and software are controlled by fingers and fingertips, tabletop devices such as the *ReacTogon* require additional hand and/or arm movement, and large-scale systems, including dance games and the *HarmonyGrid,* require whole body movements. To some extent, the size of items, counters or human body parts to be used on the cells determines the cell size and the overall grid size.

3.1.2 Activation

Activation of the grid cells is achieved in many ways. In hardware, buttons may be pushed directly, as with the *Monome* and *Tenori-On*, or counters or blocks placed on the grid, as with the balls placed on the *Bubble-Gum Sequencer* (Hesse et al. 2007, Figure 5) which uses camera sensing beneath the grid to detect ball placement.

Figure 5. The *Bubblegum Sequencer.*

In some software systems, activation is triggered when icons arrive at a particular cell or location. Some systems, such as Holland's *Harmony Space* and Levitt's *Harmony Grid* allow the mouse or pointer to traverse the grid, activating cells as they pass over them (Holland 1989).

Many systems facilitate the setting up of paths on the grid, using graphical icons to control path directions in addition to musical outputs. This may be likened to designing and constructing a network of railway tracks, along with signals and switch points, and running one or several trains around the network. In software GMSs, current location is indicated by a flashing cursor or the player's avatar/icon as it moves along the paths. For example, *Al-jazari* (Griffith 2008) has robot icons move on a grid of coloured cells, showing cells in the path distinct from the background colour, and blocking instructions appearing in “thought bubble” graphics above the robot. *Nodal* provides for “nodes” to be placed and connected on the grid, with musical start locations clearly indicated, and directional arrows indicating links between nodes. The current active location is shown by a coloured flashing disc.

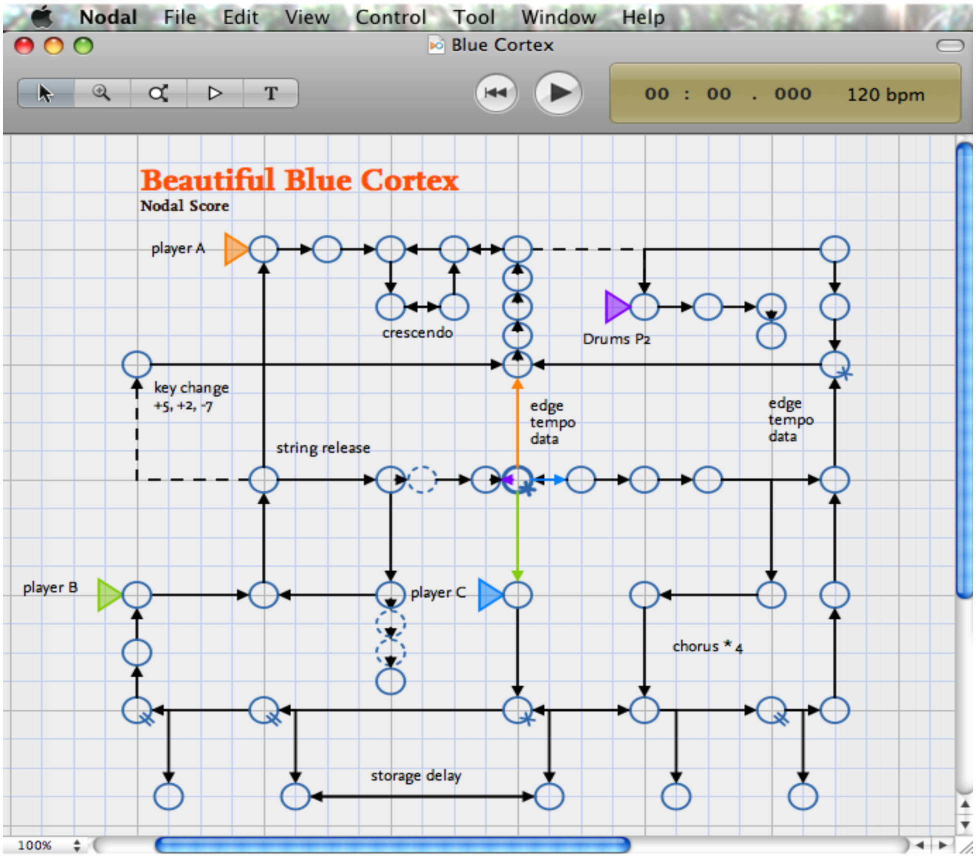

Figure 6. *Nodal* program (McIlwain et al. 2006).

Usually, several active icons may be traversing the paths. Other systems, like the hardware grids, don't provide for any complex path construction, but may retain memory of routes or paths, such as loops represented by moving “lights” or icons (e.g *Tenori-On*, *ElectroPlankton* (Electroplankton 2006)). *HarmonyGrid*, amongst others, provides for a real time path “recording”, which is then displayed as a moving sequence of icons.

3.1.3 Interface

The user interface, or Human Computer Interface where a computer is involved, is the aggregate of physical means by which the users interact with the system. An interface consists of the input, allowing manipulation of the system externally, and the output where the effects of that manipulation are shown or revealed. Hardware GMSs typically have a grid of buttons as described above, with lights under them to display recorded or activated pathways. With the *Tenori-On*, when a button is first touched a ripple of lights spreads out from it, and when held a little longer, remains lit to indicate it has been switched on (Nishibori and Iwai 2006, 172). Hardware GMSs may also have an additional LCD display and some buttons to provide further control. Software systems use monitor, mouse and keyboard, but may use additional pointers (e.g., Holland's *Harmony Space*), and additional sound equipment.

Bigger touchscreen systems including multi-touch systems provide a variety of graphical items within their designs to touch and drag. The displays may be set out like step sequencers or grid-like samplers, and may also provide virtual controls and dials for mixing and filtering, as with the *JazzMutant Lemur* (see Figure 17).

3.1.4 Input

Input for software systems is via mouse, joystick, touchscreen or other device and typically functions to set up and modify paths, rather than operate continually in real time as a tracking mechanism where the mouse pointer *is* the active component (for example, “steering” avatars or vehicles in computer games). Typically, arrows and other keys on the keyboard may assist in direction controls. Input for hardware systems is commonly provided by an array of buttons, or a touchscreen, and several other controls such as knobs and switches, occasionally with a small LCD screen. Inputs can be directed to operate on various parameters such as graphics, music, and (virtual) spatial direction, among others.

Interfaces like the *Monome* (Figure 7), that have minimal computing power, connect to software environments for programming and selection of sounds/samples. For installation-style systems, the primary input uses sensors to detect a participants' location while moving or dancing.

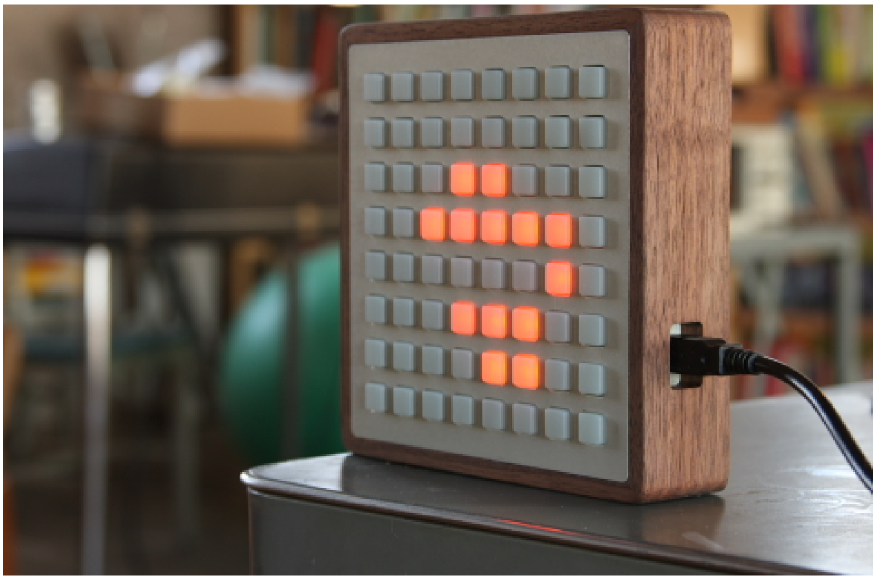

Figure 7. The *Monome.*

Some systems (e.g. dance games) favour a primary active icon operated by the user, while other systems have multiple active icons; the number only being limited by visual intelligibility.

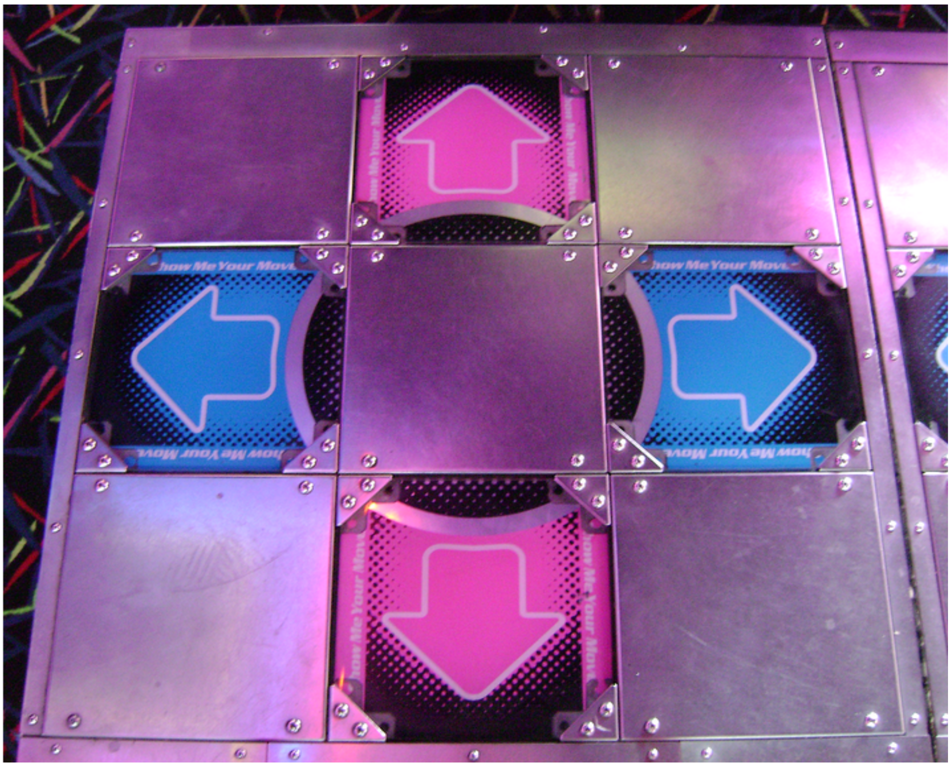

Figure 8. One side of the dance platform of *Dance Dance Revolution* arcade game.

Input for bigger systems can be via human movement or gesture, varying from limb detection to whole body detection in space, or may even extend to the detection of geographical position via GPS for mobile systems. The dance platform in Figure 8 requires whole body movement to enable detection of one's legs and feet as they dance on the platform. These systems use sensors for position detection and motion tracking (see Section 3.3.1.1), and detecting technologies can include sonar, infra-red, radio location, camera-tracking and touchpads.

3.1.5 Detection

Detection of the triggered cell in computing systems is performed by software analysis of sensor signals. Smaller hardware systems provide a console of buttons, back lit when pressed (e.g. *Tenori-On*, *Monome*). For installation-style systems, where participants move on an interactive floor grid, or for dance games, locations are detected by sensing equipment such as camera-tracking, sonar, infra-red detection, or directly by touch pads or dance mats.

The *Buchla Lightning II* allows two wands to be played or conducted in a two-dimensional grid space in front of the player, detected by infra-red sensors and outputs the wand position as a MIDI controller value. *Lightning III* extends that control to three-dimensional space, still with the space segmented into cells.

Figure 9. The Buchla Lightning III provides wands that may be used like a conductor to make music.

Regardless of the input device or detection method, decisions are required about how the inputs are mapped to various parameters, including graphics, music, and spatial direction, among others. Mapping processes can range from the direct and simple to the comprehensive and detailed, and discussion of these is well covered elsewhere (Doornbusch 2002). Mapping strategies will be discussed in Chapter 5.

3.1.6 Outputs

GMSs typically include musical and graphical outputs, with some having tactile feedback in installation environments (e.g. dance mats). Graphical outputs depict the grid itself along with active display components such as path icons and active icons or avatars. Additional menus may provide extra controls. Graphical environments tend toward diagrammatic two-dimensional designs, rather than the fuller graphics of three-dimensional worlds of computer games, as in *Audicle* (Wang et al. 2006, Figure 10).

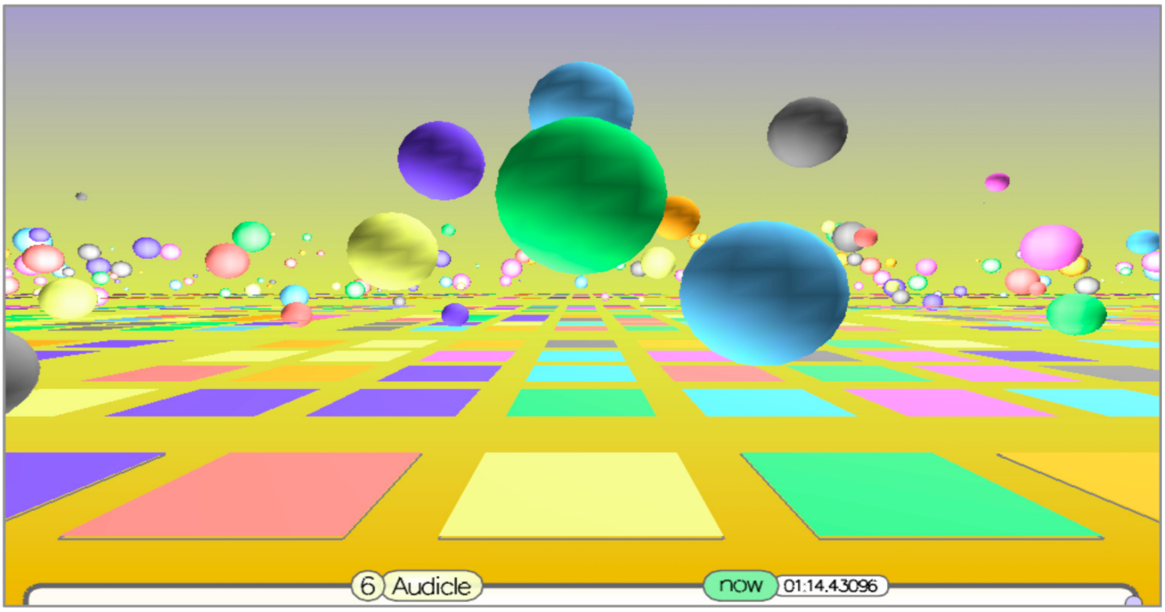

Figure 10. In *Audicle*, multiple bouncing spheres are controlled by players in this graphical interface.

The selection of music associated with a cell is quite arbitrary; however, it is typically a note, a short phrase, or a sound sample. These sounds may combine (when multiple paths are played simultaneously), layer up and accumulate to make surprisingly complex resultant music. *Tempi* are generally adjustable for all systems. Sound palettes for some hardware devices may be non-existent, if they only act as controllers (as in the *Monome)*, be simple (particularly in self-contained systems such as the *Tenori-on*), or may connect to the vast array of software synthesis plug-ins available presently. The audio spatialisation capacities of systems are dependent on the device itself, in addition to the capabilities of the software synthesizers and audio hardware employed (most GMSs don't provide for spatialised sound beyond stereo). Many systems provide MIDI outputs to the users' choice of MIDI-devices. The software systems are much more flexible, and the most extensive ones run software synthesizers and may connect to music applications such as *Ableton Live*.

3.1.7 Grid cells

Locations on the grid matrix are termed cells in the language of mathematics and computer science. However, in relation to the *HarmonyGrid*, they are graphical squares and shall be referred to as squares. In the case of many portable devices, grid cells may simply be “on” or “off”, where a button or square is lit or not. Informationally, this forms a two-dimensional matrix of binary data. Alternatively, cells may store and display more data, such as a number or letter name or colour. Grid cells may be set up as a simple array of one parameter (e.g. pitches) or relate to each other in quite complex mathematical ways, as with the “neighbour relations” between cells in cellular automata (see Section 3.2.4). Either way they form a knowledge-space or matrix, relating similar items. Simple musical grids may assign discrete pitches to the cells, though informationally this can work better in hexagonal arrays using a harmonic table as in an accordion-style layout. For examples of these, see the *ReacTogon* (Figure 11), the *Terpstra Keyboard* (Horvath and Terpstra n.d), the *Axis-49* USB music interface (C-Thru Music 2009) or the *Elysium* generative sequencer (Mower, 2008).

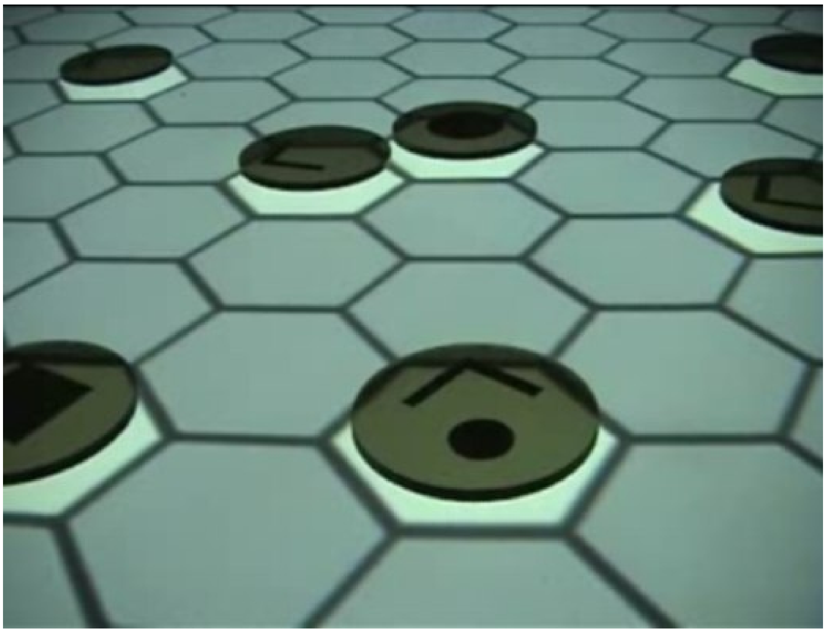

Figure 11 Close-up of the hexagonal layout of the *ReacTogon* and its buttons to activate paths.

In certain modes (modes of operation are discussed in Section 3.1.9), GMSs can operate like a spatially triggered sampler, fairly akin to the samplers with a matrix of touchpads, like the Akai MPC series originating in the mid 1980s (see Figure 12).

Figure 12. The Akai Professional MPD16 pad controller may operate samples, a sound module, or a sequencer.

All systems provide for several layouts of the cells and their functions, including typical step-sequencer layout and arpeggiator functions; and some are highly programmable (see the *JazzMutant Lemur* in Section 3.2.3).

In the language of finite state machines, a transition is the change from one state to another, where a state is the configuration of data in the machine at a particular moment. On a grid, a state transition may occur when just one cell changes its colour, or is lit up, or when many cells change simultaneously.

3.1.8 Paths

Paths are created by moving between cells on the grid, and may be rendered visible or displayed by the system. Where a path is set to be recorded, it is generally lit up and displayed as it is created. Recording a path occurs over time, as does replaying one, but displaying a recorded path may be instantaneous. Paths are sometimes said to be "tracked", for example with *KAOSSPAD* and *Reactable.* Musically, they may represent a sequence of pitches, or some other musical parameter. A typical sequence of pitches can be looped, which lends itself to various minimal or popular musical styles. Importantly, looped paths of other parameters are possible as are, in some systems, multiple concurrent loops of different paths or parameters. The creation of loops has led to a new generation of music-making machines dedicated to just this function in recent decades.

In the abstract, paths can store and represent data in the manner of directed graphs, with their vertices or nodes, and connecting edges or arrows. In this terminology, the graphs are connected (by a path) and directed (having a specific direction), and are cyclic. In implementation, the path data is simply stored as an array of numbers representing grid cells. Multiple paths can commence from different starting positions, and storage of all the data must in this case include the start or offset positions.

In some systems paths may be scaled, and used for many different parameters. Xenakis, for example, applied this technique to the *UPIC* system (Timmerman n.d.). A path may represent a small data set, such as a tone-row, that can be used to generate multiple timescales (simultaneously if desired) and patterns, which may start and stop at varying times.

By creating, replaying and layering paths, the system may generate quite complex results, and can be flexible in its methods. Even given the small data sets and huge constraints of GMSs, these ways of storing and replaying paths can be shown to generate sophisticated outcomes. They contain extensive musical potential which can be demonstrated in performance or recording.

3.1.9 Modes of operation

GMSs typically operate in a variety of "modes" or layouts. By way of example, the *Tenori-On* operates in several modes. "Bounce Mode" has distance mapped vertically and pitch horizontally, and when a button is pushed, the display represents a lighted ball that "drops" to the bottom of the screen and "bounces" off it, sounding a pitch as it does so. Many such balls may be triggered, or a whole row of them. "Draw Mode" maps pitch vertically, with any path across the two-dimensional screen playing a "clocked" plot or path that occurs over time. "Score Mode" similarly maps pitch vertically, but paths progress horizontally across the screen in sequencer style. In "Random Mode" pitch is again mapped vertically, but buttons may be pushed leaving lighted spots that form the vertices of a path for a moving spot that "bounces" between the spots, sounding their assigned pitches. The entire construct can be rotated. "Push Mode" has pitch mapped horizontally, and notes are made to sound by pushing for several seconds on buttons, which then pulse with lights. "Solo Mode" maps pitch horizontally, and for any button pushed, plays a continuous sound with a vertical series of lights. Pushing buttons anywhere on the vertical series changes the frequency of pulsing or looping of the sound.

By way of comparison, the *Bubblegum Sequencer* (see Figure 5), basically only operates in step-sequencer mode, with pitch mapped vertically and time horizontally from left to right, as in a conventional score. Its 4x16 grid provides four voices vertically and sixteen semiquaver pulses horizontally. There is a "Melody mode" that allows for some pitching, using various combinations of four balls vertically to select a pitch for each horizontal location.

The commonality with all these modes is that a pulsed or “clocked” location (or many locations) may be triggered, and that paths may occur over the two-dimensional grid that are a clocked sequence of temporal and sonic events. Some modes restrict the paths horizontally or vertically, such as the *Tenori-On*'s “Bounce Mode”. The *HarmonyGrid* uses the same movement and path modes for each grid layout. It too uses a pulsed sequence of locations as per above. The modes in this system exist in the musical topology, or layout of the musical parameters (to be described in detail in Chapter 5).

A particularly relevant subset of GMSs for this study are those systems providing grids of harmonies. Holland's *Harmony Space* and Levitt's *Harmony Grid* relate directly to the *HarmonyGrid*, in that harmonic schemes may be placed in the grids, graphically displayed as such (at least by letter name), and function as harmony discovery, improvisation and composition tools. These will be discussed at length in Sections 4.3.3, 4.4.3 and 6.3.1.

A related issue to modes of operation is the degree of automation, and timing of programmed instructions and events occurring in the system. As with music sequencers and other interactive systems, once a sequence (or path in this case) is recorded or programmed, the system can be set to run that sequence. The sequence may or may not be recorded in real time, depending on the system architecture, and may or not be recorded whilst other events are ongoing. Systems vary in their input options, and in the degree to which events may be altered whilst running. This partly determines the degree of interactivity provided by the system. In terms of digital logic, GMSs operate as synchronous systems: that is, events are “clocked” or scheduled to the central timing unit (the software has a metronome module). As with most GMSs, once the *HarmonyGrid* is running and a recorded path is playing, only some functions are immediately accessible, such as instrument selection and volume levels, whilst other functions must operate with the clock, such as playback of paths (Section 3.2.4 also refers to these issues). The scheduling of CPU resources also partially determines what is available almost instantly.

3.2 Other Systems

Other systems that use some functions of the GMSs explored previously, whilst demonstrating other methods for music-making, including block systems, the software system *M*, touchpad and touchscreen systems, and “light table” systems. By discussing a range of these related systems, including CA at the furtherest end of the range, this section provides further contextual background for the discussion of GMSs.

3.2.1 Block Systems

Block Systems have parallels to grid systems. These systems use custom-made cubic blocks, somewhat like children's building blocks, that maybe placed next to each other to make paths, as in dominoes, or they may be stacked vertically as well.

Figure 13. Blocks may be placed together to form paths in *BlockJam*.

In common with grid systems, they may effectively use square grid layouts, allow for construction of paths, and typically use several types of blocks to differentiate path directions or musical outputs. These systems may be quite sophisticated, as in *BlockJam* (Newton-Dunn et al. 2002), *Percussa Audiocubes* (Schiett 2009), *Siftables* (Merrill et al. 2007), and the *Tangible Sequencer* (Bernstein 2007). With the *Tangible Sequencer,* for example, blocks communicate with each by radio, and to a hub block, which connects via USB to a computer running software that supports drag-and-drop STK[15] sounds. Paths are made by the arrangement of blocks and placement of special path-directing blocks. *BlockJam* (Figure 13) provides switches and LED displays on each block, with the provision on some blocks to select sounds by a dialling action. Sound is outputted via an external system rather than from the blocks themselves.

Taking the block system further with its own programmable physical environment, the *Reactable* (Jorda et al. 2006) consists of a back-projected table with movable block markers that are detected by a camera underneath. Although this system is in some ways beyond the scope of this investigation (because the topology is no longer grid-like with the blocks forming a loose network), the *Reactable* is interesting as it is designed for controlling sound synthesis, with some aspects of sequencing—rather than a looped-sequence approach to music-making. The *Reactable's* extensive custom-made system uses a projector and camera (as does the *HarmonyGrid*). An exciting advance in the interface is provided by the touchable graphical fiducial markers that appear underneath the blocks to allow the computer to distinguish one from another. Similarly the *MorphTable* (Brown et al. 2007) uses blocks encoded with fiducial designs, which are read by a camera and software. These blocks can be freely moved around on the table for music-making.

Figure14. The *Reactable.*

15 The Synthesis ToolKit in C++ (STK) ©1995-2009 Perry R. Cook and Gary P. Scavone.

3.2.2 *M.*

M (Figure 15), the “Intelligent Composing and Performing System” from *Cycling '74*, is a music-making program from the mid 1980s. *M* allows interactive composition:

> where you shape the music as you hear it unfold … Instead of merely playing back what you've already composed, M becomes a part of the actual process of composition … You can control your music by clicking and dragging the mouse on the computer screen, by "conducting" in a Conducting Grid, by pressing keys on your computer keyboard, or by playing specific notes on your MIDI keyboard … in the Conducting Grid; you can start and stop the music, change the tempo, and do lots of other things … (Cycling '74 2009).

It uses a grid system for cycling around pitch, rhythm, dynamics, and other parameters independently of one another. This capacity shows *M* as a forerunner to the *HarmonyGrid.* Unlike the majority of music systems, where musical parameter data is tied to the note data, *M* and the *HarmonyGrid* allow independent access to the other musical parameters, so that, for example, a phrase of volume levels may be constructed before any note data is recorded.

The Patterns window contains the Patterns, which are collections of notes (like a pitch class) that may be transformed in any way. “A Voice in M is a "path" through the program that begins with a Pattern.” (Cycling '74 2009).

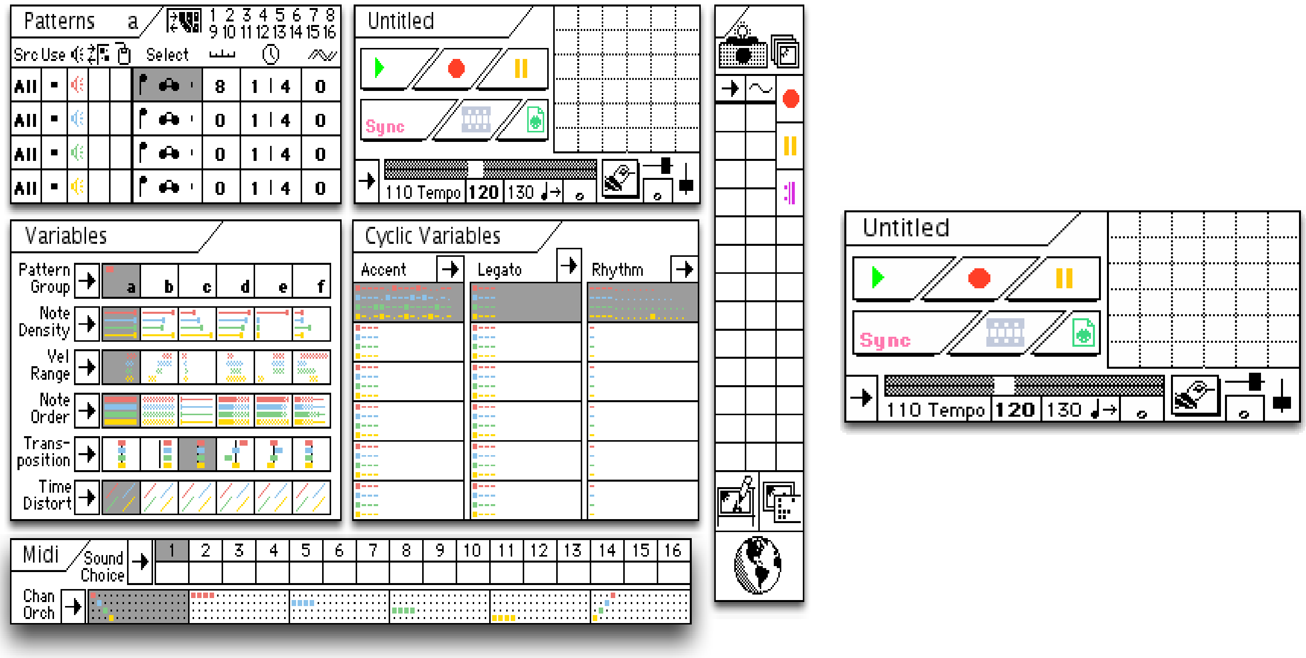

Figure 15. Screenshot of *M* music program, and (right) the conducting grid.

3.2.3 Touchpad and touchscreen systems

Several other systems need mentioning to provide further context for grid systems, although a detailed analysis and comparison of these is beyond the scope of this study. Touchscreen systems are currently on the increase, especially with consumer products such as Apple's *iPhone* with its burgeoning range of music applications.[16] Korg's *KAOSSPAD* provides XY touchscreen primarily for control of audio effects, in addition to being a MIDI controller and sampler. The latest version, the *KP3* (Figure 16), often displays a grid of squares but the control is continuous across the pad, so it is not a true GMS.

Figure 16. Korg's *KAOSSPAD* KP3.

16 Currently, in early 2010.

The *JazzMutant Lemur* is a large touchscreen interface with a multi-touch control surface, that can integrate with the users' choice of computer programs. Several interface options have been of the GMS variety, as shown in Figure 17, while other interface options have emulated current dial and rotary control displays.

Figure 17. The *JazzMutant Lemur.*

Aside from touchpads and touchscreens there have been many other surfaces developed to create music, or control it. AudioMulch's Metasurface (Bencina 2005) uses a Voronoi/Delaunay mesh structure typically to play sounds or parts of a composition. With this structure the geometry may be user-defined.

3.2.4 Cellular Automata

Cellular Automata have some similarities to grid systems. They are of interest here particularly because of the abstract nature of the representations, relations between cells, and the degree to which this abstractness is extended.

Although often formed of a grid of cells (two-dimensional CA), they can be arranged in matrices of other dimensions. All cells are potentially equally active. What is important is the relationship between cells, determined at the outset by a relational rule. CAs may exist purely as mathematical abstractions, but more commonly run as computer programs with graphical outputs, typically a grid of colour squares, where the colours represent the *states* of the cells. Each state change is an event (in time), where any number of cells may change as a result of rules about their relations to other (typically adjacent) cells; in each time step the next state for all cells is calculated (effectively) at once. A succession of states occur over time and the state transitions may be "free-running" (i.e. occurring as quick as they are able) or "clocked" to a pulse, similar to the tempo clock or metronome controlling music applications. Once they are set up or configured, CAs start running and no further input is required. No paths are constructed, rather the system runs as an entirety. And, despite their visual similarity to GMSs, CAs also differ from music grids in that there is an emphasis on cell-neighbour relations, which may be of some mathematical complexity. This indicates the vast range of possibilities for modes of interaction between cells resulting in complex behaviour, but not behaviour that has any inherent musical structure.

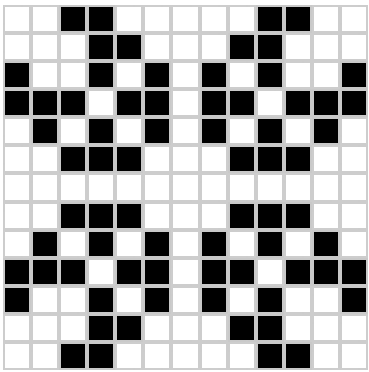

Figure18. Conway's *Game of Life* (1970) is the best known cellular automaton.

Stephen Wolfram's *Wolfram Tones* (Figure 19) is a musical CA. Functioning as a music-generating program, the system uses a rectangular CA, operating in sequencer mode as described above, with time as the x-axis. However, here the active cells have been determined by the CA maths, rather than by musical input or path construction. The system is only interactive in that the CA must be set up at the outset—seeded for an initial state, and the rules selected—prior to running it.

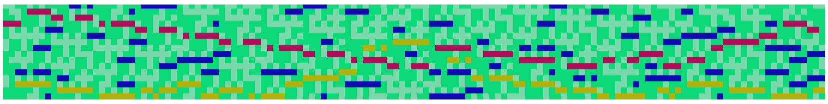

Figure 19. Example of the *WolframTones* generated by the CA on Wolfram's website.

Music grids use the grid to provide spatialised paths, which may intersect at specific points, and have similarities with network topologies. The spatialised paths allow for "clocked" musical and graphical events to occur over time. The topologies become a network operating over time, a sort of graphical score, which may remain fixed, change or evolve slowly over time, or be very active (and interactive).[17] *Nodal* uses the grid dimensions to precisely measure timings of events. For example, a simple square path of four nodes (on the corners), may be set up, to "play" as four crotchets in common time, and subsequent placement of nodes between the others will provide exact subdivision timings. Most other systems provide for rhythm as a sequence of timed events, where the active path runs over active and inactive cells, thereby triggering or not triggering sounds in a pulsed sequence. Many operate in "step-sequencer mode" where the x-axis is time; and the y-axis is pitch, or a range of tracks with sound events; and a pulse runs across the grid activating column by column. The resultant rhythm is quantised to some minimum rhythmic value, often semi-quavers.

Other hybrid systems of items mentioned above are regularly appearing. *Max for Live* combines *Max-MSP* with *Ableton Live* (Ableton - Max for Live 1999-2010). It has a step-sequencer module built-in, which, when connected to an Akai APC40 Ableton Performance Controller, shows the step sequencer operating on the 5x8 grid of buttons. These controllers have developed from a line of samplers that provided a grid of buttons to trigger samples. Native Instruments' *Maschine* is a hardware-

17 There is some breakdown of the network analogy, when we consider that time is generally taken to be one-dimensional, moving forward.

software combination, with a similar 4x4 grid of buttons, that is a new combination of groove-box and sampler. New highly-programmable grid controllers are coming out every month,[18] including Snyderphonics' *Manta,* the Novation *Launchpad* and Livid's *Ohm64.*

Graphical design of the grids could incorporate the use of game rules to traverse the grid or paths and it has been an interest of mine to explore this. Rules could be used to generate graphical paths, as in Lindenmayer systems,[19] which may then produce musical events. Of course, rules are used to generate music in many systems such as algorithmic music, but here the path topologies would determine events over time. Burraston (2007-08) covers the topic in detail, particularly in relation to cellular automata.

3.3 Movements, visuals and gameplay

In this section, topics associated with the use of, and performance with, GMSs are discussed. A discussion of movement as it relates to making music with GMSs, proceeds to a description of motion tracking technology applied to interactive systems. The topic of visuals is introduced via the projection technology applied to interactive systems. The final topic, gameplay, describes the types of interactions and motivations that locate GMSs somewhere between performance systems, systems for general music use, and game machines.

3.3.1 Movements

Almost everyone knows the pleasure experienced in movement or dancing to a rhythm, even if it's only tapping a foot. Many people know the pleasure gained in moving or dancing in patterns, as experienced by marchers or folk dancers. There is also a pleasure in watching rhythmic movement, with or without accompanying music, and in watching patterns of movement, group patterns and changing patterns. We can enjoy symmetry, precision and other aesthetics in movements. Specific

18 In late 2009.

19 Lindenmayer systems use rules such as (A → AB) recursively to layer up a graphical structure, e.g. plants.

movements associated with accompanying music can be learned and upon repetition become enjoyable. An example would be stepping forward when a loud chorus reoccurs, associating the forward step with an increase in volume. These considerations will used to clarify the use of a human-scale GMS in Section 6.6.3.

The relationship between music and movement is a large subject, beginning with the physics of soundwaves, and includes the movements of musicians and conductors, dancers and appreciators. Alexander Jensenius began his PhD thesis by stating that "music is movement" (2008, 1). He explained that "we create music by moving, and we perceive music while moving. In fact, body movement seems to be an integral part of both performance and perception of music." Jensenius breaks down what he calls "music-related movement" into sound-producing movement, sound-coordinating movement, and sound-accompanying movement; carried out by, for example, musicians, conductors, dancers respectively. Operating a GMS would include indirect sound-producing movements and sound-coordinating movements. Musicians' movements are further categorised as "sound-producing, ancillary, sound-accompanying and communicative" (2008, 43). Ancillary movements are not directly involved in sound production and include supporting actions (such as using pedals), phrasing and entrained movements (which include tapping a foot, nodding the head). Sound-accompanying movement includes actions such as tracing the movement or flow of music with a finger or hand, or dancing.

Another division of music-related movement includes the movement of performers and that of perceivers (Jensenius 2008, 43), acknowledging that any musician not playing solo will be listening and responding to the accompanying music (which is the case with the *HarmonyGrid*), and so is a perceiver as well.

Jensenius ends his thesis with the statement:

> "I am particularly interested in exploring how movements may be used to generate and control musical sound in new ways. This may lead to music systems where the musical sound is continuously adapting to the listener's

preferences, based on the movements of the listener. That way music-related movement may be used to generate body-controlled musical sound, which brings me back to the opening of the dissertation: music is movement." (2008, 232)

In performing with the *HarmonyGrid,* the musical sound may be continuously adapting to the performer's (who is also a listener) preferences, based on his or her movements. The *HarmonyGrid* is particularly suited as a mechanism to explore Jensenius's inclinations.

3.3.1.1 Motion tracking

Motion tracking is a process of detecting and/or recording movement of markers attached to points on the body (see Section 3.1.4) and translating that movement into a format that a machine or computer can use. Motion tracking and motion capture are used in many fields including military, medical, film-making and installations. In film-making an actor's body movement may be recorded through motion tracking and later used to animate a digital character in a process termed "performance animation" by Callesen and Nilesen (2004). The degree of complexity in motion tracking ranges from a single marker (e.g., a light or an infra-red emitter) being tracked on a body, up to full limb movements, gestures and even facial movements being tracked and/or recorded. The resultant data may be used immediately, as with real time systems, or later extensively processed, as for film.

Several examples illustrate the uses of motion tracking in real time systems. Berlin-based group Picamotics in a collaboration called "The SPECIAL PLAYER", stage contemporary dancers within a highly responsive motion tracking environment, using a "secret motion analysis algorithm" to project a "Digital Aura" over and behind the dancers (The Special Player 2008). High-speed infra-red cameras detect movement in a modular network of cells covering the floor space. Individual dancers are identified by the system, and audience members may join and be similarly identified.

Similar to the above system, *Baltan Tracker* (motion tracking << Baltan Laboratories 2009) also uses infra-red cameras overhead to track participants on a floor, and then projects computer graphics on a rear wall. It appears that most installation systems use projection on a wall rather than the floor, with the exception of some commercial interactive projection systems (see Section 3.3.2 for examples).

The *GAMS* system was evolved from the *GASP* system used by interaction pioneer David Rokeby and his *Very Nervous System* (1986, 1990). *GAMS* uses ultrasonic frequencies to detect a user in a small three-dimensional space. Thus a performer may play musical notes that have been programmed into the space, by moving his/her hands through the zone. Users carry the tracking devices, of which one controls melody and the other drums, media and effects. A light show is also triggered, directed at the floor. Gibson and Grigar used this technology to stage a networked performance in 2005 entitled "Virtual DJ" (Grigar and Gibson n.d.), using a networked three-dimensional grid: "Gibson leads the drum and bass and moves around the room, while Grigar leads the melody tracker. They dance in tandem with the ghostly remote presence of moving sounds and lights" (BC.NET 2005).

3.3.2 Projection

Many installation systems that use motion tracking project the images onto a wall or vertical screen. Comparisons with other non-musical media reveal a range of similar practices. Several recent commercial designs incorporate similar concepts, including *Adfloor* which uses projections for marketing in public spaces by placing screens on floors, windows and tables: "This exciting interactive projection system uses optimised motion detection to change the underfoot display in real time as you walk, run or dance over it" (Projection Advertising n.d.). The graphics are seemingly animated by contact, usually screening a product advertisement beneath, or revealed by, the motion graphics. Motion-Activated Interactive Displays (emc outdoor 2005-9) have a floor display where a participant may "kick" golf balls into a (projected) hole. Fogscreen has a projection one can walk through, made of "dry" fog (CyberTheatre 2008). GoGorilla (2007) used Adobe's *Creative Suite 3* to make an motion-activated window projection in New York, where passers-by are tracked and trigger graphics that seem to “follow” them. The commercial world is wakening to the possibilities of interactive systems placed on public display.

3.3.3 Gameplay

Usage, exploration and performance with GMSs is an activity that lies in a region overlapped by those of performance, music, exploration and play, including gameplay. Roger Caillois (1967) defined the theoretical game categories of “ludus” and “paidea”, where ludus is the more usual gameplay with its rules and outcomes (e.g. winning or losing) and paidea is where activity in the gameworld is purely for pleasure, with no obvious outcomes (e.g. just flying around in a flight simulator, or in playing *The Sims*) (Newman 2004). Usage of a GMS leans towards paidea, that form that is not goal-oriented and designed more for the pleasurable experience of it. Some aspects of ludus are apparent, where activity is structured by the rules and constraints of the system. However, there is no goal or ending, win or lose, or scoring in a GMS such as the *HarmonyGrid*.

The area of interactive art forms crossing over with games is underdeveloped, but on the increase. On the entertainment side, computer games such as *Cloud* (USC 2005) approach art by strongly favouring an aesthetic experience, a form of paidea. On the interactive side, Troy Innocent's *Semiomorph 2001* (Innocent 2005), for example, utilises a game-world and all its trappings— joystick etc.—for artistic purposes.

3.4 Placing GMSs within the field

GMSs are a subset of interactive systems used for entertainment, art and research by consumers, developers and researchers. Interactive systems, briefly introduced in Section 1.2.2, allow for interaction with a computing system by a user or users that facilitates real time output via multimedia systems.

Interactive music systems developed from electronic musical instruments and computers. The earliest forms of computer music in the 1960s were not interactive (Winkler 1998, 10); however development of sensor inputs, computing power, software techniques and multimedia outputs over the following decades facilitated building interactive music systems. By 1993, Rowe, in his book *Interactive music systems,* classifies interactive systems on one level into score-driven and performance-driven (with no determined output), and compositionally into transformative methods, generative algorithms, and sequenced techniques. In a third classification he describes an instrument paradigm, where the system is a kind of extended instrument, and a player paradigm similar to an artificial player (Rowe 1993, 7-8). Rowe further differentiates three stages in the processing chain of these systems, namely, the sensing and reading of gestural information from human input, the processing of data, and the response where the computer and sound devices sound the musical result. The input is mediated through MIDI equipment, custom controllers, and the output utilises sound modules and samplers. Rowe traces the genesis of using gestural control of an electronic instrument to Lev Termen's *Theremin* prototype of 1919. Termen referred to playing in space whilst not touching the instrument as "space-control performance".

Winkler in his 1998 book *Composing interactive music*, ties an interactive system to a performer's input: "Broadly speaking, interactive music works by having a computer interpret a performer's actions in order to alter musical parameters, such as tempo, rhythm, or orchestration" (Winkler 1998, 6).

The development of interactive systems has benefited from that of intelligent systems, which are computer or electronic systems that use AI to learn, or at least to process, their environment, in order to function intelligently and act or perform some task in the real world. However, intelligent systems generally do not operate using real time human input, or output results via multimedia systems. For example, many intelligent systems may be used as computer programs to run engineering applications. Perhaps an example that overlaps with interactive systems would be a Japanese toy or domestic robot which allows for human input, and produces outputs in the visual, physical, and auditory domains.

Camurri and Ferrentino define "Multimodal Environments" (MEs), as systems “capable of establishing creative, multimodal user interaction by exhibiting real time adaptive behaviour.” (Camurri and Ferrentino 1999, 32). They describe such a system as having one or more users immersed in the environment, and able to communicate by bodily movements and singing or playing. The system provides feedback, via music and graphics for instance, to the user/performer. They further describe MEs “as an extension of augmented reality environments integrating intelligent features” (1999, 33), where augmented reality combines real world with computer generated graphical and/or video data. In the 1999 article, they divided MEs into two categories of virtual environments, and hyper-instruments[20] that provide sonic feedback, and criticised virtual environments for being simple real time cause-and-effect mechanisms. By 2004, Camurri and his colleagues were writing of the analysis of expressive gesture leading to modelling expressive interfaces as the way forward in ME design (Camurri, Marrarino and Volpe 2004).

3.5 Summary

This chapter has laid out the nuts and bolts of GMSs as the central technological solution to spatialised music-making, and has compared the more typical systems with a range of other systems. Overall, the use of time and spatial domains are accessed and facilitated via these devices, which then connect to the artistic domains of music, graphics, animation, and to human performance via movement, gesture and staging.

On an ending note, it bears mentioning that, although this chapter has been presented in a technical style, largely taking an engineering perspective (as does the first half of Chapter 5 specifying the design of the *HarmonyGrid*), the latter half of this exegesis increasingly incorporates the performance perspective, taking music and space as its main orientations.

20 “‘Hyper-instruments’ are large scale musical systems which enable the control of complex musical events by a performer” (Anderson, 1994, 1).

Chapter 4. Space, and Music in Space

Chapter 3 discussed GMSs in detail, and how they facilitate constructing, composing, improvising and music-making in space. GMSs provide grids that necessarily occupy the physical dimensions of space, and arrange their musical access and representation spatially. In short, both input and output of these systems are mediated via space. The present chapter covers a broad range of historical, scientific, psychological and abstractly constructed versions, perceptions and understandings of space, chiefly relating to how music and sound may exist and be perceived in space. These considerations lead to a discussion of the production, presentation and experience of music in space.

Previous discussions in the literature on space have explored the issues independently, but few writers have attempted to tie together the musical, experiential and technical domains. Previous discussions have revolved around mathematical and engineering perspectives, psychological perception and cognition, perspectives on pitch relations and harmonies in abstract space, some compositional placement of music in space; however much of the music-related efforts have come from audio engineers, and have been largely concerned with recording and reproducing sound and music spatially.

This chapter sets out by discussing general concepts and perception of music and space (largely in Western culture), and then considers various concepts of musical spaces, such as soundscape and acoustic space, followed by more traditional perspectives. The next section presents structured spaces for music and sound including virtual spaces, followed by a discussion on the more abstract theories of music representative space. Following these theoretical spaces the discussion moves toward experiential music space, and presents my concept of music-space. The final section briefly considers the combining of music representative space with music-space. At various stages the *HarmonyGrid* is discussed in context, and is compared with other systems.

An aim of this discussion is to show how various internal representations of space, involving musical perception and conceptions and termed 'music representative space' in this exegesis, can coexist with music-space, a new definition of experiential, concomitant music and space, and can provide for a multi-modal complete musical-spatial experience in music-making and performance. The research has explored how a music system can, and ideally would, provide such a capability. The chapter describes these spaces, in relation to the key concerns of the exegesis (Section 1.6). More specifically, the chapter provides a theoretic basis for the claims of originality of the *HarmonyGrid*: that it facilitates the musician moving in the space which he or she makes (or *produces*), that it provides a partially immersive environment—spatially, sonically and musically—and that it allows for the combining of music representative space with music-space. Additionally in Section 1.6.1 I raised issues relating to spatial access and arrangement of musical parameters and their embedded knowledge; and including the composition, facilitation, performance and experience of music in space. The insights and understanding gained from this chapter will be used in Chapters 6 and 7 to address the research questions relating to the design of a spatial presentation, facilitating immersion in a GMS, and how a musician may spatially engage with a system.

4.1 Concepts and perception of music and space

4.1.1 Concepts and Perception of space

There have been many concepts and perceptions about space (meaning the spatial dimension, rather than outer space) discussed and presented during the last four or five centuries of Western culture. These discussions concern what space is, how we perceive it, how we operate in it, and how we may construct it, and have included consideration of space and artistic expression.

From Newton onward through several centuries, there have been two fundamental philosophical and scientific viewpoints on space: firstly that it is a given, *a priori* (knowledge independent of experience) and that it exists more or less as we think we perceive it; or secondly that it is a relational construct of the mind constructed to deal with the everyday world of objects. Philosophers (including Leibniz, Descartes and Kant), mathematicians and physicists have added to our concepts about space, including multi-dimensionality, space-time, and curved space (for example Gauss, Poincaré, and Einstein), but these bear limited relationship to our everyday experience (Jammer 1993). Psychologists, neuropsychologists and physiologists have examined the perception and cognition of space from fairly limited viewpoints (Møller 2003). Phenomenologists including Foucalt, Deleuze and Guattari (Casey 1997; Merleau-Ponty 2002), sociologists and geographers have described cultural associations of space (Bonnemaison 2005). Religions, particularly the East Asian (e.g. Zen Buddhism in Raud 2004), have described space itself and experiences with it. For the present, this study will consider the more everyday perception, cognition and experience of space, for a person (or performer) moving on a horizontal surface or floor, usually inside a building. Aside from physical space, other concepts and experiences of space to be considered include the psychological, emotional, visual, aural, conceptual (Idea space), and that of place (Worrall 2003).[21]

4.1.1.1 Space perception

We normally conceive of space as bounded by the three dimensions of length, width and height. This can be re-specified, in reference to a perceiver, as azimuth or flat plane radial location, elevation or height, and distance or nearness (Worrall 2003). Visual perception of space is a central component of space perception, and is aided by auditory, kinaesthetic, olfactory, and gustatory perceptions. In addition, the sense of balance (vestibular sense), and other modes of sensing body orientation (proprioception), provide further spatial cues. However, visual perception and, to a lesser degree, sense of balance provide the bulk of the information in lighted conditions. In the dark, other senses come to the fore, primarily touch and the auditory sense (Alais and Burr 2004). To an extent, the more modes that are operational the better the space perception is, and ordinarily we rely on this combined effect (known as inter-modal perception). Auditory perception is called a "distance sense" like vision, but is a significantly weaker one in gauging distances,

21 The notion of place is deemed beyond the range of the present discussion.

especially at longer distances. However auditory perception comes into its own at the periphery of vision, where other visual components such as colour are “filled in” by the brain, even for close distances (Troncoso, Macknik and Martinez-Conde 2008).

For visual perception of space, James J. Gibson proposed his “ground theory” as distinct from the conventional view where the perception of objects is paramount: "the spatial character of the visual world is defined not by objects but by information contained in the ground upon which these objects rest" (Goldstein 1981, 191). In particular, Gibson considers texture gradients to provide superior visual information as opposed to normal depth cues; where "constancy of texture helps define the scale of space, since equal amounts of texture represent equal amounts of terrain” (Gibson 1979, 83). Furthermore, regularity in a texture as in a pattern provides "a regular and lawful event which leaves certain properties of the pattern invariant". Gibson claimed that 'invariant' information is processed immediately by the visual system, and especially while the subject is moving around. “Invariants” include straight lines, and the unchanging relations among four angles in a rectangle (1979, 72). Therefore, according to Gibson's ideas, the use of a grid as ground will reduce visual processing because constancy of perception is aided by the invariant texture.

Dennis Smalley, a theorist on musical spaces, considers that “most listeners cannot easily appreciate space as an experience in itself” (1997, 122). However, auditory cues can aid visual perception to a significant extent in perceiving and understanding space, and it seems that auditory and spatial perception are more intimately linked than previously thought. The auditory system of a human foetus is already developed at six months:

> It is also important to notice that the first consciousness of space is given by sound. The child doesn’t see but hears the voice of the mother high or low in her body... and the sounds or noises in various locations coming from internal or external surroundings. This sense of space is important for the child to position itself in the right way, head down, in preparation for the moment of birth. (Reznikoff 2004-05, sec 2.4)

Auditory cues aid visual perception by aural detection and location of objects and surfaces, but also by their reverberation qualities. This is the most commonly discussed sense of aural perception and space, calling on the science of acoustics. Reznikoff makes the historical case that paleolithic man, moving in caves without torches, used resonances of the caves to sense their way in the dark, by vocalising noises. He states this “demonstrates the main importance of sound in discovering space and in proceeding through it” (2004-05, sec 2.5).

4.1.1.2 Space and time

Several thinkers find it impossible to separate space and time. Since the early 20th century, we have become used to the concept of space-time, which folds space and time together in a single continuum, with space occupying the first three dimensions and time the fourth.

Trochimczyk supports this view saying “space may be experienced only in time, and time only in space” (2001, 1). Therefore, in her view, the perception of time must accompany or overlay the perception of space. She continues:

> It is important to note that music drawing the space of performance into the realm of meaningful elements, that is, 'spatial or spatialised music,' is really 'spatio-temporal' and not 'spatial'. The categories of spatialisation may seem to belong outside of time, but their realization is always temporal. (2001, 1)

This is akin to saying music *produces* space, after the manner of Lefebvre (see Section 4.4.1.1). Furthermore, she imbues sound with spatial attributes: “'Space' in music is neither empty, nor absolute, nor homogeneous; it is revealed through the spatial attributes of sound matter” (2001, 1). It seems that space is structured by sound.

Some thinkers regard both space and time as somewhat illusory, in line with the second viewpoint from the beginning of this chapter that space is a relational construct of the mind. Kant is of the view that "space is an inadequate form of sense-knowledge, because it is divorced from the pure objective form of geometric intuition (i.e., pure reason)" (Kant in Rawes 2008, 2). This is of interest when we consider virtual spaces later in the chapter, although the experience of them must proceed through time. A further discussion of Kant ensues in Section 4.3.1.

4.1.2 Concepts of sound and music

Music exists in space, through time. It could be said to occupy and operate in space. We may then manage, sculpt or manipulate it. The atmosphere in space carries the fluctuating densities of sound waves to the ear so we can experience hearing music. We will ignore the case of headphone or earphone listening, as very little space is involved, except the virtual aural space which simulates sound coming from loudspeakers. We will mostly consider music, as opposed to pure sound or soundscape made of non-conventionally-musical sounds, and will discuss the experience of music made of tones, harmonies, timbres and rhythms.

Different cultures have varying conceptions of space and sound. Edmund Carpenter speaks of the Aivilik Eskimo's sense of space as acoustic:

> Auditory space has no favoured focus. It's a sphere without fixed boundaries, space made by the thing itself, not space containing the thing. It is not pictorial space, boxed-in, but dynamic, always in flux, creating its own dimensions moment by moment. It has no fixed boundaries; it is indifferent to background. The eye focuses, pinpoints, abstracts, locating each object in physical space, against a background; the ear, however, favours sound from any direction. (Schafer 1993, 157-8)

Once again, it appears that sound produces space, and structures it.

4.1.3 Musical spaces: soundscape, acoustic space, and other spaces

There are, and have been, various formulations and conceptions of musical space over the centuries. One way to categorise these conceptions is to draw a distinction between externalised space, experienced as coming from the external or outside the body, and internalised space. This division is reflected in the methodology in Chapter 2 where the creative journey could be defined by three categories of space: external space, virtual space, and combined external and virtual space. Some recent conceptions of musical spaces that are located in externalised space include those of soundscape, acoustic space, aural architecture and acoustemology.

R. Murray Schafer defines soundscape simply as “the sonic environment ... The term may refer to actual environments, or to abstract constructions such as musical compositions and tape montages, particularly when considered as an environment” (1977, 274-5). This concept presumably covers any environment that is heard. The space will be defined and experienced by the listener as that sonic environment, its objects and particular characteristics. Schafer extends the concept of objects by “formulating the concept of the soundscape as a mixture of aural architecture and sound sources” (Schafer in Blesser and Salter 2006, 6). Aural architecture is discussed in Section 4.2.1.

Blesser and Salter consider music as a component of a soundscape. They claim that “Whereas traditional music is the art of creating sound from instruments, soundscape music is the art of the aural environment. It is a shift in emphasis, from space as the container of the art, to space as the art of the container” (2006, 177). Components of a soundscape can include natural and artificial sounds including musical sounds which may, for example, emanate from instruments or from loudspeakers distributed around an environment. Soundscapes can be created quite artificially in buildings, as part of the architecture or as an installation. These kinds of soundscapes are conceptually different from the kinds of geometrically organised sound output from centralised sources, such as musical ensembles (e.g. a choir or a band). The structural organisation of soundscapes tends to be much looser, less geometric; it may be over a bigger area, more random, and may be designed for experiencing while moving around or through it, rather than being stationary.

Acoustic space is a localised part of a soundscape around sounding objects. Schafer says “The acoustic space of a sounding object is that volume of space in which the sound can be heard. The maximum acoustic space inhabited by a man will be the area over which his voice can be heard. The acoustic space of a radio or a power saw will be the volume of space in which those sounds can be heard” (1977, 214). Acoustic space also applies to artificial environments: “The perceived area encompassed by a soundscape, either an actual environment, or an imagined one such as produced with a tape recording and several loudspeakers” (Traux 1999). Artificial environments can be carefully constructed, as Truax observes: “A HI-FI environment, in which all sounds may be heard clearly, is characterised by a well defined sense of acoustic space in that all sounds may be perceived as occurring in the direction and at the distance where they originate”. By intention, this HI-FI environment may produce “realistic” sounds or entirely non-realistic, artificial or constructed sounds. Additionally, according to Truax, acoustic space may be discriminated from its ambient environment. “Acoustic space may also refer to the profile of a sound or sound signal over its surrounding environment. The acoustic space of any sound is that area over which it may be heard before it drops below the level of ambient noise”. The concept of acoustic space also currently applies to virtual sound space, to be discussed in Section 4.2.3- Virtual spaces.

In considering the relative sizes of different kinds of musical spaces, Emmerson considers them from the subjective and travelling outwards: “Simon Emmerson (1998) conceptualised musical space as progressively expanding circles, from the smallest to the largest: sonic event, performance stage, acoustic arena, and soundscape. .... but with a soundscape, the space is far larger and determined only by the acoustic horizon” (Blesser and Salter 2006, 177). These concepts may help us to conceptualise various overlapping musical spaces at play in a given arena.

By way of contrast with the constructed and designed spaces above, Steven Feld's “acoustemology” is an extended form of musical space that combines Schafer's eco-consciousness with a sense of place and culture. His term acoustemology, i.e. acoustic epistemology, was conceived in the forests of New Guinea:

> These days I am exploring acoustic knowing as a centrepiece of Kaluli experience; how sounding and the sensual, bodily, experiencing of sound is a special kind of knowing, or put differently, how sonic sensibility is basic to experiential truth in the Bosavi forests. Sounds emerge from and are perceptually centred in place, not to mention sung with, to, and about places. Just as "life takes place" so does sound; thus more and more my experiential accounts of the Kaluli sound world have become acoustic studies of how senses make place and places make sense. (Feld 2001)

Reznikoff proposes “sound space”, akin to acoustic space, as multi-dimensional aside from the many dimensions of physical space. He lists its qualities of “height or depth, proximity or remoteness” (2004-05, sec 2.6) and intensity, in addition to timbre represented by the first sixteen harmonics (so as to include include all seven tones of the diatonic scale). This tallies to a minimum of nineteen dimensions, plus several more to accommodate non-pitched sounds and noises. The concluding picture is of “a global representation of sound as a multidimensional sphere or globe centred in our body the higher extremity directed towards the sky and the lower down towards the earth” (2004-05, sec 2.6). He describes the sound space as dense, even continuous, yet bounded. “This representation is half phenomenological and half physical” (2004-05, sec 2.6). Reznikoff's location of the sound space emanating from within the body and travelling outwards, relates to Emmerson's concept in that he considers sound spaces from the subjective outward. This is pertinent to the present study, in considering the subjective experience of music-space (in Section 4.4.4).

4.1.4 Traditional perspectives and presentation of music in space

Generally speaking, when most people consider music in space, they think of acoustic space. They consider how sound occupies and moves around in space, reverberates etc., and the simple physics of waves and reflections. Acoustic space, and to some extent the “aural architecture” discussed in Section 4.2.1, are the conception of musical space used by audio technicians, acousticians, recording engineers, and sound equipment designers, to name some of them; that is, they represent the 'scientific' conception that has come to dominate our cultural viewpoint. An approach of many technicians is to consider sound spatialisation in terms such as these, similar to terms used by Andrew Lyons (2002): spatial resolution, scale issues, temporal resolution, spatial dimensions, among others. For present purposes, this perspective is limiting, as it considers music largely from a static listening location, and discusses sound (rather than music) by deconstructing it into its component parts. Particularly, it doesn't consider the experience of music in space as textural (expanded upon in Section 4.4.4 Music-space).

Traditionally, music and space are linked by the spatial terminology used to describe and understand music. For example, pitch is said to move “up” and “down”, or is “high” and “low”, tones are “dense” (from physics of materials in space), and loudness appears to have “volume”. Sloboda takes this further, and argues that “meaning in music comes from the way it embodies the physical world in motion. Human understanding of music comes from our capacity for analogical thinking” (1998, 25). Many thinkers consider that internal experiences, compositions, and thought structures use metaphors of structure and human physical movement from the real spatial world as building blocks.

Traditional Western art music has been presented with limited spatialisation from the audience perspective. During the last few centuries, audiences have generally been presumed to be static, often seated. Musical ensembles, and the composition of the music itself, have catered to some degree to the placement of music in space. Instruments and voices have been organised spatially, particularly for larger groups. For example, an orchestra has its sections of instruments, and specific placement of violins, violas, cellos, and percussion etc. The sonic principles involved include location of treble and bass instruments, grouping of similar and blending instruments, the separation of loud and delicate instruments, and the balancing of volumes and timbres from stage left to right, and other practical considerations. For the seated listener with an ensemble in front of him/her, the direct sound will have a horizontal spread from left to right, a vertical spread (soundwaves emanate spherically) probably compressed by the floor and ceiling, and all the fluctuations of point sources, groups of instruments, blends between and across, and alternating between groups spatially. This experience might be described as a musical matrix. Naturally, listening seated would be less of a dynamic spatial experience than moving around within the group of musicians on-stage. For our purposes, the scenario above is similar enough to the experience of the lounge room listener, seated in front of loudspeakers, in the proper triangular configuration.

Twentieth century composers, followed by practitioners of electronic music, have increasingly utilised spatialisation of music. Several composers have written for ensembles in ways that seek to provide more elaborate spatial experiences, sometimes surrounding the audience. In acoustic performances, this related to the placement of musicians and allocation of specific parts to them. The American musician Henry Brant was a pioneer practitioner of spatialised composition and performance. His reasons for paying attention to spatialisation included his opinion that spatial separation of instrumental groups clarified the texture, allowing similarly pitched passages to be separated aurally from other groupings nearby (Harley 1997, 73-4). He stipulated that spatialisation needed to be planned carefully whilst allowing for the local situation. For instance, planning might solve rhythmic synchronisation problems. A compositional example is John Tavener's *Ultimos Ritos* (1972), which places vocal and instrumental groups on a circular floor plan surrounded by the audience, but also provides for verticality, situating flutes in the lower gallery (above) and trumpets in the upper gallery (Trochimczyk 2001, 11). In one section of the work, a “descent” in the text is simulated by alternating upper and lower groups of instruments. These sonic experiences can't be reproduced in a lounge room with stereo speakers, but may be, at least partially, reproduced with a multi-speaker system (although only an extensive system would cater for verticality). Xenakis was another composer who paid attention to spatialisation. One of his approaches was to compose for performers dispersed among the audience, in *Terretektorh* (1966). Some composers have written for moving or roving musicians, as with, for example, a marching band. Additionally some have composed for the audience to be moving around, as in John Cage's *Musicircus* (1967), or for both to occur, as found with roving musicians at an outdoor festival.[22] These scenarios would provide a similar experience to the matrix idea described above: a living matrix of musical sound, particularly experienced where the listener moves around within it.

Electronic music compositions have been created for multi-speaker arrangements, most famously by Varèse for the Xenakis-designed Philips Pavilion at Expo 58 in Brussels. Varèse's *Poème électronique* (1958) placed 400 loudspeakers throughout a series of rooms, created as a sound and space installation that allowed the audience to experience a sonic journey, or a matrix of sound, as they moved through the building. Electronic improvisations, using multi-speaker systems, have been created that allow for spatialised music-making, that is, placing and moving musical components around in space. The Acousmatic[23] practice of live sound projection deployed by musique concrete composers from the 1960s is a famous example. At its simplest level and in a contemporary context, DJs pan or filter-sweep musical sounds across the dance floor in nightclubs with multi-speaker arrays. Also cinema sound routinely uses multi-speaker systems such as 5.1 and 7.1 surround configurations to provide an immersive sonic experience. Other spatialisation techniques, including that of sound-field synthesis, can create sound sources that are much bigger than point sources: that have shape, size, location, orientation, and direction, speed and acceleration if they move. These may occupy a location, with considerable size and “density”, - parameters that may change over time. By these means, for larger installations, it is possible to create a “virtual architecture” of sounds of varying sizes, shapes, and locations that may move around over time.

The ability to control sound location in multi-speaker arrays has challenged composers to consider more carefully issues of sounds in space, but even prior to that composers often considered musical space geometrically. This notion too has been developed and extended. Alty (1995) likened the traditional composition process to a planning or navigational task. He proposed a compositional state space, using the concept of states mentioned earlier in relation to cellular automata (Section 3.2.4).

22 Trochimczyk details many composers' spatial arrangements, mostly of static musicians, in her 2001 paper.

23 Acousmatic music is pre-recorded music that includes non-acoustic sounds and processed sounds, which is “invisibly” presented via loudspeakers.

This is a non-traditional perspective on music in space: "A musical work can be thought of as movement through a set of interconnected states from the beginning of the work to the end" (1995, 215). He defines a state as an instance of a set of (musical) parameter values, and the complete state space as encompassing all musical possibilities. A state change is said to occur whenever anything—e.g. timbre, volume—changes. The merit in this concept perhaps lies in characterising the compositional journey, as navigation through state spaces, using rules. Alty goes on to discuss "planning horizons" of short-, medium- and long-term consideration, where, for example, a short-term may involve a pitch change, medium-term a phrase, and long-term a structural change. Although he has no evidence for these ideas, the relevance to this study is in the relationship of composition to a journey in space—a somewhat abstract and theoretical space.

4.2 Structured spaces for music and sound

The discussion so far has considered concepts of musical spaces, the links between music, space and geometry, and various traditional but somewhat limited ideas of spatialisation. This section will consider more ways of organising structured spaces for music and sound, before Section 4.3 introduces more theoretical music structures.

Reconsidering the second idea from Section 4.1 of space as a relational construct of the mind, many theorists have conceived of abstract musical spaces, taking ideas from mathematics, geometry and informatics. They have conceived of structured abstract spaces: "In the domain of music, theorists like to discuss ''musical space,'' usually equating it with a two-dimensional pitch-time space, not the space of performance (e.g., Kurth 1969, originally published 1931; Bernard 1983, 1987; Lerdahl 1988; cf. Harley 1994a)" (Trochimczyk 2001, 1). Arnold Schönberg considered ideas of musical space for much of his career; both his treatises on tonal harmony proposed regional spaces (Lerdahl 2001, 71) similar to those of Kellner and Weber, placing tones in two-dimensional spatial configurations.

Structured spaces have been advocated for specific uses. Wessel (1979) proposed timbre space as a structure for multi-dimensional musical control. Based on the idea of locating similar timbres close to each other, the scheme has been applied to various control surfaces. More recently Wessel and Wright (2002, 15) note that multi-dimensional configurations are not necessary – a reduction to two dimensions serves sufficiently well, and can then be controlled using a digitizing tablet.

By way of contrast, some writers fail to see how music in space has any real coherence: "The space that comes alive through sound entirely lacks the essential spatial characteristics of optical space, such as three-dimensionality, spatial order, multiplicity of directions, form, and above all, occupancy by objects" (Revesz in Zuckerkandl 1956, 280-1).

The musical spaces noted above, and Revesz's rejection of the precision of musical space in comparison with optical space, provide an introduction to musical spaces which are structured and organised, by musical or graphical means, in real or virtual space, and provide a richer, more calculated experience than the looser concepts of soundscape, acoustic space and "sound space" described in Section 4.1.

4.2.1 Aural architecture

The notion of "aural architecture" is a more physically constructed version of acoustic space. Blesser and Salter speak of musical acoustic spaces as spaces for music to be played in, such as concert halls: "Every space has an aural architecture" (2006, 2). "Accordingly, aural architecture refers to the properties of a space that can be experienced by listening" (2006, 5). This process includes listening to sound objects or sound emitters, locating and sizing them, and hearing their reverberation qualities. Aural architecture refers to a structured space. "An acoustic architect is a builder, engineer, or physical scientist who implements the aural attributes previously selected by an aural architect" (2006, 5). Aural architecture is intended to comprise not just consideration of acoustics and acoustic properties of materials, but also social considerations of sites. So, an aural architect is "someone who selects specific aural attributes of a space based on what is desirable in a particular cultural framework" (2006, 5). To sum up, aural architecture appears to be a specifically physically constructed, and intentionally designed version of acoustic space, made by acousticians and architects.[24]

4.2.2 Spatially presented music

In Section 4.1.4 examples were provided of how music may be presented with an array of instruments or loudspeakers or electronic equipment, to provide a structured musical spatialisation. Examples included a spatialised acoustic ensemble by Tavener and an electronic presentation by Varese. In this section I will explore physical presentations of music that place instruments and their component parts spatially.

Spatial arrangements of harmonies can occur in live performance with groups of instruments, or in electronic music through multi-speaker arrangements. The plotting of harmonies on instruments, via arrays of buttons or keys, though usually not heard spatially, has occurred on a range of instruments including accordions and more recent electronic keyboards, such as those using hexagonal arrays (see Section 3.1.7 Grid cells). A discussion of plotting and using harmonies spatially, particularly in software systems rather than with physical instruments, is presented in Section 6.3.1.

The *gamelan*, and other similar groups such as a marimba ensemble, feature spatialisation of melody and phrases, of motives, resultant harmonies, and interlocking rhythms. Because each pitch is played on a different key of the metallophones, or pitched kettle of the *reong*, melodies and phrases have spatial patterns, and sometimes oscillating paths between instruments as interlocking riffs are exchanged. Sitting within a *gamelan* whilst its musicians play is an exciting experience, with the interlocking rhythms criss-crossing the space between sub-groups of instruments, sudden comings-together of the music to homophony for a few clashing chords, and the accelerations, decelerations and sudden stops of the tempo. This degree of spatialisation can only occur (with acoustic instruments) where each note has its own sounding device (e.g., key, string or pipe).

24 Aural architecture will be differentiated from “virtual architecture” in Section 4.2.3.1.

4.2.3 Virtual spaces

Virtual spaces are artificial, but our brain and senses try to interpret them in the same way as for real spaces. Virtual spaces may simulate real spaces to a greater or lesser degree, or present more amorphous or fictional spaces. These spaces have some bearing on this research in terms of the way spaces are structured, constructed and perceived; in addition they relate to augmented reality, in that augmented reality includes a component of virtual reality/space.[25]

There are various concepts of virtual space, as it applies to sound and music. For instance, "Virtual Acoustic Space (VAS), also known as Virtual Auditory Space, is a technique in which sounds presented over headphones appear to originate from any desired direction in space" (Wikipedia contributors 2009). More generally, virtual space is a component of virtual reality: an artificial reality created within a computer environment. Virtual spaces are commonly thought of as the graphically created environments typical of computer games, where real or imaginary worlds are represented. Players' avatars may move around inside these worlds, aided by sensory cues including simulated three-dimensional visuals, audio location sounds, sound effects, and other haptic feedback. The spaces vary in size from a computer chess gameboard, to a virtual lounge room for listening to music in (like a CD audio experience), to vast worlds in fantasy games. More abstract informational spaces may also be thought of as virtual spaces, including data-scapes.

Perhaps more pertinent to this study is the quality of the "reality" of constructed virtual space, and being able to comprehend and determine that "reality". This will be defined by objects within it, their sounds and the reverberations they cause, and to some extent the boundaries and surfaces of the space. This scenario relates fairly directly to perception and comprehension of real physical space (see Section 4.1.1.1) where, for example, reverberations help determine qualities of the space (e.g. warm, dry, large). The shape, size, and topography of the virtual space would be estimated by listening to objects near and far, and their reverberation, as well as virtually moving around in the space to survey it to some extent, perhaps meeting boundaries

25 Augmented reality is introduced in Section 3.4, and the combining of the spaces is considered in Section 7.1.

(usually formed by the technical structure or haptics). The construction of virtual space is the reverse process; it involves designing and building it, and then populating it with sound objects: “Whether modelling reality or creating a fantasy, the creator of a virtual space is an aural architect” (Blesser and Salter 2006, 132). As with any fantasy construction, people will interpret and comprehend it in terms of their experience, largely from the real world.

The field of virtual space is still young, and research continues. Ardito and others introduce the Interaction Locus as a cue to locating oneself within a virtual environment: “The concept of Interaction Locus (IL) has been introduced to help the users to orient, navigate, and identify relevant interaction areas in three-dimensional Virtual Environments (VEs). In particular, the IL emphasises the role of music as a navigation aid in a VE” (2007, 201). The IL uses hyper-linked text for a label and extra information, along with auditory, visual and tactile components. An older technique uses auditory icons—an aural version of visual icons that can provide a semantic link to represented objects within the same environment. “Earcons” (without the visual icon) have similarly been used to successfully provide feedback to users by providing sonic cues to computational states. For example, the sound of dragging a file on a computer desktop may have the sound effect’s pitch correspond to the file size, even when the visual size of the icon does not vary. “Earcons are composed of motives, which are short, rhythmic sequences of pitches with variable intensity, timbre and register. They are abstract, synthetic tones that can be used in structured combinations to create sound messages representing parts of an interface” (Ardito et al. 2007, 203).

Blesser and Salter extend their concept of aural architecture (see Section 4.2.1) into virtual spaces, created by audio engineers:

> To broaden the concept still further, aural architecture includes the creation of spatial experiences where a physical space does not actually exist, so-called virtual, phantom, and illusory spaces. While listening to recorded music in our homes, we experience a virtual space created by a mixing engineer who

manipulated a spatial synthesizer in a recording studio. (2006, 6)

4.2.3.1 Virtual architecture

We may distinguish between aural architecture, which refers to space experienced by listening, and "virtual architecture", which refers to building-like structures, surfaces and shapes, or actual architectural models made in virtual space. This is a visual, graphical (and architectural) way of structuring space, which may accompany a sonic and musical space.

As a practitioner of virtual architecture, Gerhardt Eckel developed the *Camera Musica* installation project at the German National Research Center for Information Technology (Sankt Augustin, Germany) from 1994 to 1997. The *CyberStage* was a virtual reality (VR) system, like its *CAVE* predecessors (Cruz-Neira, 1993), where the participant stood in a box with projections on three walls and floor, fitted with 8 loudspeakers and 6 vibration emitters in the floor. The participant could move virtually through a specially constructed virtual environment of various shapes and spaces (see Figure 20).

Figure 20. The virtual reality system, Cyberstage.

The music in *Camera Musica Sketch*, a work developed as part of the *Camera Musica* project, is conceived as a family of various interrelated musical situations composing, in their interplay, what we may call a musical space. The virtual (and architectural) space is overlaid with the musical (compositional) space in the installation. The participant may navigate from one situation to another within this space, and slowly explore its special features through the relations between individual situations. What is fascinating and unique about this installation is that "while moving through an architecturally structured space, the audience explores the music. Structural aspects of the music are related to spaces and their attributes"; and "...virtual architecture becomes a vehicle for the exploration of music" (Eckel 1997). Each situation is characterised by certain possibilities of choosing the musical material and arranging it, thereby determining the particularity of the situation—its mood, atmosphere, form and air. Depending on the position and orientation of the participant, these choices are taken by a program whose development is part of the composition (Eckel 1998). The key point is that the participant may explore the music composition spatially, as it is generated, in a space that is primarily structured by "architecture".

Although largely pre-composed in the sense that loops and samples are constructed and organised, the music is seems to be fluidly generated and sited within the spatial structure, without actually being generative music.

> In the musical discourse, spatial terms are used fairly often and also in our imagination we are constantly making use of various spaces. They serve as a means of ordering things. We arrange things in space … When I am talking of musical space, I am not always referring to one and the same thing, but I do have a clear picture of what I mean in each concrete case. It always has got something to do with the relation between different elements, with the distances between them, with the possibilities of getting from one element to the other or with the forces working between them. (Eckel, 1997)

The relation between the elements, and the forces "working between them", is a similar idea to Lerdahl's harmonic tension model (see Section 4.3.2.1).

In contrast to Eckel's installation, the *HarmonyGrid* provides spatialised music-making by creating a musical and graphical space that is organised quite geometrically. Eckel provides a virtual three-dimensional experience, as opposed to the space above and on *HarmonyGrid*'s two-dimensional projection. Both use organised space as a medium to structure a musical composition. Eckel's space presents an adventure of discovery, with its sophisticated VR system, whilst *HarmonyGrid* presents an obvious geometric game-like structure which suggests patterns and possibly rules. Eckel's work is a pre-structured environment, and for a journey repeated exactly again (if this were possible to organise), the music would remain the same. The same could be be achieved with the *HarmonyGrid*, but it is a flexible environment and such a use would not exploit its potential for improvisation, in that new music can be generated each time by layering up accumulated structures in ways that vary as interaction varies. Musically, Eckel's work is largely pre-composed, though each version will be different due to its ordering, whereas *HarmonyGrid* provides for music-making that is different each time.

In this section we have made the journey from unstructured spaces for music and sound, describing and defining some of them, to more structured spaces, including spatialised music performance, virtual space, aural architecture, virtual architecture and its accompanying musical space. The next section addresses more organised structured spaces.

4.3 Music Representative space

Over the centuries various writers and theorists have presented a variety of constructions of music spaces. Some are quite bizarre and difficult to comprehend, but each may add something to our understanding of musical space, and of various abstract music spaces and knowledge spaces possible in the human mind. These spaces may comprise, or represent, a knowledge space of musical components and how they relate—e.g. a grid of harmonies—and may be either theoretical or embedded knowledge. All of these constructions of music spaces are more abstract, mental, and mathematical in nature than the musical spaces discussed above. They are aligned with Lefebvre's: “Representations of space: the idea of space that we conceptualise” (Lefebvre 1991, 39) (see Section 4.4.1.1).

I use the term “music representative spaces” to cover all these more abstract informational spaces, in contrast to the more experiential and physically organised musical spaces discussed previously, and to music-space (to be defined and discussed in Section 4.4.4). “Music representative spaces” is a term that includes:

1. abstract, mental representations of music, including harmonic schemes or layouts, pertaining to current and previous knowledge about musical materials. This may also parallel innate knowledge of music in the brain (see Section 4.3.4).
2. visible data, layouts or plots of data, of musical components as might be utilised in a GMS.

Although these spaces are largely intellectual, either held in the mind or described in theory with or without diagrams, they may also be projected onto, align with or overlay a real space.

Various musical elements may be arranged or presented in music representative spaces. The arrangement and possible diagrammatic arrangements of pitches in space has been the subject of quite some research, usually in relation to harmony where the pitches are the root notes of chords. Harmony refers not only to chords which are combinations of pitches, but to the structure, progression and relation of chords within musical textures. The use of, and psychological results of what is predominantly Western harmony have been studied extensively in the literature. Diagrammatic arrangements of harmonies are made possible by the coexistence of geometry and space, especially in the mind (see the next Section). Many abstract concepts, schemes and diagrams have been developed regarding the arrangement of pitches, pitch classes, and harmonies in space, as opposed to other musical parameters. Extensive recent studies include those by Lerdahl and Jackendorff (1983), Lerdahl (2001), and Mazzola (2002), and are covered in Section 4.3.2.

4.3.1 Geometry and music

This section explores the relationships between geometry, the mind, space and music. We begin by identifying the links between geometry in the mind, and external(ised) space. Geometry cannot exist without space, and yet our creations, plans and manipulations of it begin in the mind. In addition, the body inhabits and produces space (after Lefebvre—see Section 4.4.1.1), yet constructs internally (in the mind) a representation of it, from sense data and experience. Many mental representations of musical spaces use geometry as a primary organising strategy, originating in the mind, and perhaps partially informed by neuro-scientific tendencies to do so (see Section 4.3.4). Geometry forms the framework of many musical representative spaces, particularly of the large-scale theories of Lerdahl and Mazzola (see Section 4.3.2).

vii	ii	IV	vi	I	iii	V
iii	V	vii^0	ii	IV	vi	I
vi	I	iii	V	vii^0	ii	IV
ii	IV	vi	I	iii	V	vii^0
V	vii^0	ii	IV	vi	I	iii
I	iii	V	vii^0	ii	IV	vi
IV	vi	I	iii	V	vii^0	ii

Figure 21. Euler's chordal space, using Roman numeral notation.

Geometrical schemes of harmonies, and the concomitant idea of geometrical musical space, have existed since Baroque times (Lerdahl 2001, 42). Various circular graphical schemes have been devised and, from the 18th Century, lattice structures evolved as a means to explore harmonic relations and intonation. Euler made the harmonic scheme (Figure 21) in the latter half of the 18th century.

The *Tonnetz* of Riemann, from a century ago, is probably the best known historical model of recent times. It shows a grid (Lerdahl 2001,45) similar to the one above, with the letter names for pitches having intervals of fifths horizontally and major thirds vertically. Much work has been done in recent decades, especially by Lerdahl, in what he calls "tonal pitch space" based on these geometric harmonic organisations.

Emmanuel Kant, in the *Critique of Pure Reason*, discusses the relationship between geometry and space "in the form of intuition or a priori judgements" (in Rawes 2008, 2):

> Geometry, Kant tells us, is an intermediary knowledge, because it is unextended intuition in the special science of mathematics. Yet intuition also exists in our extended 'sense-intuitions', that is, space and time, which constitute our 'outer sense' (i.e., space) and our 'inner sense' (i.e., time). So intuition is both the 'pure' absolute form of geometric knowledge and the spatial and temporal forms of our sensibility. As a result, geometry, space and time are a priori, irreducible to simple concepts or ideas. (Rawes 2008, 11)

However, Kant goes on to re-categorise space and time as limited to being "phenomena", merely as forms of appearances derived from the extended world outside of the mind or "intuition" (Rawes 2008, 11). Geometry gets legitimised, both in the external world of "material bodies or ideas", as well as from the internalised world. Because space and time are considered to be internalised "intuitions", and geometry somewhat external, Kant proposes "embodied connections", "generated by the reflective subject's powers" (Kant in Rawes 2008, 11). Furthermore, "the productive powers of the imagination enable the abstract science of geometry and the sense intuitions to be unified in the reflective subject" (Kant in Rawes 2008, 11). Later on, in the second edition of the *Critique of Pure Reason*, in the section 'Transcendental Exposition of the Concept of Space', Kant re-inserts geometry back in the internal mind or intuition (Critique of Pure Reason 176).

This section has introduced the intimate links between geometry space and time in the mind, which aligns with the link between music perception and the geometric in the brain. It seems feasible that a complete geometric musical space may exist in the mind, or may occupy a real space and be understood by the mind. Section 4.3 overall refers to a combination of real musical space and mental musical knowledge, contained as music representative space.

4.3.2 Major theories of music representative spaces

Music representative spaces and musical spaces can combine, or co-exist, in the mind, on paper, and in experimental systems. The following paragraphs describe two major theorists on music representative spaces, of the last several decades. It should be stated at this point that, in relation to Lerdahl's and Mazzola's theories discussed below, a complete exposition and critique is not the intention of this study. I am concerned with comparing the general and musical experience of various spaces as they may apply to musical experience and performance, rather than with the precise validity of these more abstract schemes.

The theories by Lerdahl and Mazzola don't appear to consider the direct experience of music in space in real time, that is, in the normal conception of space, or in music-space. Rather, they extract mental constructs of how listeners perceive music, and project that into hypothetical mental spaces of some mathematical and informational complexity, albeit with some backing from cognitive psychology and neuroscience. These theories introduce complex models which arrange musical components, especially pitches and harmonies, in multi-dimensional musical spaces that are precedents, admittedly of greater complexity, for the real-world installations of the scaled-up GMSs discussed in subsequent chapters.

4.3.2.1 Lerdahl

Lerdahl and Jackendorff's 1983 book *A Generative Theory of Tonal Music* (GTTM), was the first large-scale modern theory of music and space. It claimed to have psychological backing and, according to Sloboda (2005), signalled that music psychology as a field had come of age.

> GTTM treats music theory as the branch of theoretical psychology concerned with modelling the musical mind (Sloboda 1985). In the spirit of recent cognitive theory (Fodor 1983; Jackendorff 1987), the musical mind is seen as possessing characteristics of modularity, specialization, automaticity, speed, impenetrability to consciousness, and corresponding brain localization. (Lerdahl 2001, 4)

GTTM theories were intended to be sufficiently precise to be testable by cognitive psychological means. Krumhansl (1983, 1990), a colleague of Lerdahl, remains a key theorist doing the groundwork establishing the psychological underpinnings of musical spaces.

> A well-known finding in music psychology is that listeners' judgements about the distances of pitches, chords, and regions (or keys) from a given tonic form consistent patterns … When submitted to multidimensional scaling, the empirical data are represented as geometrical structures in which spatial distance corresponds to cognitive distance. The regular geometry found for regions (Krumhansl & Kessler, 1982) corresponds to musical spaces proposed earlier by music theorists (Schoenberg, 1954; Weber, 1817-21). (Lerdahl and Krumhansl 2007)

In 2001, Lerdahl criticised his earlier work:

> GTTM makes assumptions analogous to those found elsewhere in cognitive sciences. First, it takes as given the musical surface (the aural perception of pitches, timbres, durations, and dynamics), ignoring the complex process by which the surface is constructed from the acoustic signal. In the same spirit, the notated score is taken—minus bar lines but with the addition of harmonic roots and tonal orientations—to represent the surface. Second, GTTM assumes an “experienced listener”. (Lerdahl 2001, 5)

GTTM construes the musical surface “as a single sequence of discrete events that assemble into hierarchically organised groupings” (Lerdahl 2001, 6).

In GTTM, musical structures are organised hierarchically into grammars, or system of rules: “the rules take as input the sound signal as organised psychoacoustically into a “musical surface” and attempt to give as output a structural description that models aspects of the heard structure. GTTM proposes four types of hierarchical structure simultaneously associated with a musical surface” (Lerdahl 2001, 3).

These structures aim to represent how an experienced listener would understand a piece of music. “Grouping structure” segments music into phrases, motifs and sections, “metrical structure” into strong and weak beats, “prolongational reduction”, and “time-span reduction”, as Lerdahl explains; “the primary link between rhythm and pitch, establishes the relative structural importance of events within the rhythmic units of a piece. Prolongation reduction develops a secondary hierarchy of events in terms of perceived patterns of tension and relaxation” (Lerdahl 2001, 3).

Lerdahl also has a system for measuring the continuity and ascribing integer values to it. This is developed as a model called “The Harmonic Tension Model” based on the idea that “The degree of tension and relaxation between two events depends on the degree of continuity between them” (2001, 14). The idea of considering tensions or forces between components in musical space parallels Eckel's concepts (see Section 4.2.3.1).

Lerdahl lists various kinds of abstract space, including pitch space, regional space, scale-degree space and chordal-regional space. Pitch-space paths are said to occur in these spaces. Pitch-space paths are a key component of the functioning of the *HarmonyGrid*.

"Tonal pitch space" is said to be multi-dimensional, in contrast to the earlier two dimensional geometric model proposed by Riemann (Quaglia 2002).

> [Lerdahl's tonal pitch space] is essentially a reductional model of pitch space that transfers cognitive distance across several levels simultaneously. The resultant model reduces that distance to a single integer value. The multi-dimensional model proposed is consistent with a large body of referenced research in the fields of psychoacoustics, cognition, and, perhaps of particular note, recent brain-function research on neural nets. (Quaglia 2002, 88)

Lerdahl " privileges a non-geometric cognitive space that is more suited to the ambitions of his theory and which sets it apart from many historical precedents for tonal pitch space" (Quaglia 2002, 88).

Lerdahl hopes that GTTM structures represent how an experienced listener would understand a piece of music. His time-span reductions provide a representation of music in two-dimensional diagrams and, as such, they are models. The *HarmonyGrid* provides a means of accessing such a diagrammatic presentation of harmonies or musical elements, and of actively playing the music spatially, using pitch-space paths. It may prove to be one of the best direct means to test Lerdahl's theories. However, a thorough investigation of GGTM in GMSs would be beyond the scope of the present research. In addition, Lerdahl's theories don't appear directly to consider the experience of music in space, that is, located in and laid out in space; rather they prefer to project mental abstractions, derived from music listening or analysis, into abstract mental spaces.

4.3.2.2 Mazzola

Guerino Mazzola's massive book *The Topos of Music* (2002) deals with "mathematical music theory and its operationalization by information technology" (Noll 2007). The vast discussion of music reconfigures musical elements into objects for abstract data structures, to project into mathematical spaces of complexity "as the system of musical signs can be associated with the mathematical theory of topoi, which realizes a powerful synthesis of geometric and logical theories" (Mazzola 2002, pdf1).[26]

Mazzola starts from a semiotic standpoint: "Definition 1 ... Music is a system of signs composed of complex forms which may be represented by physical sounds, and which in this way mediate between mental and psychic contents" (2002, pdf6). Music is considered to operate on many levels, and he suggests that "To understand music as a whole, you have to specify simultaneously its levels of reality, its semiotic character, and its communicative extension" (2002, pdf10). For Mazzola, these levels include physical, psychological, and mental layers. "It is not question of reducing one of these realities to the others: Either of them has an autonomous existence which can at most be transformed into others, but not eliminated" (2002, pdf10). A phenomenon in one layer can then be related to one in another layer. The three layers become three dimensions of a cube describing a musical topography, and then each one is subdivided into three "coordinate" values, totalling twenty-seven "topographic locations" (2002, pdf19). This coordinate space becomes the *topos* of music.

The physical, psychological, and mental layers are related as "ontological dimensions of reality, communication, and semiosis" (2002, pdf19), which he summarises in the following way:

- reality: physical—psychological—mental
- communication: creator—work—listener
- semiosis: significant—signification—significate.

26 Unfortunately page numbers in Mazzola's book don't match printed page numbers in the pdf version. I shall use the pdf version, and cite them as pdf (page number).

Mazzola paraphrases Molino in splitting communication, referring to artistic creation, into three parts: creating, the creative work itself, and listening. Considering the situation of music-making (see Section 1.3.1), these parts would seem to collapse into unity. The act of music-making, as part composition and part improvisation, includes creating and listening, alongside the work in progress. Mazzola alludes to this as the “conceptual zoom-in effect” when discussing how the topological cube may operate (2002, pdf21). Creating and listening could be seen to also form an interesting parallel to Lefebvre's “conceived” and “perceived” spaces (see Section 1.4.1.1); thereby blending our experience and cognition of both music and space.

“To describe the ontological position of a musical object, we have to specify its three coordinates in reality, communication, and semiosis” (2002, pdf19). In fact, Mazzola's scope extends far beyond music into knowledge domains so that “a powerful concept system for any field of knowledge must provide us with a thorough navigation method that works on an extensive concept space” (2002, pdf40). He then defines the “EncycloSpace” as the general concept of an encyclopedic knowledge space. This conceptual structuring of knowledge goes beyond the scope of this research, but indicates the extent of the abstract nature and direction of Mazzola's thinking.

Mazzola then defines a data format for musical elements or objects: “... the universal data format of denotators ... generalize the structures of local compositions in mathematical music theory as well as the data model used in the RUBATO® software. They do, however, *not* include deeper semantic layers. ... Their semiotic structure resides in a purely mental level usually attributed to mathematical objects” (2002, pdf47). Denotators are described by “navigation methodology” as “a recursive formalism composed of a "substance-point" in its own "form-space"” (Tuner 2008, 81). Denotators can be used to describe basic note information, or an FM-synthesis object.

> One of the central ideas of the entire approach is that musical objects are inhabitants of ambient spaces whose transformations contribute to the constitution of their musical meaning. A more radical formulation of that idea —upon which the denotator language is built—considers transformations themselves as basic constituents of musical objects … Thus, to understand and to estimate this central idea in its radical formulation one needs first of all to understand and estimate the musical relevance of affine transformations[27] … The musical meaning of pure translations is broadly acknowledged throughout music theory. (Noll 2007)

Within grid music systems, or cellular automata, the movement from one cell to another represents a transformation of information, and can perhaps be seen to parallel the idea of transformation outlined above. Certainly the musical objects in the *HarmonyGrid* are inhabitants of (what can become) ambient spaces.

4.3.3 The *HarmonyGrid* and music representative space

The *HarmonyGrid* presents and allows access to music representative space, but doesn't claim to present embedded knowledge. It presents visual information via semi-animated graphics that show values for musical parameters on the current grid. At any time, a grid layout of each of the four musical parameters may be selected as the projected grid. The Harmony grid shows richer information with its chord symbols showing the chord and its character (e.g. #iiid is the diminished chord on the sharpened third degree of the scale selected). This grid layout could be called an information space or information matrix, upon which the musician may apply their knowledge to explore harmony and make music. The musician may map their mental layouts of musical knowledge onto the projected grid data, or access their mental knowledge or maps, item by item as needed whilst using the *HarmonyGrid*. Unlike some of the theories discussed above, the *HarmonyGrid* doesn't claim to embed theories of knowledge in the layout of harmonies and rhythms, but provides a range of choices for the user to move from square to square and form paths. However, some known designs are incorporated in two of the Harmony grids. The overall

27 An affine transformation first rescales an object and then translates it in space

effect of the system is to provide access to music representative space whilst being in and experiencing music-space (to be defined and discussed in Section 4.4.4).

4.3.4 Evidence for music representation in the brain

Longuet-Higgins proposed in 1976 that "a central part of experiencing any music as music is the assignation of sounds to positions in tonal and metrical space" (Sloboda 2005, 99). His computer program took as input a sequence of pitches and durations, and produced a "sensibly notated version as output" (Sloboda 2005, 99). This reinforces the idea that musical space is internal and innate, echoing Kant (Section 4.3.1), and has been partially proved by experimental results showing perception of a spatially notated score.

There is support for these music representative spaces from neuroscience and psychology, suggesting these spaces may be more than mental constructs. Earlier historical models including Euler's and Riemann's *Tonnetz*, were mathematical models represented in two-dimensional space on a page. Cognitive psychological work, notably from Krumhansl and associates (Krumhansl 1983, 1990) using probe tone tests, showed these types of models had some psychological reality. Evidence then came from neuroscience, specifically using magnetic resonance imaging on human subjects hearing musical material, to further support these kinds of models:

> Western tonal music relies on a formal geometric structure that determines distance relationships within a harmonic or tonal space. In functional magnetic resonance imaging experiments, an area has been identified in the rostromedial prefrontal cortex that tracks activation in tonal space. Different voxels in this area exhibit selectivity for different keys. Within the same set of consistently activated voxels, the topography of tonality selectivity rearranges itself across scanning sessions. The tonality structure is thus maintained as a dynamic topography in cortical areas known to be at a nexus of cognitive, affective, and mnemonic processing. (Janata et al. 2002, 2167)

To paraphrase, a tonality structure can be maintained geometrically, as a "dynamic topography" in the human brain. So a mental, mathematical or geometric representation of music may have a real basis in the brain's structure, or at least may be accommodated more naturally than if it were entirely artificial or arbitrary.

Janata *et al* locate the brain's musical activities, and suggest "that the rostromedial prefrontal cortex not only responds to the general degree of consonance but actively maintains a distributed topographic representation of the tonality surface" (2002, 2169). However they found that the mapping was relative, and not absolute in location: "... we found that the mapping of specific keys to specific neural populations in the rostromedial prefrontal cortex is relative rather than absolute... the populations of neurons that represent different regions of the tonality surface are dynamically allocated from one occasion to the next" (2002, 2169).

Concurring with Shepard (see below) and Holland, Janata and his associates located musical keys on a torus shape: "However, the keys themselves are distributed on a torus at unique distances from one another" (2002, 2169). Below are Shepard's summarised conclusions about music cognition in the brain:

> (1) Very general principles of perception and cognition apply in the domain of music just as they do in other domains. Between musical objects (tones, chords, melodies, keys, rhythms, styles, etc.), I propose that generalisation probability falls off exponentially and discrimination time falls off reciprocally with distance in the appropriate representational space. On the other hand, time to achieve a full mental connection between those objects (as parts of the same melodic stream, chord cadence, etc.) increases linearly with the least-time transformational path between them in the appropriate space. (2) The perception and cognition specifically of music is, however, subject to large individual differences among humans in those components of the representational space corresponding to higher order cognitive structures, such as the circle of fifths, tonal hierarchies, and structural relations among keys or modes. (3) Despite differences among individuals within any one culture, sensitivity to these higher order structures is manifested by the more

> musical individuals within cultures having such diverse musics as those of Bali, West Africa, and Western Europe. (4) Because these higher order structures are determined by physical and abstract mathematical universals, I conjecture that they may be universally approximated in all sufficiently advanced musical beings. (Shepard 2004, 16)

It is interesting to note Shepard's higher order structures paralleling Mazzola's structures. However, it is beyond the scope of the present study to query or determine the validity of the above studies. I have attempted to present the current knowledge and opinion on the topic as providing some backing for music representative spaces.

This section has explored music representative space, beginning with considering the links between geometry, music, space and the mind, and then examining two major theorists who present large-scale theories and versions of music representative space. Sorting through the evidence from neuroscience and psychology provides some backing for these ideas. The next section investigates experiential musical spaces.

4.4 Towards an experiential music space

This section sets out to accumulate support and evidence towards the definition of music-space. Along the way it will touch on the topics of production of space, immersion, and spatially presented music. It will focus on the experience of how musical spaces are shaped, formed and produced, in contrast to previous sections which explored knowledge structures in music representative spaces.

4.4.1 Production of space, and immersion

4.4.1.1 Production of space

Is space unknowable? Leibniz answers that it is undiscernable (Lefebvre 1991, 169). "...what Leibniz means to say is that it is necessary for space to be *occupied*."

(Lefebvre 1991, 169). Lefebvre introduced the notion of "the production of space" which he described in the following way:

> Can the body, with its capacity for action, and its various energies, be said to create space? Assuredly, but not in the sense that occupation might be said to 'manufacture' spatiality; rather, there is an immediate relationship between the body and its space, between the body's deployment in space and its occupation of space. Before *producing* effects in the material realm (tools and objects), before *producing itself* by drawing nourishment from that realm, and before *reproducing itself* by generating other bodies, each living body *is* space and *has* its space; it produces itself in space and it also produces that space. This is a truly remarkable relationship: the body with the energies at its disposal, the living body, creates or produces its own space; conversely, the laws of space, which is to say the laws of discrimination in space, also govern the living body and the deployment of its energies. (Lefebvre 1991, 170)

Generally speaking, a person is required to be suitably situated in space, in order to create a performance. In the sense of Lefebvre's 'production of space', a performer inhabits, develops and produces the space as a performance medium. This is perfectly well understood, if only intuitively, by accomplished performers. The performer cannot operate without space. A performance space is somewhat bounded or delineated, and the performer moves generally within that zone (although this occasionally may not be true, as in roving, mobile or environmental performance). Techniques to define and delineate the space are performative, and may derive (at least historically) from ritual, or are simple stagecraft. Most methods of producing space for performance are quite obvious, such as a lit area on a stage, and some less so, as in a circle formed by viewers on the ground for an informal dance display.

The performer works with the space in the performance, plays on, through and with this medium. Typically, performer(s) simply move around in the space, and occupy it. Additionally, a performer generally engages with an audience, and works with them to makes the space function performatively. (This exegesis will, in general, tacitly assume an audience.) An audience is required to perceive the production and performance of and through space, together with the production, performance and sonic results of the musical performance.

4.4.1.2 Immersion

The degree to which the performer works with the space in the performance, plays on, through and with this medium, relates to the degree or quality of immersion. It is somewhat a measure of engagement. The technology of a system may or may not have bearing on this degree of engagement, as traditional performance experiences can also be very engaging or immersive.

The term immersion was originally derived from the experience of being submerged in water, according to Murray (in McMahan 2003, 68). In one definition, immersion is where consciousness of one's awareness of physical self is diminished or entirely left behind, as a result of being surrounded "in an engrossing total environment; often artificial" (Nechvatal 2009). The term is used to describe a participant's or performer's experience in areas such as immersive virtual reality, installation art and video games. The word is considered over-used in contemporary culture and "people tend to use it to describe any kind of intensely pleasurable artistic experience or any absorbing activity. In this usage we can be immersed in a crossword puzzle as well as a novel..." (Ryan 2001, 14). For this study, the definition above is preferred, which is more in keeping with performance systems.

Immersion is a desired characteristic, a measure of engagement, in areas such as virtual reality and video games. Part of the technological development of such systems has been driven by the perceived desire for increasing immersion. Immersion includes such concepts as presence, "defined loosely as 'the feeling of being there'" (McMahan 2003, 68). Music listeners often describe experiences in terms of immersion, with comments along the lines of, "I was really there". Björk and Holopainen (2005) describe three categories of immersion as sensory-motoric immersion, cognitive immersion and emotional immersion, but add spatial immersion, psychological immersion and sensory immersion—experiencing a unity of time and space in a three-dimensional environment. The *HarmonyGrid* is a scaled-up GMS that becomes a partially immersive one in four related ways: spatially, graphically, and sonically and musically. From the categories above, spatial immersion is matched, and sensory immersion would cover graphical, sonic and musical immersion, but the *HarmonyGrid* experience also includes aspects of cognitive, psychological and emotional immersion.

McMahan itemises three conditions for immersion in virtual reality and computer games: "(1) the user's expectations of the game or environment must match the environment's conventions fairly closely; (2) the user's actions must have a non-trivial impact on the environment; and (3) the conventions of the world must be consistent, even if they don't match those of 'meatspace'"[28] (2003, 68-9). For interactive music systems, the first condition might mean that paths or layouts map to known and conventional musical components, e.g. pitches; the second that the user's actions are clearly visible on the grid, and the results are audible; and the third that the conventions of the grid are consistent. In the case of the *HarmonyGrid,* and to extend McMahan's conditions over the "life" of the user's experience, the first-time user may have limited expectations, as the system is unusual, and these may only refer to moving on gameboards. However, after some familiarity the user will expect consistency of operation from the environment, and that their actions are quite noticeable.

The initial idea of scaling up the *HarmonyGrid* was to allow bodily access to the grid, to "get in and onto" the grid and its graphical environment that is akin to a gameboard or a small virtual world. Because the projection is downward onto the floor, there is a sense of being within a three-dimensional zone of light and of augmented reality. Additionally, it was realised that sonic and musical immersion could be provided by a surround sound system. To these ends the *HarmonyGrid* provides an immersive experience. However the degree of immersion is not intended to be to the exclusion of all other experience, internal or external. For instance, the performer may wish to be aware of an audience and their reactions.

28 "Meatspace" refers to the real world, in the language of cyberspace or virtual reality.

This subsection has explored ideas and theories of production and performance in relation to space. The discussion proceeds to examine some historical and current methods, in relation to these notions, in the spatial music presentation.

4.4.2 Arranging music spatially

Spatialised music can be arranged and presented in such a way that one can experience a textured music space. A scenario can be developed to explain this idea. With natural sound sources, such as voices and instruments (referred to for convenience as "instruments" from now on), the sound emanates from a localised source which, except for very big instruments, is experienced more or less as a point source. Several instruments may blend to create an area of sound source, whose size is obviously dependent on number of instruments, their distance away, secondary echoes etc. For a group of instruments relatively close, a listener may hear increased volume from point sources (instruments), and blending of music and musical sounds, with decreasing volume between those sources. For a listener moving within the area formed by the group, the experience may be like moving around a living matrix of musical sound, as different intensities of instruments and blends of sounds are passed through, and intensities vary at point sources and between them. This would be especially true for larger ensembles, such as choirs and orchestras, and a good example of this is the Indonesian *gamelan* (see Section 4.2.2).

Similar musical spaces, with a matrix-like texture, have been constructed electronically. Electronic music compositions have been created for multi-speaker arrangements, most famously by Varèse for the Xenakis designed Philips Pavilion at Expo 58 in Brussels. Varèse's *Poème_électronique* (1958) placed 400 loudspeakers throughout a series of rooms, created as a sound and space installation that allowed the audience to experience a sonic journey, or a matrix of sound, as they moved through the building. Electronic improvisations, using multi-speaker systems, have been created that allow for spatialised music-making—that is, placing and moving musical components around in space. At its simplest level, DJs pan, or filter-sweep musical sounds across the dance-floor. Another aspect of music-making is the making and placement of spatialised sounds. Techniques of sound-field synthesis can create sound sources that are much bigger than point sources, that have shape, size, location, orientation, and direction, speed and acceleration if they move. These may occupy a location with considerable size and perceived “density”, parameters which may change over time. By these means, for larger installations, it is possible to create a “virtual architecture” of sounds of varying sizes, shapes, and locations that may move around over time.

4.4.3 Spatialised music-making with the *HarmonyGrid* and other systems

As discussed previously (Section 4.2), space may be quite structured and organised, or may be more loosely arranged. This section compares the *HarmonyGrid*'s use of space with other systems.

The way a system is set up and the space and musical components organised, will result in different spatial and musical experiences. The *HarmonyGrid* has been created as a music system that provides spatialised music-making, where space is organised quite geometrically. This is in contrast to, for example, Eckel's *Camera Musica*, which provides a pseudo-three-dimensional experience, as opposed to the *HarmonyGrid*'s two-dimensional projection. Both use organised space as a medium to structure a musical composition. Eckel's space presents an adventure of discovery, with its sophisticated VR system, whilst *HarmonyGrid* presents an obvious geometric game-like structure which suggests patterns and possibly rules. Eckel's work is a pre-structured environment, and if a journey through it that were repeated exactly (if this were possible to organise), the music would be almost the same. The *HarmonyGrid* is a flexible environment, in that new music can be generated by layering up accumulated structures, and these can be dynamically created and controlled during performance. Musically, Eckel's work (and others like it) is largely pre-composed, though each “version” will be different due to its ordering, whereas the *HarmonyGrid* provides for music-making (not just music-experiencing) that is different each time.

In Eckel's system the musical composition is to be explored spatially. The composition is generated and plays dependent on where the participant is located virtually, and where they are moving to. What is fascinating and unique to this installation is that “while moving through an architecturally structured space, the audience explores the music. Structural aspects of the music are related to spaces and their attributes”; and “... virtual architecture becomes a vehicle for the exploration of music.” (Eckel 1997)

With the *HarmonyGrid*, musical components may be arranged spatially in a performance space, to be accessed by the participant to provide spatialised music-making. The placement or arrangement of pitch materials, for instance, might be accomplished by many methods or designs mentioned previously, or laid out on a grid as with GMSs. Other musical parameters, including volume, timbre, and rhythm, may be arranged by similar methods. These musical components form a textural matrix in which a musician/performer may operate.

In the situation where musical components are arranged statically, spatial movements of the performer translate to spatialised music-making. Where musical components are caused to actively move around the space, as with many GMSs, controlling these events becomes spatialised music-making. Performed and operated by a solo musician, *HarmonyGrid* allows for musical components to actively move around, and to form, store and repeat spatial patterns. More importantly, it does so interactively, informed by the musician's location. In this system the performer's spatial movements may both access static musical components and actively trigger movements or patterns of musical components. In that, this system is rare. What makes it possibly unique is that the musician controls the music-making process whilst moving in the space that he/she makes. To put it another way, the musician moves around in the space he/she has produced, which is delineated by the performance setup, accessing musical components via the music representative space of the geometric grid, to create music-space (see next Section).

A similar arrangement is provided by Holland's *Harmony Space* (1989), where the participant's spatial movements translate to spatialised music-making. In this case the participant is not a performing musician. *Harmony Space* has several versions and implementations. In the standard software implementation, the mouse or pointer is simply moved around over the onscreen grid to trigger harmonies. The system plays chords directly via a synthesizer, rather than engendering a more complete musical response as with the *HarmonyGrid*. The software setup is appropriate for exploring students' harmonic discoveries or harmonic attempts to accompany known works (to be discussed further in Chapter 6). In the “abracadabra” implementation of *Harmony Space*, extra hands control the software program, manually “tracking” the movements of the participant on a large-scale projected image on the floor. This implementation was made in order to explore the system's capabilities, prior to deciding on specific tracking systems and how they may be used. *Harmony Space* is further discussed in Section 6.3.1.

Spatialised music-making or composition is termed “spatial music” by Begault:

> When the spatial element of sound is unchanging, spatial hearing is not regarded by the listener as an important compositional or expressive attribute of the music. By contrast, a musical composition that involves any sort of compositional control over the apparent spatial location of sound is termed spatial music. In spatial music, the spatial parameter is either dynamic (undergoing change) or static (and calling attention to itself through the use of an unusual distribution of performers or loudspeakers). (1990, 46)

4.4.4 Music-space

We have discussed various concepts of musical spaces in Section 4.2, including soundscape, acoustic space and virtual space, and discussed structured spaces in various arrangements, theories and systems. Previous sections have considered how experiences of musical spaces are shaped, formed and produced. An important theoretical proposal in this exegesis is that the synthesis of one's experience of music and space could be conceived, as music-space.

The idea of music-space is my personal conception, introduced in this publication. It refines the concept of musical space as a more textural experience. This discussion begins with the experience and sensations of music in space, by considering musical components and their properties situated in space, and then discusses sensations of texture through the sensory modalities. Next I consider the role of gesture in music-space perception, and then examine a range of notions of musical spaces. To conclude I present a preliminary definition of music-space.

By way of introduction, some writers and musicians have come close to the idea. For example, Morgan suggests that “The extent to which music can properly be said to be "spatial"—or put differently, the question of the existence and attributes of something called "musical space"—is a problem that has long concerned aestheticians. My own concern is to look at the matter specifically from a musician's point of view” (1980, 527-8).

Morgan considers that the way to discuss musical space is to consider the materials of music, and how they are shaped. Musical sounds may be perceived to possess “volume” or “density” that seems to occupy or fill up space, and to have a “weight” or “density”, such that sounds are often described as “thick” or “thin”. Morgan suggests that “The combination of simultaneous events produces what musicians call "texture" (a term clearly betraying a spatial bias), and musical textures are characterised by, among other things, their degree of density” (1980, 528). Morgan's consideration of musical materials interestingly leads directly to texture, which is discussed later. Burrows distinguishes musical space from physical space, based on the ways in which sounds can flow around each other and superimpose themselves on each other (Dura 2006, 27). Dura relates similar qualities to sound saying it resembles and is related to imagination in that both consist of flow, flux, and ephemerality (2006, 29). Idhe relates music to space stating that the “surroundability” and “immersion” involved in listening to music implies the concept of a space, musical or physical, in which movement can occur (2006, 33).

Dennis Smalley is a key theorist on musical space, who speaks at length about the shapes musical entities[29] take in space, their size, location, shape, intensity and density, and qualities such as movement, thrust, and direction. In his 1997 paper “Spectromorphology: explaining sound-shapes” he defines “spectromorphology” as “the interaction between sound spectra[30] (spectro-) and the ways they change and are shaped in time (-morphology)” (1997, 107). This is a useful concept for thinking about, and perhaps discovering how to perceive shapes of musical entities, and how they change or evolve over time as textured shapes located within music-space. And this is the first concept mentioned in this exegesis that considers texturally the space occupied (or internal space) of an evolving musical entity, rather than, for example, the space of a whole soundscape, although acoustic space does cover the space occupied by a single sound source.

Among many other notions of musical space, Smalley defines “vectorial space” as “the space traversed by the trajectory of a sound”. Additionally he describes the note as “the basic gesture-unit of instrumental music”, and gestures are further discussed later in this section. Smalley considers the note as having an onset, a continuant and a termination, similar to attack, sustain, and decay. He defines a shape and a “lifetime” for the note, and asserts that the notated version is dangerously reticent on this kind of information.

Before continuing this discussion it is worth making a few considerations in regards to Smalley's work. Firstly, he is largely concerned with acousmatic music: pre-recorded music that includes non-acoustic sounds and processed sounds, which is “invisibly” presented via loudspeakers. Smalley considers acousmatic music to be “the only sonic medium that concentrates on space and spatial experience as aesthetically central” (2007, 35). I contend that the *HarmonyGrid* is also a means to explore music-space. Smalley's emphasis on acousmatic music is not problematical —rather it allows a heightened awareness of non-visual senses and therefore music-

29 I use the word “entities” here, to distinguish from the previously used words musical “components”, which referred to compositional components e.g., a riff, or components defined by their musical parameter.

30 Smalley refers to a spectrum as “the internal components which make up sound” (2007, 44), yet its difficult to ascertain if he uses the term in the usual sense, as in a “spectrum of frequencies”.

space—but the addition of the visual comes into play with live performance when considering gesture later on. Secondly, Smalley does admit that he considers space from a static listening position. One of the chief means of perceiving music-space, as presented in this research and with the *HarmonyGrid*, is to move around within the space, sensing the texture of music-space. However, from his static perspective he produces a large and fruitful discussion on musical space, and constructs many definitions and types of space that are intended to help establish a framework, from which we can begin to seriously discuss music in space. Additionally, as stated earlier, he is mainly concerned with "chunks" or gestures of sound as musical entities in space, that can be partially defined by their context and their means of production; as opposed to a spatial continuum or contiguous space, although he does briefly consider a "background space". However, a strong point is his emphasis on trans-modality, particularly as it applies to gesture.

Morgan constructs a scheme of musical space by considering "locations" of significant pitches in "tonal space", and subsequently "a more generalised musical space" which includes compositional elements (1980, 529). He considers that "If, as in the physical sciences, one thinks of space as an ordering of individual events in relation to one another, rather than as an absolute physical medium, then clearly the spatial model is eminently, and inescapably, applicable to music". This is similar to Smalley's views in that an array of events or elements are of chief interest. Morgan also considers musical time to be sufficiently different from "psychological time", because of its structured spatial quality.

Although texture is generally regarded primarily as a tactile, and secondarily as a visual and spatial concept, I am using the notion of texture to convey localised musical experience or sensations in music-space to musical sounds or components, and/or the entire musical/spatial experience available to the perceiver. Smalley links texture with music-making, saying "Our sense of texture is learned through vision and touch as well as sound; our experience of the physical act of sound making involves both touch and proprioception" (2007, 39). Morgan also links combined musical events with creating texture. An example of musical texture is chords or harmonies that may have a texture to be heard, felt and experienced, or the entire musical fabric of a composition currently playing may have a texture to be heard, felt and experienced. The experience of texture also may be partly metaphorical, mapping or overlaying a mental conception on top of a musical/spatial experience.

Sensations of music-space include the normal sensory components of musical perception – hearing and listening, musical comprehension, sense of vibration, and pressure waves or the force of loudness upon the body. Other sensations of music-space include the spatial perceptions of vision, kinaesthetic, olfactory, and gustatory senses, the sense of balance (vestibular sense), and other modes of sensing body orientation including proprioception and gravity.

Smalley is concerned about physical gestures, gestures made while playing instruments, and the way people interpret sounds they perceive in terms of these. Rarely do they listen without this overlay of interpreting gestures, as in "reduced listening" which is Schaeffer's term for removing or stripping away a sound's real or supposed source and the meaning it may convey. Sounds are usually treated by listeners as vehicles. Smalley presents the idea of an original gesture, a "*primal gesture,* on which sounding gesture is based, [which] occurs outside music in all proprioceptive perception and its allied psychology" (1997, 112). Smalley creates levels of "surrogacy" from the primal gesture, extending outwards. First-order surrogacy projects the primal level into sound, where "many unique sound-gestures are transplanted directly into music from this level, for example gestural play with materials like wood or metal", and second-order surrogacy is the traditional instrumental gesture, third-order is where the gesture is inferred or imagined, and "remote surrogacy" where only vestiges of the original gesture remain (1997, 112). This schema is useful in considering how the listener interprets musical sounds. Akin to the idea of sounds as vehicles, is Smalley's concept of source bonding which he defines as "the natural tendency to relate sounds to supposed sources and causes, and to relate sounds to each other because they appear to have shared or associated origins" (2007, 37). Therefore, sounds may be related to gestures or to sources, or to sources via gestures. An intuitive extension to this is that specific gestures may *produce*, in Lefebvre's sense, a particular shape and texture of musical space. Interestingly Smalley notes that “most musics are texture–gesture mixtures, either in that focus shifts between them, or because they exist in some kind of collaborative equilibrium” (1997, 114). Parts of a composition may be perceived as gesture-carried or texture-carried.

Smalley introduces quite a range of notions of musical spaces.[31] Some of these describe physical areas or spaces around the listener, akin to mappings of listening or “awareness” space, some relate to perception of sound entities, and others relate to their functions such as performed space, gestural space and microphone space. For example, “prospective space is the frontal image, which extends laterally to create a panoramic space within the range of vision” (2007, 48), and “panoramic space” is defined as “The breadth of frontal space, extending to the limits of the listener’s peripheral view” (2007, 37). “Circumspace” extends around the listener, and includes perceptions of location, direction, movement and scale of sonic entities. “Perspectival space” also relates to sound entities, and Smalley defines “the ‘perspectival space’ of the acousmatic image as the relations of position, movement and scale among spectromorphologies,” (2007, 48) from the listener’s location. Additionally, “Perspectival space can be regarded as the flux in relations among three views – *prospective space*, *panoramic space* and *circumspace*.” And for some functional spaces, Smalley differentiates between a “composed space”, “space in all its facets as composed into the image” (2007, 53), and the “listening space” in which the music is heard.

Smalley identifies three delivery modes of “circumspace” via loudspeakers. The “enacted mode” where the space “is actively diffused, expanded and rearticulated in real time” (2007, 51), is a kind of enacted space without the complications of performance gestures. The “fixed mode” maintains a static spatial format, while the “automated mode” involves automated processes and systems, commonly associated with live interactive performance systems (2007, 52). Simple automated systems

31 Although these notions could have been introduced in sections 4.1.3 or 4.2, they are included here so as to be located with the discussion of Smalley's work, and because they specifically concern acousmatic music.

may simply assign sounds to the loudspeakers, with little or no attention to audio image subtly, and the third dimension of height can be lost – although gestural performance and other performance aspects can compensate for this. The delivery modes are frequently mixed in general use.

Although Smalley generally only considers the static listener, a type of "circumspace" called "immersive space" accommodates various listening locations "where the spectral and perspectival space is amply filled, surrounding egocentric space,[32] where the pull of any one direction does not dominate too much" (2007, 52). For interactive systems, audience attention operates multi-modally. "Immersive space" is akin to music-space created by the *HarmonyGrid* in that the space may be quite filled at times, and is formed and organised by the grid without any particular direction being favoured (in fact the grid may be orientated any way).

Two concepts similar to music-space are "circumspace" and Lotis's "ambiophony" (2003). Ambiophony "defines the global perception of the surrounding sonic environment" (2003, 258). A somewhat indistinct concept, ambiophony "is the voice of a place that encompasses all its sonic qualities" (2003, 257), and seems to entail the listenable space surrounding the listener, as a "diffused ambience", focussing on large-scale perception rather than distinct locations. The encompassed space is a container for spatial composition to be perceived within. Ambiophony is said to be strongly related to the acoustic properties of the listening space. In a similar idea, Smalley (2007, 47) considers "High sustained, continuant morphologies" may indicate the presence of space, an "aeriform presence, a means of suggesting space itself". A suggestion of a horizon or boundary produces a frame of space, as exemplified by "the spectral planes at the opening of [Smalley's composition] *Valley Flow*" (ibid), whereas other more defined entities are components of, or inhabit the musical space.

Considering the various notions of musical spaces, and in practical research with the *HarmonyGrid*, I have come to an idea of music-space that is quite similar to several

32 Smalley defines as the personal space (within arm's reach) surrounding the listener.

of the musical spaces discussed previously, including soundscape, acoustic space, aural architecture, circumspace, immersive space and ambiophony, but is rather more textural and “alive”—and therefore very conducive to interaction. The idea of music-space, is one of a geometrical multi-dimensional musical space, closely aligned with conventional three-dimensional physical space. Here is a preliminary definition:

Music-space is that space occupied by music, set within normal space, which may be perceived by a person located within, or moving around in that space. The music may be performed by live musicians, be prerecorded, or created electronically in the space. The person perceiving is assumed to be normally responsive to music (to not to have amusia). It is suggested that music-space has a perceivable “texture” made of tensions and relaxations, and to have spatial patterns of these formed by musical elements such as notes, harmonies, and sounds, changing over time. This results in a four-dimensional “tapestry”, experienced through immersion.

Several clarifications can be made. Firstly, music-space is phenomenological, it is perceived by someone—that is, it is not worth discussing if no-one is present. Obviously it is a fairly subjective experience but, along with all discussions about music and sound, there are commonalities of experience for most people, especially people from the same culture. The person perceives the general condition(s) of sound and music in that particular environment, as previously discussed in soundscapes and acoustic spaces. The person perceives music in the ways we normally discuss it, i.e. as a series of sonic events over time, having musical structure and function, and in the more specific musical terminologies of instruments, voices, chords, notes, spatial layout etc. In addition to all this, the person may perceive music-space also as one of the abstract mental representations, discussed previously as music representative spaces. Although music-space is a real-world experience, it could also be imagined. It is expected that the perception of music-space does not normally impede or alter our spatial perception, but rather *overlays*, combines with, or is concomitant with our spatial perception, providing an additional enrichment to it. It also may be combined with music representative spaces and/or knowledge about musical materials.

Smalley's spectromorphologies may inhabit music-space, and be experienced as musical texture changing over time. Spatially the music-space will often extend around and behind the perceiver's vision, beyond panoramic space, and like circumspace, include perceptions of location, direction, movement and scale of sonic entities. But unlike most of Smalley's musical spaces, music-space occupies continuous space including any gaps or silences in the musical texture, as with ambiophony.

The *HarmonyGrid* system has been developed to enable the experience and exploration of music-space, and the outcomes of these experiments and experiences is documented in Section 6.5.4.

4.5 Combining music representative space with music-space

Perhaps the ultimate musically and spatially satisfying condition would be an overlay of music representative spaces with music-space, in a real performance situation. Immersive music-making systems such as *HarmonyGrid* and, to a lesser extent, Holland's *Harmony Space*, with their explicitly visual musical symbols, have this capability. The *HarmonyGrid* allows the performer to access music-space immersively, whilst moving over and around a grid that presents a music representative space. The visual terrain, and its accompanying graphical design accompanies, overlays, but does not impinge on, the experience of music-space. This terrain is animated with icons representing musical components, so that components of music-space are graphically indicated. The visual and the musical work together synergistically, also aiding memory. The coupling of music representative space with the music-space facilitated by the geometry of the grid, operates via the sensor and projector technology. The *HarmonyGrid*, in a sense, becomes operational via the music representative space.

In Section 4.3.1 we explored the link between geometry and music, noting that Kant proposed “embodied connections” between internalised space and time, and external geometry. This parallels the connection between internalised knowledge of music structures and music representative space and its geometries.

4.5.1 Conclusion

A discussion of general concepts related to the perception of music and space, created a basis from which to examine various concepts of musical spaces, including soundscape, acoustic space, and more traditional perspectives. More structured musical spaces include aural architecture and virtual spaces. With the addition of musically specific visual data, such spaces become music representative space. A discussion of this includes historical theories and the more abstract theories including those of Lerdahl and Mazzola. A cluster of topics including the production of space and immersion provided the impetus toward considering experiential music space, concluding with a discussion and definition of music-space. Music-space and music representative space are then considered together as a synthesis, as an ideal, as facilitated by the *HarmonyGrid* and, to a lesser extent, Holland's *Harmony Space*. In particular, I have outlined my theory of music-space, a new definition of experiential, concomitant music and space.

The next chapter describes the *HarmonyGrid* design in more detail, and Chapters 6 and 7 apply the ideas of music-space and music representative space to GMSs, and in particular, to the *HarmonyGrid*.

Chapter 5. The *HarmonyGrid* design

The *HarmonyGrid* is a scaled-up GMS, with the following main features:

1. The grid is a 4x4 matrix projected onto a 2x2 metre area on the floor from above
2. Full body location becomes the spatial input to the grid. The system becomes partially immersive in four related ways: spatially, graphically, sonically, and musically
3. Detection of body location by tracking enables hands-free operation, thereby allowing the musician/performer to play a musical instrument in addition to "playing" the grid system
4. Visual information regarding musical parameters may be enhanced.
5. A remote control device is worn on the body of the performer
6. A generative music system plays accompaniment that can be added to and transformed during performance by movement on the grid or via the remote control.

Given the richer knowledge matrix, the user or musician may fully engage with the music representative space (comprising existing spatial knowledge of musical materials). The result is that the music representative space is overlaid on, and combined with, the music-space (see Section 4.4.4). Part of the rationale for developing this system is to create an enhanced audio-visual performance presentation, through interactive musical, graphical and spatial activity.

This chapter presents a detailed description of the *HarmonyGrid* including an explanation of all its functions.[33] A brief overview of the *HarmonyGrid* was provided in Section 1.5, which included a photograph of the system in operation. The present chapter provides a formal and detailed description of the system, firstly, from an engineering perspective by way of its physical and functional components, and

33 Chapter 6 will provide further evidence of the performative affordances of this system, especially in relation to music improvisation.

secondly, from a musical and performance perspective.[34] Two additional sections cover control of the system and the building of an interactive system. Finally, there is an introduction to how the system's various aspects relate to the main themes of this exegesis, a discussion that is continued through all subsequent chapters.

5.1 A detailed overview of the system.

This section provides an overview of the system, before getting into specific detail in Section 5.2 of music production and the grids. A list of terminology used for the *HarmonyGrid* is followed by overall system layout, the grid and its graphics and mechanisms of activation and detection, concluding with software program flow and a discussion on paths.

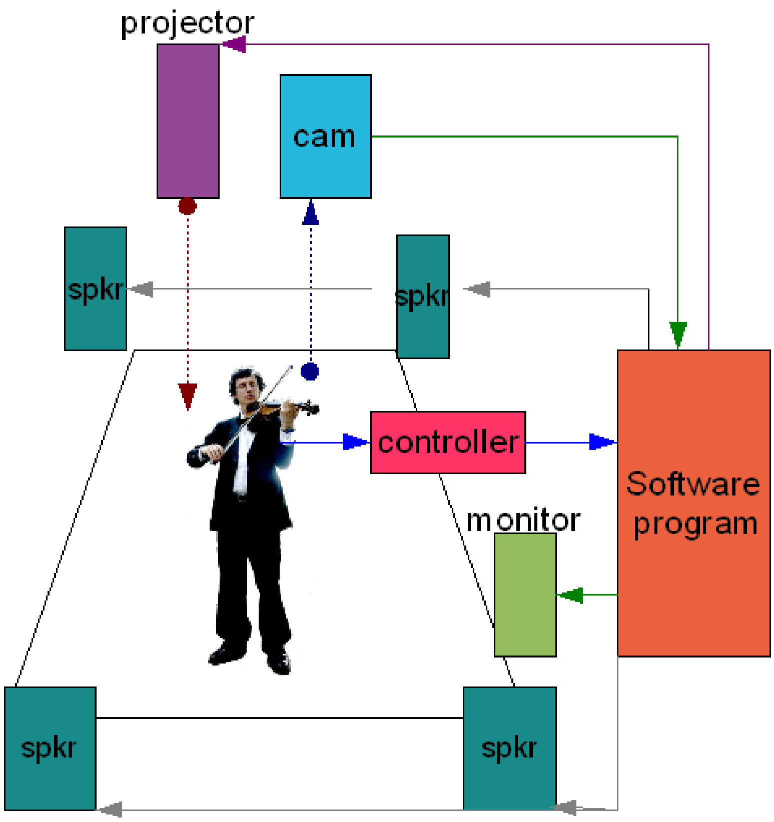

Figure 22. System components and flow of information.

34 Video 15 on the DVD covers a complete walk-through explanation of the system, and its functions.

5.1.1 Terminology

Below is some terminology used for describing components and functions of the *HarmonyGrid*:

Active part—the main part "performed" by the performer moving around the grid, which actively triggers musical harmonies, arpeggios, or groups of notes

Voices 1&2—independent musical voices (that must be recorded before being played) are shown by moving icons on the grid, and heard as separate musical voices or parts with individually assigned timbres (The older names of Sample 1 & Sample 2 linger in the software and menu screens)

Steps—steps in a sequence of squares including their corresponding notes/chords. Sequences of steps can be looped continuously until cancelled or altered. The number of steps is selectable prior to "recording" the sequence

Recording—here refers to storing a sequence of squares (or steps) in the computer's memory

Metro pulse—the pulse generated by the main metronome, which is the main clock pulse for the whole program. This corresponds roughly to a crotchet pulse at faster tempi, and to a bar pulse for slower ones

Volume grid—the grid displaying volume as the accessible parameter

Rhythm grid—the grid displaying rhythm as the accessible parameter

Timbre grid—the grid displaying timbre as the accessible parameter

Harmony grid—the grid displaying harmony as the accessible parameter, not to be confused with the name of the whole system, the *HarmonyGrid.*

5.1.2 The overall system

The *HarmonyGrid* is a hardware/software system. Setup starts with placing a white mat on the floor, and rigging a projector with webcam attached, directly overhead. The computer is placed nearby, and connected to the sound system and surrounding four speakers via a mixer. Software is loaded on the computer and initialised, and sound output checked. The projection is aligned with the floor mat, and then the webcam detection must be aligned with the projected grid. The speaker placement needs to be aligned with the grid: to be more specific, icons at particular grid squares should trigger sounds precisely located at those squares. Once everything is functioning correctly, the performer puts on the lighted hat and controller, and carries a musical instrument. Further detail and fine tuning of the setup is discussed in Appendix 1 (see Figure 22 for layout of the system).

System components include:

- a computer (with bluetooth, double-headed graphics card, and soundcard providing 4 channel output)
- webcam or video camera with a five-metre lead
- video projector with a five-metre cable
- *Pd* software program,
- VST synthesizers – presently set up with *Zebra* software synthesizers
- Bluetooth dongle (if not build-in)
- custom-made controller incorporating the *Arduino* Bluetooth controller
- custom-made lighted hat
- 2x2m white mat (semi-reflective)
- sound system (preferably in four speaker array around the grid and audience) and mixer if necessary
- improvising performer with portable instrument.

5.1.3 The grid

The grid is a 4x4 matrix of squares with thin coloured borders, projected onto an area of around two metres square, straight down from approximately four-and-a-half to five metres above the floor. It was found in testing that around fifty cm squared was a comfortable size of squares to stand on, and partially cover or shadow with an instrument, whilst being able to see the neighbouring squares. Regular projectors require around four-and-a-half metres focal length in order to expand the projection to cover two metres squared. White linoleum has been used as a floor/screen to show up the projection, but any pale semi-reflective material would suit. A choice of four grids provides access to the musical parameters of volume, rhythm, timbre, and harmony,[35] and their subtly animated projections. The graphics are controlled by the

35 This should be labelled “pitch” more correctly, and Section 5.2.1.4 discusses the choice.

software in real time. When a grid representing a musical parameter is selected, the software reads a lookup table, to determine the graphical layout to be displayed. The change is effected within a fraction of a second.

5.1.4 Graphics

Each grid has its own distinctively designed graphics. For volume, blue circles represent volume levels by their relative size (larger for increased volume) (Figure 23). For rhythm, icons for each square show an upper and lower set of note stems, like quavers, for the rhythmic grouping assigned to that square (Figure 24). For timbre, somewhat animated coloured circles represent the level of each of four types of timbral filters (Figure 25). A separate colour represents each filter. These include filters specifically assigned to the current synthesizer sound, like envelope cut-off, resonance, drive, gain, VCO and LFO controls, comb filters, etc. For harmony, Roman numerals show chord symbols for the particular grid layout read in from a table (Figure 26). There are currently five layouts to choose from, and a further discussion about these designs occurs later. The colours for the squares and chord symbols are taken from Scriabin's colour scale (Wells 1980, 103) (Figure 27).

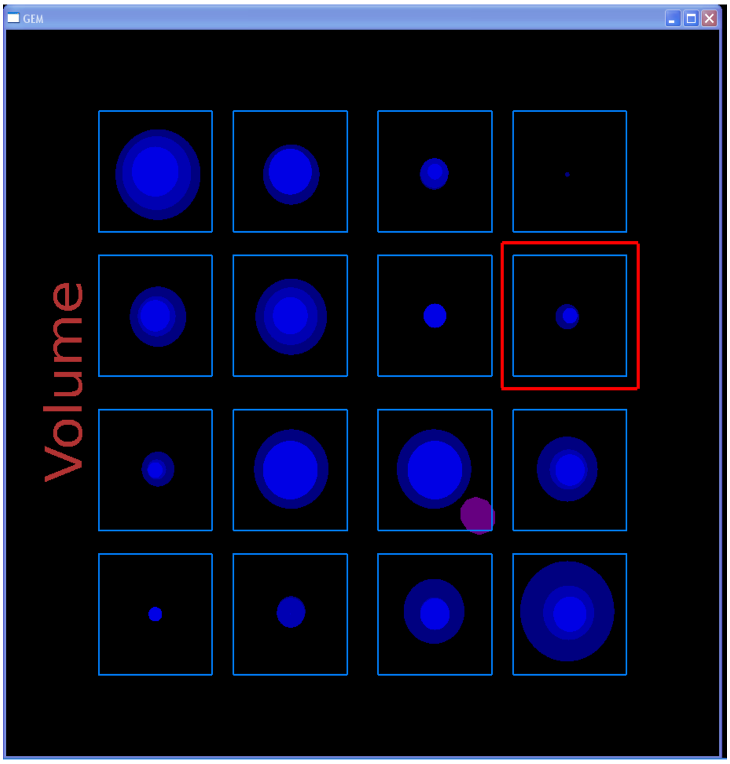

Figure 23. The Volume grid, with the Active square outlined in red.

Figure 24. The Rhythm grid.

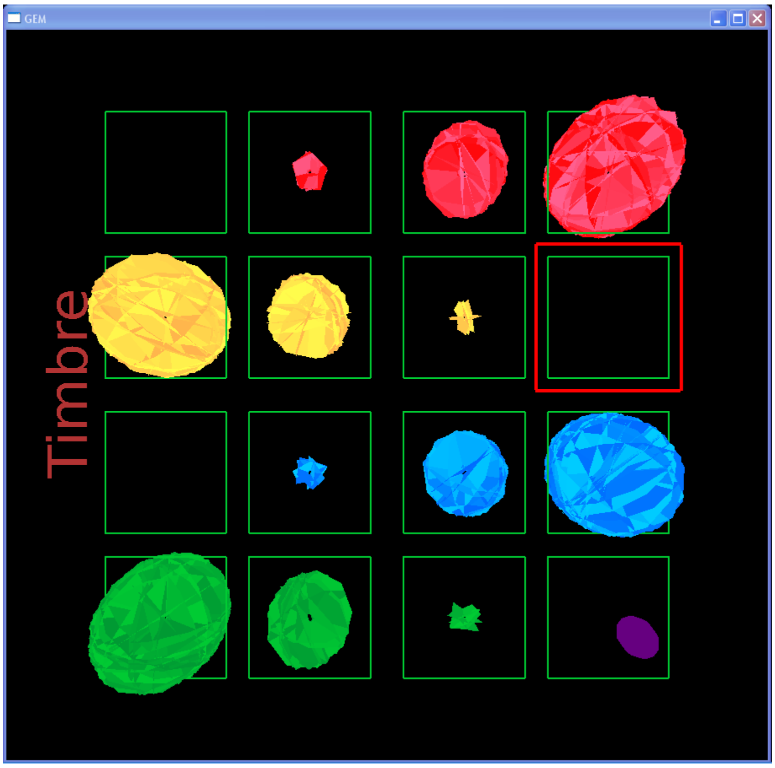

Figure 25. The Timbre grid.

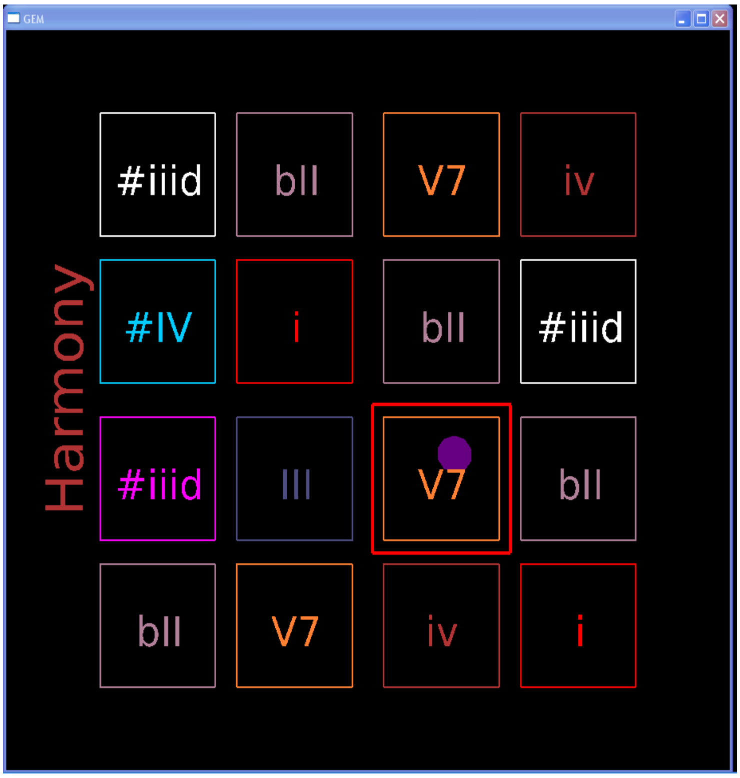

Figure 26. The Harmony grid.

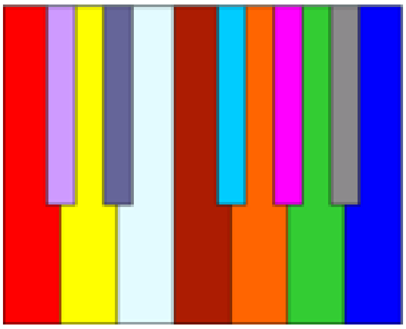

Figure 27. Scriabin's colour scale (red is C) was used to colour the Harmony grid squares.

As the performer moves on the grid, a purple disc (which may be switched off) shows the detected location of the performer. Where the disc falls at the time of the metronome pulse is deemed the “active” square, and its red border flashes with the metronome pulse and sounds the active part. The red square appears to follow or track the performer as he/she moves. Immediately the program has been started, a recording sign shows and the current set of steps (between two and eight) is recorded into the computer. Thereafter, the additional parts, Voice 1 and/or Voice 2, may be switched on and off as desired. The Voice 1 icon shows the blue quaver on red squares, and the Voice 2 icon shows the clear minim on the blue squares. These voices have borders that flash on the metronome pulse, and function musically as treble and bass parts. The icons track the recorded path continuously, until further instruction. They may overlay one another, or be offset rhythmically and graphically by up to seven or minus seven steps, and seem to follow or chase each other. These Voices function on all of the four grid parameters (Volume, Rhythm, Timbre and Harmony grids). The tempo of the whole system can be varied from very fast to very slow (from near 0 to 17 B.P.M.), and the graphics respond accordingly.

The graphics have been designed with several issues in mind. Aesthetically they are made to be pleasant and colourful, and form part of the overall look of the system in a performance space, which usually has the ambient lighting level low or switched off. Additionally, they are simple, to fit in with the somewhat “retro” styling of the grid and the menu screens. For accessing musical information, the graphics are intended to be simple to see and comprehend, even while moving at a reasonable pace. And from a system operation viewpoint, the graphics need to be not too bright and intense, so that the lighted hat can be easily distinguished by the webcam.

5.1.5 Visuals

An additional effect of the graphics is to provide a partially immersive environment for the performer to inhabit. This provides an exciting, colourful environment to explore and operate by triggering icons and numerals on the squares. The projected virtual environment on the floor of a real space forms a type of augmented reality (introduced in Section 3.3).

One small problem is that the performer creates a shadow, blocking out the projection beneath him or her. This looks insignificant to the observer, but can be a small hindrance to the performer trying to read symbols on the grid. A pair of projectors separated overhead by some distance, would have overcome this problem. Originally it had been envisaged that there would be another monitor or screen display of the grid at head height, positioned either behind or to one side of the setup. This would have required an additional graphics card in the computer, or some outboard splitting of the video signal.

Figure 28 Intriguing shadows on the *HarmonyGrid* during performance.

The grid projection in a darkened room looks lively and intriguing to onlookers, and the addition of the lighted hat on the performer adds to the spectacle. The use of reflective and sparkling fabrics was tested on the performer, with the intention of capturing some of the projected image onto the fabric for enhanced visual appeal. The effect was limited until further lighting was added. The addition of some coloured lights directed at the performer, from close to or on the floor, highlighted the performer's reflective apparel adding to the visual spectacle without interfering with the projection or detection systems. An unexpected bonus was the appearance of some intriguing shadows on the grid, cast by the performer's instrument and lighted hat (see Figure 28).

5.1.6 Activation and Detection

Upon detection of the performer on a square, that square is made active and the red boundary flashes in time with the metronome pulse. A camera (webcam or video camera) is mounted directly overhead, usually on top of the projector, and its detection is carefully aligned to the grid (see Appendix 1.1.2). A lighted hat (custom made), named the 'halo hat', is worn on the performer's head to facilitate detection from above, against the projection on the ground. (An LED light, such as for a bicycle headlight, can be substituted). A method of detecting overlapping boundaries is used in the software to determine the current square and to stop glitches between squares. This means the active area is actually slightly larger for the currently active square and provides greater stability for the tracking signal. The Active part, shown by the flashing red square underneath the performer, has its own individual musical voice, and may be arpeggiated (the Active part plays a pitch and may be arpeggiated even for grids other than the Harmony grid). It is automatically muted when Voice 1 and/or Voice 2 play.

5.1.7 Program flow

After setup, and checking that everything is functioning, the system commences with the Volume grid displayed. Nearly all program functions are accessed by buttons and knobs on the controller (see Section 5.3), the status of these being displayed on menu screens on the monitor to the side of the grid (details of technical control are located in Appendix 1.) Pressing the Start button starts the Active voice sounding on the current synthesizer voice setting. Sound or patch selections for the synthesizers are available at any time, using the controller buttons and the Instruments menu on the monitor (for details see Appendix 1).

The system creates a generative musical accompaniment using modified arpeggiation, primarily for the Active voice and Voice 1, with various rhythmic schemes, to be detailed in Section 5.2.2. The arpeggiator may be started, and the performer may commence moving around the grid and improvising with it. Paths may be recorded (see below), and the grid is selectable for the desired musical parameter. The Harmony grid comes with a choice of five grids (or harmony layouts, discussed below), and the musical scale may be selected from seven major and minor scales. The tempo is adjustable—quite radically if desired—and Voices 1 and 2 may be switched on and off. Voice 1 can be set to perform arpeggios, single notes or chords. Voice 2 has controls for a phrasing arpeggiator, rhythmic patterning, and an octave switch (necessary to raise some bass voices). All voices have separate volume controls. Normally the system is rhythmically quantised to the metronome pulse, but a particular feature is the Dance mode, where single pitches are triggered in free time by “dancing” around the grid. Here the metronome pulse is switched off, but the grid square triggering is somewhat quantised to keep some rhythmic integrity. Dance mode includes its own selection of synthesizer voices.[36] When switched off, the system returns to the previous settings.

The program has a facility to read and write 'Preset' files that set up most functions and parameters, including the selection of the grid, paths, number of steps, scale, tempo and instrumentation. The choice of functions to be read or written is also selectable. In addition, a 'RandomFile' button sets up the above functions randomly, and can be used at any time.

5.1.8 Paths

A path is a sequence of cell activations. The performer may choose to record a path with between two and eight steps, which is then stored for the current parameter, e.g. the Volume path on the Volume grid. Paths are played when one or both of the Voices are activated; these voices only operate to play paths. Paths may be written from the current grid to another parameter at any time, e.g. the Volume path may be copied to the Rhythm path. Paths (of the same length) may be recorded and stored for each grid. Paths for each of the other parameters may play whilst on the current grid. Voice 2 is only available for the current parameter—all other paths are aligned with Voice 1.

While the *HarmonyGrid* allows path recording using the grid and controller, the system status is also reflected visually in the *Pd* patch. Figure 29 shows a section of the patch that relates to the selection of grid. The top yellow buttons select the displayed grid. The bottom coloured buttons select which paths are playing. Selecting the “All” toggle on the left plays all paths, and deselecting “All” returns to previous selected paths. Note that the switches appear in another configuration on the controller display screen for the performer—see Appendix 1.2.2 for an example.

36 During testing it was frequently found preferable to use sounds with a clear attack than to use the currently active sound.

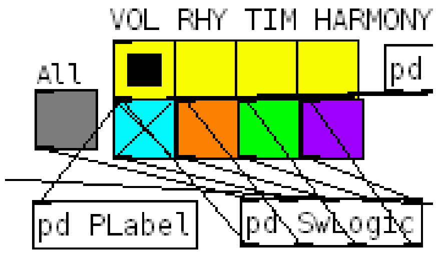

Figure 29. Switch array on the main program screen, to illustrate functionality.

Normally, only the current grid's path shows graphically on the projected grid, unless All_Paths is switched on (see Figure 30). In this mode all four paths (or however many have been recorded) are shown stepping around the grid at the current tempo. This graphical mode doesn't interfere with the musical material generated, which continues playing.

Additionally, only the current grid's path sounds at the displayed locations. Other parameter paths add to the combined sound, but the location of those paths don't affect placement of current sounds.

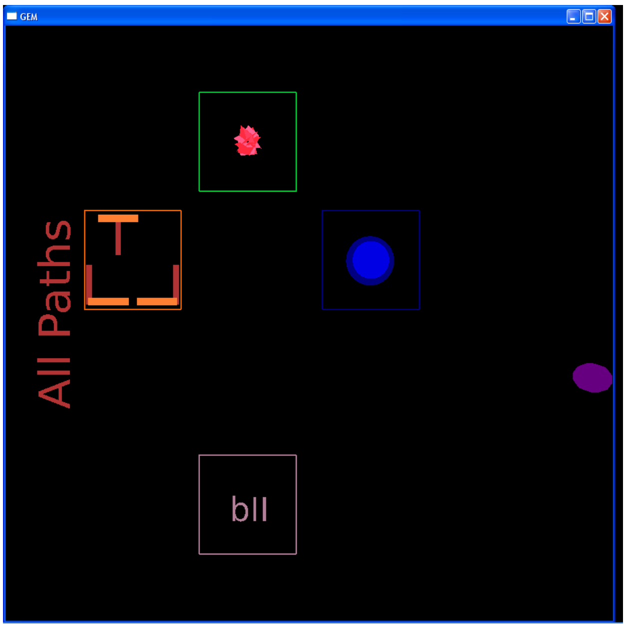

Figure 30. All_Paths displays all currently active paths. From top and clockwise: timbre, volume, harmony, and rhythm paths.

Paths may be recorded and played as a musical end in themselves, either for canons or for harmonic patterns with bass lines, or may form accompanying musical material whilst activating the grid live. An example of this would be moving around the Harmony grid, and playing along with one's acoustic instrument, whilst a Rhythm path accompanies. This subject area is covered in detail in Chapter 6, and specifically Section 6.2.2.

5.2 Music production

At the outset of project development, only the Harmony grid was imagined, and relatively slow movements from one square to another were envisaged, so as to allow arpeggios to sound for a sufficient length of time per harmony. The system was developed partly as a harmony generator to improvise along with, but also as a visible one where one could traverse a harmonic landscape. Later it was realised that a vast range of tempi was possible, and arpeggiators could be switched off to allow single notes to sound, at very fast tempi if desired. In this mode, minimalist music styles may be emulated, and canon (where Voice 2 follows Voice 1) can be set up and modulated (voice steps varied, scale selected, or even Harmony grid change—any of which affects the generated notes).

In the final design, the system runs as though it is in one-in-a-bar, triggered by the metronome pulse, the Active Voice is traced by the “flashing” red square that in recording or dance modes tracks the performer. The beat is outlined by the bass part (the Active Voice has treble and bass voices, separately programmable), along with quaver or semiquaver subdivisions of the arpeggiator (between two and eight, dependent on tempo). There is no pre-set timing specification, in terms of notated beats, and no time signature specified. The metronome pulse doesn't provide strong and weak accents, but a path may become metrically structured via its volume and rhythmic patterning. For example, a four-step path may seem like four crotchets to a bar in common time, given a suitable volume path. A limitation with such a clocked system is that it is not possible to choose whether or not to play the pulse. The pulse is continuous, and rests may only be implemented by selecting a volume level of zero for that step on the volume path.

5.2.1 The Grids

5.2.1.1 The Volume grid

The Active voice plays as described above, sounding notes or arpeggios based on the root note of the current scale (see Figure 23). A lookup table sets up the volume levels (about 6 different levels) for the grid squares. So far, only one grid layout has been provided. A recorded Volume path may be used later to affect a path on another grid, e.g. to modulate a path of harmonies.

5.2.1.2 The Rhythm grid

The Rhythm grid provides rhythmic percussion patterns for each grid square, set up by a lookup table upon starting the program (see Figure 24). These provide an "upper" and "lower" voice, depending on percussion sounds selected, that can specify a pattern of up to four semiquavers or semiquavers rests. For each pattern different percussion sounds are assigned to the voices. Overall, the sound scheme is changeable through eight different settings. Voice 1 or 2 can play a path of rhythmic patterns. If any of the other grid paths are switched on to play, pitches with or without arpeggiation will play also, with the relevant volume or timbre paths. If no paths have been recorded for these additional parameters, they play at a default level.

A typical use of the Rhythm grid would be to play rhythmic patterns accompanied by a Harmony path playing a bass line of pitches. This arrangement provides a musical texture to improvise acoustically with. A simpler arrangement is to trigger the rhythm patterns with the Active part only, and "jam" along with them.

5.2.1.3 The Timbre grid

A lookup table sets up the timbre effects and their levels, selected from 22 different effects and 4 different levels, for each square (see Figure 25). Each grid row affects a different timbral effect, pre-programmed into the synthesizers' patches (or programs).

Choices had to be made about the selection of effects associated with different synthesized timbre choices, as only some effects are audible for particular patches. Currently, only one timbre grid layout can be specified. A recorded Timbre path may be used at any time to modulate another path on the grid.

5.2.1.4 The Harmony grid

The Harmony grid specifies the choice of single pitches, or chords that can be made into a chord progression, by a path that navigates the harmonic space (see Figure 26). A selection of triads are semi-randomly played, for each square. Major or minor root, first inversion, or second inversion, augmented or diminished triads can be selected from a lookup table, based on the root note of the current square. The table sets out which chords are allowable for that root note of the selected scale. The ordering of arpeggio notes is randomly selected from five choices.

Although pitch would be more correct as a label for this musical parameter, I have used harmony as the name of the grid, because that is largely its function, and because harmony is a main emphasis and design choice in the *HarmonyGrid* as a system.

Five different grid layouts of harmonies are currently available (see Chapter 6, Figures 33 and 34). These represent a variety of schemes tested through the development of the system. The initial idea was simply to be able to form workable and pleasant chord progressions whilst moving around the grid, similar to using an arpeggiator. Harmony grid layout 3 was constructed simply and quickly to provide pleasant progressions. Harmony grid layout 0 is Euler's scheme from the 18th century (see Figure 20), with intervals of thirds running horizontally and sixths running vertically. Harmony grid layout 1 is fashioned after Lerdahl's (2001, 57) scheme, and Harmony grid layout 4 simply uses a simple pitch spiral ascending from the centre, to obtain small and large intervals dependent on radial distance.

5.2.2 Arpeggiators, phrase, and rhythm construction

The Active voice may play with arpeggiation. The note grouping, for example, four semi-quavers or six triplet semi-quavers, is selected based on tempo, playing more notes for slower tempi so as to maintain an arpeggiated style. For individual notes of the arpeggios, various humanising functions are applied to durations, attacks, and velocities, to keep them varying.

Voice 1 may play with arpeggiation. A rhythmic scheme for the distribution of note values (quavers, semiquavers, dotted quavers etc.) is selected from a bank of rhythms, depending on the number of steps selected for path recording. These note values are randomly ordered until all are used, to make the current pattern for the current tempo. Tempo is divided into ranges, from fast to slow, providing between two to five notes per pulse. A phrasing curve is created by adjusting volume levels for each note, depending on the number of steps in the path.

Voice 2 has independent phrasing with its own rhythms and pitches, used to create a lower or bass voice or part. To create rhythms, a random selection is made on each metronome pulse from nine preset patterns, to provide a series of durations for the current step. With pitch selection, two methods are available for use, both of which match pitches with the series of durations to form phrases. In the first method two computer compositional techniques are used, (i) probabilistic weighting of note choices, considered within the program as intervallic choices from the current root note, and (ii) a rule obtained from the literature on melodies (Huron 2006, 92) by which a small interval is likely to be followed by another small interval in the same direction. Interval movements of 2nds, 3rds, and 5ths are assigned increasingly higher weighted preferences, with repeated notes carrying the highest weight. In addition, the scale degree of the root note is checked to select diminished or augmented intervals where appropriate.

The second method is selectable on the main program screen. A similar probabilistic weighting to that above selects intervals, and similarly selects intervals appropriate to the scale degree of the root note, but also provides a random use of major and minor seconds. An additional melody rule from Huron allows a large interval to be generally followed by a direction reversal. A further modification is that if the current step is in the latter half of the path's series of steps, then the probability of an interval falling is increased by one third.

Overall, rhythm is created by the metronome pulse continuously triggering notes, and a subdivided pulse generator that controls arpeggios, in addition to the rhythm generators for Voices 1&2 described above. Rhythmic percussion patterns may also be selected from the Rhythm grid. With these few choices it is clear that direct rhythmic control is limited, as with many generative music systems and unlike a traditional instrument. However the choices reflect aesthetic decisions in keeping with the personalised nature of the *HarmonyGrid* design.

5.2.3 Audio output of the system

The *HarmonyGrid* system is built using the *Pd* software program that manipulates numeric data, which become MIDI messages sent to the *Zebra* software synthesizers. Note data generated by the arpeggiators, rhythm and phrase generators, includes pitch, duration, and volume information for each note in each voice.

The *Zebra* synthesizer has been selected for its high quality audio output and contemporary and interesting range of sounds or patches. Instrument selection of Zebra sounds is presented on the user interface in four groups of eight instruments, in the categories titled “tonal”, “dance”, “ethnic” and “odd” (or more unusual) sounds. The percussion selector has two banks of eight settings each. Instruments are selectable at any time via the controller, and an instrument selection display (see Figure 40 in Appendix 1.2.2) is shown on the computer monitor to the side of the performance area. Timbral effects are activated from the Timbre grid, and the data is used to select the effect and its level. Suitable effects (four per voice) have been pre-programmed for each of the *Zebra* instruments.

Spatial data from the grid drives both the graphical and audio outputs including panning in the two-dimensional (horizontal) plane of the quadraphonic sound system. Sounds generated for a particular grid square are heard at a quadraphonic location corresponding to that squares position on the grid. The required computer system includes a four channel sound card, which usually outputs to a mixer and then to the loudspeakers. During setup of the system, the acoustic or amplified sound of the performer's instrument needs to be balanced with the loudspeaker output.

5.3 Control of the system

The primary control of the *HarmonyGrid* is via the performer's location and movement around the grid, as tracked from webcam input. This tracking is continuous, and so is always on during performance unless switched off at the computer. The performer there needs to constantly be aware of his/her position on the grid and what is being altered as a result. A secondary control system is via the custom-made controller, which is a means to simply switch on and off functions, select functions, and adjust levels (see Figure 31). This secondary control is used intermittently, when desired. The idea of the controller is to enable the performer to manipulate all software functions while moving freely around the grid, and not have to return to the computer to use a mouse. Additionally the controller has been designed to be easy to use whilst holding an instrument, by situating it on the performer's chest and requiring only one hand to operate. Without it performer would need to leave the grid and go to the computer, lean down to see the screen, and use the mouse, with an instrument in hand.

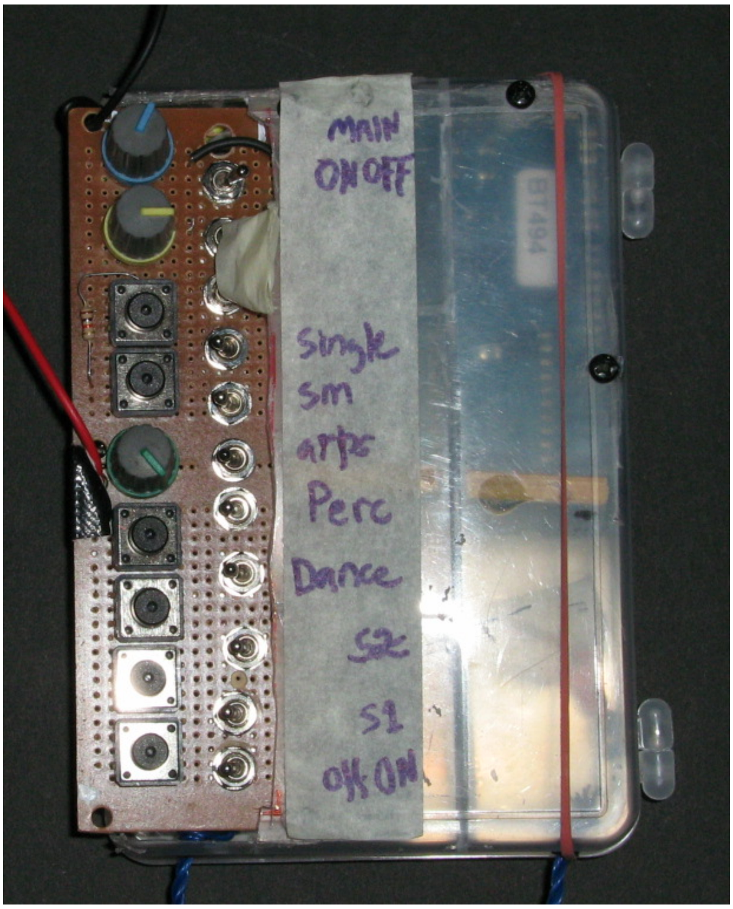

Figure 31. The *Arduino*-based controller, worn on the musician's chest.

The prototype controller is housed in a 14x10x4 cm custom-made box (see Figure 31). A collection of buttons switches and knobs input their signals to an *Arduino* electronic board,[37] which communicates via Bluetooth[38] to the computer. A four-layered control display shows on the secondary screen at the side of the performance area, providing visual feedback. The secondary screen also runs the *Pd* program's main page, with its own onscreen mouse-driven controls as a backup. The controller has buttons that start and stop the program, the voices, the recording of paths, the playback of paths, the settings of arpeggiators, and rhythm generators; it can also be used to select instruments for each voice, and the currently displayed grid. Rotary knobs provide tempo and volume controls. Dance mode and All_Paths mode are selectable. Video 15 on the DVD, from 7.04 minutes, shows the controller in the talk-through demonstration.

37 *Arduino* is an open source project, assisted by the team of Massimo Banzi, David Cuartielles, Tom Igoe, Gianluca Martino, and David Mellis. http://www.Arduino.cc/

38 Bluetooth is a short-range wireless standard for communications.

The controller sends rather erratic data that requires smoothing (the non-Bluetooth *Arduinos* perform much more stably), and some workarounds have had to be used. This first version of the switching layout in the controller, and the current version of the control display, make the system somewhat difficult to operate, and more refined versions are anticipated for the future. For instance, experience with the system shows that familiarity with the switches and knobs of the controller and accompanying menu displays is necessary, even though all changes are shown onscreen. A secondary issue is the interruption to the instrument playing in order to use the controller. The first issue could be improved by a more tactile design of the switches and knobs to reduce the need to look at the device.

5.4 Building an interactive system

There are many choices to be made when designing an interactive system, and often many difficulties to overcome. These issues were introduced in Section 1.3. The current section will itemise and discuss in more detail the issues and problems that were faced in creating the *HarmonyGrid*, and concludes with a consideration of music as an input to an interactive system. A primary design and construction choice was whether to build a software or hardware only system, or to combine the two. In building a combined system, additional equipment needed to be either sourced or designed and built, and then tested. Furthermore each component had to communicate correctly with the other components in the system.

The target user for the system needs to be identified, and in this case was a clear choice between the general public and the expert user (musician). The target purpose and, by association, appropriate type of performance or exhibition needs to be at least partly determined. The *HarmonyGrid* was originally created for a cluster of outcomes including performance, installation, and possibly education. Choices were made along the way, including aiming the *HarmonyGrid* at the expert musician, thereby restricting the range of users (this is further discussed in the next section).

The process for building the current hardware for the *HarmonyGrid* controller started by selecting the *Arduino* electronic board and then the controller built around it. Once the controller was working, the Bluetooth dongle and software had to be installed and setup. Following this, firmware was sourced and loaded onto the *Arduino* and, finally, the hardware to software connection could be programmed in *Pd*.

After some construction came the testing phase for the system, involving setting up in a variety of locations and carrying out performance testing. This involved informal feedback from several test users, both novices and experts, who helped by trying out the system at various stages of its development. As with much system testing, the use of novices quickly ironed out how the system was perceived to function, the degree of understanding that was quickly evident, and what needed to be made more explicit. This was an iterative process of testing, identifying faults and design improvements, as identified in the research methodology (see Section 2.1).

More technical details about the *HarmonyGrid* and instructions for use are discussed in Appendix 1, including details on the audio and video hardware components and their connections.

5.4.1 Design choices

As mentioned in Section 1.3, it was initially intended that the *HarmonyGrid* be an interactive installation for public access. One consideration for public use was that the casual user would need to feel engaged with the system quite quickly, in the order of thirty seconds to a minute, so as to be encouraged to continue long enough to discover and engage with the system's possibilities. To that end, the processes in the system would need to be quite transparent to the user. This interaction design goal led to a decision that a multimedia system would be far more engaging where the processes of production are made explicit, and are part of the theatrical fabric of the performance.

Upon reflection, it was clear that this design would be much more difficult to build than a design for the expert user/performer and may involve limitations to the expressiveness of the system that would be compromises for my own use in performance. It was also clear that the playing of an acoustic instrument in the grid space would require a proficient musician of some ability to improvise with the system and to understand and follow written harmonic patterns displayed on the grid. The decision to focus the design on proficient musicians allowed the visual representation of knowledge to be very specific, e.g. Roman numerals for harmonies. For the general user, visual information would have to have been reduced to a simplistic level, possibly undermining musical quality. However, at some future stage, other strategies may be tested to adapt the system for a broader range of participants (see Section 7.2).

It was always felt that a real time interactive system was the key to an engaging performance. Interactive systems such as the *HarmonyGrid* blur the lines between performance, play, and art participation and experience. Indeed it was a personal goal for this research to break down the ritual of audience engagement in traditional artistic performance, and to replace it with a more spontaneous flow of interactivity, with the less formal feel of gameplay. As suggested in Section 7.2.1, it may be a possibility at some future time to allow more participants onto the grid, and in some circumstances, non-experts such as children. This would further break down the formality and ritual of traditional audience engagement and open up exciting possibilities for education and enjoyment.

5.4.2 Music as input

Music as the input, can arrive at the system as either sound or gesture. Sound as input starts with the relevant parameters being extracted or filtered out of the signal, such as volume, pitch, rhythm or timbre. Then these are mapped to another mode, often graphics and/or text, and used to generate appropriate musical output. The output of interactive systems is usually multimedia, operating in several modes such as music and graphics (video displays, instrument displays etc.).

Using sound as part of the interface for interactive systems, including games, has been a relatively minor occurrence due to technical constraints, but is increasing in popularity as computing power and algorithmic analysis processes improve. It was an ideal for this researcher to use musical audio as input, and this has been the subject of some experimentation, but for the current project gestural input proved to provide sufficient scope for experimentation.

In the last few years, it has become increasing popular to use musical input for arcade and video games. Normally, this is not sound itself that forms the actual input, but gestures provided by input devices: mouse, joystick, and touchscreen. These gestures typically transmit rhythmic material and different triggers are used for each pitch, track, or musical part. Pre-recorded music usually forms the output, with graphical representation of instruments, sound waves and so on, added for contextual effect. For example, the game *Guitar Hero* allows gamers to “play” a simplified representation of guitar strings with the pen on the screen of the Nintendo *DS*. Other versions provide a pseudo-instrument, such as a guitar-like controller or touch pads to “play” the drums,[39] along with “scores” for rhythmic accuracy. Another type of game with rhythmic gestural input is the dancepad games, where players must step in time to the music, on specific locations or pads on the dancemat, with targets and successes indicated by the graphics (see Section 3.1.4).[40] A recent dance game in a Brisbane arcade (June 2008) presented the dancemat as a screen about 1.5m square, with graphics projected onto it from below. The graphics included animations, along with the usual cells for dance steps, some narrative elements, and game scoring.

Interactive systems that involve music as input include those by practitioners Jonathan Impett and George Lewis. Impett works with his “meta-trumpet”, an extended instrument, which he describes as “an integrated interactive instrument–interface–composition system” (1996, 203). For the composition *Mirror-Rite* (1994), the trumpet's output creates live and processed sound, while the positioning and directional movement of the trumpet in space also influences software to process compositional material. Most data including sensor data from the valve magnets and mouthpiece can be mapped to any performance parameter. The software processes

39 Where the drumpads are close enough to the real thing, this is arguably music as input.
40 In one earlier version I played, the graphic indications and subsequent 'scores' did not match the tempo of the music!

data on two levels, system and composition, manipulates audio samples, and performs compositional procedures such as grouping musical events into “scenes”. “The piece functions as a complex of simultaneous event-driven algorithmic processes” (1996, 204).

In Lewis's composition *Voyager* (1993), as in earlier works, the piece functions as an improvised concerto performed in dialogue with the “computer-driven, interactive chamber orchestra acting as a 'virtual improvisor'” (1999, 103). The computer analyses the incoming music and generates complex responses, outputted via a sampler. Combinations and processes between the sixteen sampler parts are partly influenced by pitch-follower data from the performer. Volume, velocity, sounding and inter-onset durations, pitch, octave, register, interval, articulation and silence are among the variables influencing the composition.

Cipher (Rowe 1993) and *Jambot* (Gifford 2008) are improvising “robot” computer programs that respond to external improvised music, typically from an acoustic instrument, with generated musical output. *A.Shooter* (a.Game 2005) is a computer game that has no graphical output—game play involves shooting a sound source that moves across the stereo field, with the mouse.

HarmonyGrid uses movement in space (on the grid) as the input to the system. The intention is that music is sensed or felt as the medium being interacted with, that it feels like the input medium, *via* space. At the current stage of development, improvised live music does not feed back into the system, as this would vastly add to the complexity of the software and is beyond the scope of the present research.[41]

5.5 Summary

Chapter 5 has provided a detailed overview of the new system, the *HarmonyGrid*, listing system components and describing functions and software flow. It has included a discussion of music production processes and described the technical

41 It would require signal processing and intelligent music detection to “understand” the musical input, and then a processing module to shape the current output accordingly.

procedures from the perspective of each musical parameter represented. This chapter also discussed the process of building and controlling an interactive system and the many choices involved. It has essentially laid the groundwork of a new GMS. This sets the scene for an extended discussion of performance with the system to be provided in Chapters 6 and 7.

Chapter 6. Discussion: Music-making with the *HarmonyGrid*

Having defined and described GMSs, developed a perspective on music and space, and fully described the new *HarmonyGrid* system in the previous chapters, the exegesis now turns to an integration of these topics, by discussing the complete performance system in all its aspects, including technical, presentational and musical perspectives.

Topics addressed in this chapter include the mapping of music to space using grids and paths, and in particular the mapping of harmonies to the grid, prior to the main subject of making music with the *HarmonyGrid* system. Other topics developed here include space and immersion, and performance considerations with GMSs such as movement. The final sections compare and contrast the *HarmonyGrid* with other systems, to illuminate the advantages of this system. The discussion will be contextualised by referring in depth to the two scaled-up GMSs, the *HarmonyGrid* and Holland's *Harmony Space.*

This chapter refers extensively to the video examples on the DVD that demonstrate musical and technical issues under discussion. The reader is also referred to the video examples in Appendix 2, where the first section provides a listing of events on each of the videos as they occur on the DVD, and the second section provides analyses in table form.

6.1 Mapping between music and physical space

Music may be mapped to physical space, which may be overlaid with a visual display or graphics. Visual music refers to “time-based visual imagery that establishes a temporal architecture in a way similar to absolute music. It is typically nonnarrative and non-representational” (Evans 2005, 11), and may accompany music or even be silent. This art form has its roots in the work of Oskar Fischinger (Moritz 2004) and John Whitney, who reported he was “devoted to the concept of an abstract visual art of motion structured in time” (1980, app. 183). Visual music also refers to methods or devices that translate music into a related visual presentation. Sometimes visual music is called “colour music” and it has often been associated with colour organs, including Oskar Fischinger's *Lumigraph* (Moritz 2004, 137) of 1951 and the updated *21st Century Virtual Color Organ* by Jack Ox (2001). In recent decades visual music has been popularised through contemporary “VJ-ing”[42] and music “visualisers”, which display animated graphics in response to the user's music selection on computer music players such as *Windows Media Player*. These recent forms are illustrative and evocative rather than explicitly representing musical data.

The mappings range over a continuum, from obvious and explicit animation of sounds and music, to an amorphous relationship. Examples of the former include “Cathedral Music Animation” (Crognale and Lytle 2005) which precisely animates and synchronises the playing of fantasy instruments to music, Michal Levy's “Giant Steps” animation of Coltrane's music (Levy 2001) with its more artistic representation, and Disney's “Fantasia” (2000). Examples of the latter include many early experimental works and Whitney's first digital piece, “Arabesque” (1975).

Alternatively, space may be mapped to music, converting images to sound. This may be done with drawn objects and figures on a film's soundtrack, in a technique known as “drawn” or “graphical sound”, or by rendering images and paintings directly as music with software such as RGB Music Lab 35 (Kojima 2010) or MetaSynth (U&I Software 2010).

Some internet-based interactive works can demonstrate the possibilities of mapping music to graphics and vice versa. *Grotrian pianos* (GROTRIAN Pianos n.d.) allows graphical action and intervention to create and affect the music. By placing coloured squares representing pitches within a rectangle onscreen and allowing them to “bounce” off the sides, pitches are sounded to form musical textures. The simplicity

42 “VJ” is the equivalent of “DJ” but for video—a video performance artist.

of the analogy with bouncing balls provides a wonderful animation to time the playing of multiple pitches. Many other examples may be played on the Soundtoys website (Stanza 2011). Downloadable programs include *Music Animation Machine* (Music Animation Machine n.d.) which converts music from MIDI files to graphics in "piano-roll" style, and VJ programs such as *Neuromixer* (Neuromixer n.d.) which maps tempo to affect the graphics.

In GMSs, the grid provides the format for physical space on which the musical data is displayed, and therefore becomes music representative space (see Section 4.3). Interaction with the graphics appears to directly affect the music, but this actually works via a tracking mechanism with large-scale GMSs. Movement on the grid creates paths, shapes and even gestures for smaller systems, that are displayed by the graphics. The time and motion of music then becomes an animated visual display, or interactive visual music.

6.2 Design and function: the grid and paths

In this section I discuss the physicality and functioning of the grid and paths, before considering the application of musical data to the grid environment in the following section. At the level of the grid design there are two issues that need to be discussed at this point: the grid design itself and the functionality of paths.

6.2.1 The Grid

The *HarmonyGrid* design maps music to space, and each grid square can provide up to four single values or choices.[43] For example, a harmony square triggers the harmony assigned to that square in the Harmony grid. If a path is switched on for another parameter, the square will also trigger that relevant parameter value, and so up to four types of parameter values can be mapped to one spatial location. Currently there are five alternative mappings for the Harmony grid, and one each for the other grid types, making it a total of eight possible values per grid square, but only four values are in use at any one time. A higher-order mapping could have been

43 A harmony represents one choice, or one item, but informationally holds several values, including the root note and intervals above that for each note of the chord.

implemented, for example, where triggering a location creates a melodic shape, i.e. an array of values for that parameter, however it was decided that there was already sufficient complexity to manage as a performer. Although *HarmonyGrid* maps single values per square, in the case of the grid of harmonies the relationship of the squares has a design and meaning, and so the matrix of values has informational value.

The choice of a small grid was originally designed to facilitate a relatively simple system in order to explore the ideas of spatialised music. The choice presents a reduction of decision space, as in, for example, the use of a tone row in musical composition. The grid could be made to be infinite, as with *Nodal*, or have a wrap-around geometry, as in the toroidal spaces of Lerdahl's chord lattices (2001, 57-8), but these options were considered unnecessary. The small number of cells in the *HarmonyGrid* limit the amount of visual information displayed at any one time providing a partial network picture. However, the large cell size of the *HarmonyGrid* can show more information than cells in the small portable devices which may display only on/off status with the backlit buttons.

A feature of the *HarmonyGrid* is the constraint or necessity to inhabit the confined grid, that often requires the performer to loop back, to cross over previous paths, and to see loops of harmonies played out. The projected grid currently occupies around two metres squared and adding more squares would require additional floor space. The current size seems suitable for several likely performance venues, including foyers, galleries and private events. Limitations and constraints are part of any simple system or game, and help define the character of that system. A limitation of *HarmonyGrid* is that one cannot jump to a square further than one square away, without triggering the intermediate square. Workarounds include jumping outside of the grid and running around it, or slowing the tempo so as to have time to get to the target square. However, as in any system, limitations make operating in that environment simpler as there are less decisions to make, and obvious ways to proceed. Section 6.7.2 discusses limitations in more detail.

Decisions as to where to move next on the grid involve several factors. Firstly, there is the informational content of the squares, which may make them desired targets, moderately desired targets, and targets to avoid. Secondly, there are the possible physical moves required to navigate to another square. As the grid is made of squares, the four internal squares have eight neighbour squares each, providing choices of perpendicular and diagonal movements, but the twelve outside squares have fewer neighbours with correspondingly limited movement choices. Many movements are direction changes, including reversals. This number of options keeps the performer fairly busy even at moderate tempi. Additionally, the direction the performer faces can affect the options in view; albeit that performer orientation is partially informed by where audience members are positioned and the location of the monitor screen that displays controller information. A larger grid may entail less frequent turns and reversals. Another possible consideration is that of any choreographic inclinations (see Section 6.6.3.1). The performer is also required to physically align with the squares on the grid for tracking purposes, which may involve checking visually the position of his/her feet on the grid, and paying attention to the musical feedback provided by the generative music system.

6.2.2 Paths

Moving on the grid makes a physical path that translates to a temporal chain of musical events. The path or visible 'plot' through space is visible and audible as a “plot” through time. There is some similarity to the use of notation, where traditionally a plot from left to right represents time. The grid is only used for immediate retrieval of information (plots or paths), whereas notation is used for permanent recording, and retrieval at any time later. A video recording of a performance might function partially as notation of the event. However, in an ideal system it would be possible to record all paths, and their offset starting positions, and the sequence of all Active squares, along with tempo data.[44]

Technically, triggering a cell is a case of binary decision-making, in that a cell is either activated or not. There is no other state for the cells, although the number of

44 Additional data may be desired—instrumentation, volume levels; and there would be a compromise to be made between functionality and complexity. A data “playing” software module would be necessary.

musical parameters activated may vary (see the previous section). A path is formed usually, but not necessarily, of adjacent cells, up to any number of cells, including repeating some, over time. A recordable path in the *HarmonyGrid* is from two to eight steps, which provides reasonable complexity for music-making. There is no provision for playing a path backwards. As the performer moves of his/her own free will, the paths may have any topology, twisting and looping back over each other at will. Other systems use direction-changing devices such as markers in software e.g. *Nodal*, or direction-specific blocks in block systems, as in *Blockjam* (Newton-Dunn et al. 2002). These are necessary in automated or computerised systems, where direction changes are desirable. Paths in *HarmonyGrid* are relatively simple due to the limited number of steps and small grid size, and the fact that all paths must have the same number of steps. Whereas, for example, paths may vary greatly in length and topology in *Nodal* or *M* and have multiple dead ends (see example files in the software).

As noted earlier in discussing movement choices, paths are somewhat determined by the informational design of the grid for the current musical parameter. Factors in play here include the performer's perception and understanding of the parameter values displayed, and his/her capabilities to make structured decisions around constructing paths of musical parameter values. This is relatively trivial for volume and timbre, but more complex for harmony. Naturally the performer will simply try out some simple paths, will inevitably make less desirable ones, and so re-record new paths. Previous paths for any one parameter are erased step by step when a new path is recorded.

The Volume grid is visually intelligible, but the Timbre grid, which also uses disc size is less obvious, it maps size of the coloured disc to the degree of the timbral effect, and relates colours to particular effects. The available effects vary with the selected synthesizer voice. However, selections make for listenable results, because the grid choices of timbral effects were designed with care. Generally speaking, it is large changes in values that may make a path sound uneven, overly active, or perhaps exciting. Many other coloured designs for mapping graphics to timbre are possible, but there is no definitive mapping, and so the system needs to be simple to read and memorable over the short term.

The spatial layout of rhythms on the Rhythm grid provides a special case in regard to mapping a parameter on the grid. This is partly because the rhythm groups themselves are temporal, (they occur over time), and like harmonies hold more than one value. Visual perception of the rhythm icons is problematic, as they refer to conventional notation, showing quaver groupings top and bottom, which are all oriented in one direction on the grid. The performer may require effort to visually select rhythmic groupings, one after another in real time, and initially may take several attempts to record a favourable path. However, generally speaking, the results are not critical, with many selections sounding well. Largely, the choices may revolve around the amount of percussive activity desired in a given path.

The original design choice to build a smallish grid reduces the decision space, as noted earlier. Such a reduction can have both positive and negative benefits—positive in that it is simpler with less choices and negative in that more choices can mean a better, bigger range. The grid could be made to be infinite or to have a wrap-around geometry, as in the toroidal spaces of Lerdahl's chord lattices (2001, 57-8). However, a feature of the *HarmonyGrid* is the necessity to inhabit the confined grid, to loop back, to cross over previous paths, or even to step outside and back again elsewhere, and to see loops of harmonies played out. The topic of limitations of this GMS is further explored in Section 6.7.2.

6.3 Mapping music to the grid

I now consider the application of musical data to the grid environment, concentrating on mapping harmonies, a key interest of the *HarmonyGrid*.

6.3.1 Mapping harmonies to the grid

By moving on the Harmony grid the performer engages with a progression through harmonies. Harmonies provided are of the diatonic system, with its embedded knowledge from centuries of use. The harmonies relate to each other functionally as part of that system, and this has been the subject of extensive musicological, philosophical and psychological research. Harmonies relate by consonance-dissonance theory, scale degree functionality, and the “rules” of harmony laid down by pedagogues since the latter half of the 17^{th} Century. Two current streams of research into harmony in musical space include that of Lerdahl and Jackendoff (1983), and the neo-Riemannian (Lerdahl 2001, 42). These theories address mappings of musical elements onto a representative spatial domain, in some ways similar to actual cortical mappings (see Section 4.3.4).

Several other systems have provided similar access to a graphical plot of harmonies, although not accessed bodily on a projection. The first system as reported by Holland (1992) is Longuet-Higgins' *light organ* where each organ key connects to a square array of light bulbs that illuminate note names. It displayed music being played “in Longuet-Higgins' non-repeating space” (Holland 1992). Understandably the information couldn't be made to flow the other way—by the note name selection playing the organ keys.

The first software system of this kind was Levitt's *Harmony Grid*: “the first computer-controlled device using a generalised two-dimensional note-array... with a pointing device to control a musical instrument” (Holland 1992). Levitt's program was a mouse-driven music application using a grid, where position on the grid selected pitches, and the speed of mouse movement over the grid affected note duration. The large grid (approx. 20x12) allowed intervals between pitches on the cells, horizontally or vertically, to be adjusted for any number of semitones. However, chords had to be individually selected for each cell.

Longuet-Higgins (1962) investigated the human perception and processing of harmonies by considering a grid with ascending perfect fifths on one axis and major thirds on the other axis. His theory stated “that the set of intervals that occur in Western tonal music are those between notes whose frequencies are in ratios expressible as the product of the three prime factors 2, 3 and 5 and no others”

(Holland 1989, 69). Steedman extrapolates from this that "the set of three intervals consisting of the octave, the perfect fifth and the major third is the *only* co-ordinate space that can provide a unique co-ordinate for each interval in musical use" (Steedman in Holland 1989, 69). This can be plotted graphically with columns of notes in the three respective intervals for each axis. The octave dimension is left off, leaving the familiar two-dimensional grid with fifths and thirds.

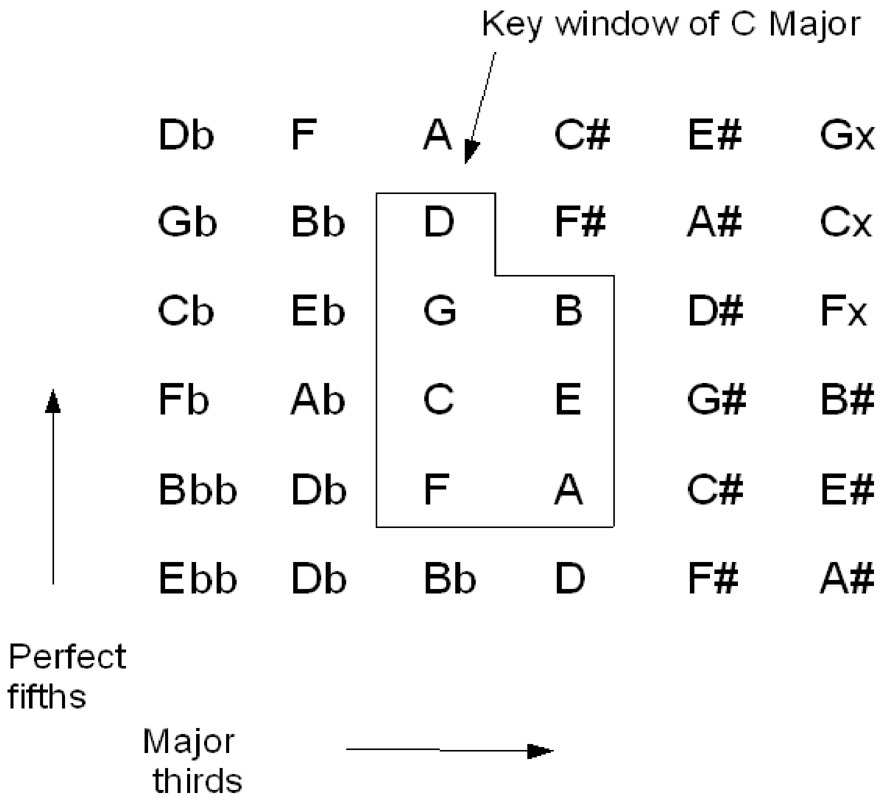

Figure 32. Diagram adapted from Holland (1992, 3), originally after Longuet-Higgins (1962).

A rectangle, with a corner missing, forms a "key window" that is overlaid diagrammatically on the grid. In Figure 32 the key window only contains notes of C Major, and then of another key when the window is 'slid' across the grid to another location. Moving it straight up one position modulates to the dominant, and down one position to the subdominant keys. Crossways movement makes modulations of major thirds. Diagonally one way modulates by semitones, and the other way by minor thirds. Holland has re-cast this diagram as a 12-note version, avoiding double sharps and flats and ignoring enharmonics, for his *Harmony Space* system. Examining the key window for C Major shows that the root triad notes are right next to each other, and the subdominant and dominant triads are just above and below the root triad. Holland points out the "clear spatial metaphor for the centrality of the triad" (Holland 1992).

Holland's *Harmony Space* (1992) software program is based on his update of the Longuet-Higgins grid that provides a grid of circles for pitches (or chord roots) which sound as a mouse passes over them. A second mouse or pointer is used to adjust the number of notes available per chord. Chords for each degree of the scale have default characters—major, minor, dominant or diminished; as they do in the *HarmonyGrid.* Moving around the grid is akin to sliding the key window around such that "the shape of the chord appears to change to fit the physical constraint of the key window" (Holland 1992). The second mouse moves the window and thus changes the key. Moving the key window whilst holding a root note changes the chord and the window shape. Either of these techniques results in a harmonic progression, and "many of the fundamental harmonic progressions of Western tonal music correspond to very simple paths in Harmony Space" (Holland 1992). Simple progressions like II-V-I and VI-II-V-1 form vertical paths, with straight line paths on the grid being termed "harmonic trajectories" by Holland. Other benefits of this design include that common related harmonies are physically close, as are related keys; and that tonic chords are always spatially central in the key window. The chords for each note of a scale are always easily accessible—unlike on other instruments such as piano keyboards. "A single spatial metaphor is used to describe interval, chord progression, degree of the scale, and modulation" (Holland 1989, 139). Further discussion on the *Harmony Space*, including its aims and uses, occur in Sections 6.3.1 and 6.4.5.

A special "human-powered" version was performed in 1990,[45] also referred to as the "abracadabra" (or "Wizard-of-Oz") implementation, with the aim of allowing participants:

45 This occurred at Utrecht Art School's Centre for Knowledge Technology, Utrecht, The Netherlands.

> to experience and control harmony and melody with the movement of their whole bodies. In a series of games, participants moved around in a large Harmony Space grid marked out on the floor. Their movements 'controlled' a specially trained group of musicians whose playing was partly determined by the Harmony Space configuration. A large, specially constructed wooden key window was shifted around under the players' feet to control modulations. Games included 'exploratory walks', polyphonic games, improvisatory games and discovery learning games. (Holland 1992)

Holland was testing the system in a mock-up version prior to selecting a suitable type of tracking mechanism such as webcam or sensors.[46]

Based on this information, and other data reported elsewhere (Sections 6.3.1 and 6.6.4), it can be concluded that both the update of the Longuet-Higgins grid and the similar Bolzano grid—a skewed version of the former (Holland 1989, 125)—are sophisticated means for playing with and exploring harmony in a spatial array. Section 6.6.4 deals with performance testing of the various harmonic schemes, reporting on Holland's work and the *HarmonyGrid* system.

6.4 Music-making with the *HarmonyGrid*

This section discusses procedures for music-making with the *HarmonyGrid* and illustrates these with examples from the DVD. These examples demonstrate the musical and technical capabilities of the system, and the experience they provide (as well as listing some deficiencies and limitations along the way).

Musical activity with the *HarmonyGrid* could be construed as a combination of composition and improvisation. I choose to call it music-making (as discussed in Section 1.3.1). The *HarmonyGrid* facilitates music-making, in that a simple structure is already in place and therefore some of the “composition” has already been

46 To date, Holland has yet to report installing such a system.

provided. In this sense it is neither pure composition or pure improvisation from a blank slate. The mapping presented through the design provides a compositional framework. Making music with the system then becomes an exploration of an extended music composition, through space.

Naturally it takes some time and practice to become proficient at music-making with the system. This generally involves setting up a musical "scene" and then creating some level of complexity, which entails switching between settings and sub-systems, and then having sufficient control to be able to recreate earlier musical scenarios or sections so as to provide some compositional coherence. To this end, a "snapshot" feature might be desirable, where current system status (or musical "scene") is stored, with the ability to return to it later (see Section 7.2.2).

6.4.1 Analysis of the Videos

Video examples of music-making with the system accompany this exegesis, and analysis of the videos examples was a source of reflection and data collection in this research. Complete analyses are provided in Appendix 2 including, for each video example, a table of timed events and their description from five viewpoints, followed by notes and discussion. Concluding observations are collated and presented from the visual, spatial and musical perspectives. An overview of the results is presented in Section 6.6.2.

This section references these video examples extensively as it discusses the issues and themes about *HarmonyGrid* music-making that arose during this research.

6.4.2 Musical starting points

The *HarmonyGrid* is not a musical blank slate. The design of the system provides some musical bases from which to start, as do most systems "straight out of the box". The 'Preset' feature and the 'RandomFile' button generate starting conditions almost immediately. Otherwise the performer proceeds manually. After switching on the *HarmonyGrid* software the Volume grid appears, and the Active voice plays on the triggered grid. Switching on the arpeggiator immediately creates a simple musical background on which to improvise. The performer's next inclination is usually to select a suitable synthesizer sound. This is musically similar to simple jamming on a keyboard or synthesizer. In Video 2 on the DVD, the Timbre grid is visible but a synthesizer voice has been selected and I walk around on the grid triggering arpeggios. The arpeggio patterns alternate inversions and root position of the one chord of E minor, and I play a violin line over them. In this example, further interest is provided by the timbre variations, and the colour of the overall presentation. With grids other than the Harmony grid, the performer may walk around triggering squares to modulate the current sound—either a single pitch or drone or an arpeggio—by the grid parameter.

As with countless musical situations, playing a lyrical line over arpeggiation can provide almost endless musical material. Selecting the Harmony grid allows access to changing harmonies, in contrast to the previous example. This provides a similar musical function to an arpeggiator as provided by many electronic keyboards including the early electronic organs. With the *HarmonyGrid* triggering system it is pleasurable to walk over the grid triggering arpeggios, to discover what is there, and to make musical sequences. Additionally the system provides the experience of walking into, across and around a musical landscape. Video 15, from 2.50 minutes, demonstrates triggering arpeggios on the Harmony grid.

Other basic musical starting points provided by the system upon start-up, include drone effects (played with by moving around the timbre grid), and rhythmic patterns to jam to. Both are demonstrated on Video 12 at 0.58 minutes, after which (from 1.20 mins.) an extended jam occurs over a bass drone and rhythmic pattern. Video 2 plays a bass drone under the arpeggiations, providing a “bedding down” or “holding” of the musical texture and in this case giving something of an “epic” feel or “spacey” character (of outer space). A different kind of drone is achieved in Video 6 at 0.09 minutes, by a repeated bass note played by a volume path on top of the Rhythm grid. Video 14 shows free triggering of rhythms on the Rhythm grid, by walking around the grid, and the kind of percussion soundscape achievable.

It should be mentioned here that the 'Preset' read and write facility aids in creating compositions, because a 'snapshot' state can be recorded when a performer enjoys a musical moment or a whole musical section. Following some different musical material, the performer can return to the initial material to shape the composition and provide continuity in the performance.

6.4.3 Using paths

The next level of activity provided by the system is to record a path or loop to subsequently improvise with. Paths on Volume and Timbre grids are quite straightforward, and may require a small number of attempts to obtain a reasonable result (e.g. with enough variability). Video 4 demonstrates a simple loop on the Volume grid using a "tambura" sound that provides an evocative bed for a solo violin line. The layout of the Rhythm grid is more arbitrary than the other grids, and may take several attempts adjusting rhythm settings (sample selection) to obtain a desirable result. Paths on the Harmony grid are influenced by the selection of a grid on the menu (one of the five grids of harmony layouts). Examples of harmonic paths appear on Video 7 and 9, among others. Video 7 demonstrates change of harmony grid at 2.22 minutes, and Video 9 at 0.08 minutes.

Moving around the grid triggering musical components is spatialised music-making, made at the locations at which it sounds. To recall the second statement in the claim of originality and contribution to knowledge in Section 1.6.3: "the musician controls the music-making process whilst moving in the space which he or she makes (or *produces*)". Recording paths is a more structured spatialised music-making, as a second path may be added and offset, and paths may then loop for some length of time, to become a compositional segment. Video 9 shows a path of harmonies and bass notes moving around the grid, while I remain at the rear of the grid observing the harmonies. In Video 13 I address the grid from several standpoints, and at 1.27 minutes I move around live triggering. With paths playing (looping), the performer can play his/her instrument at various locations or from various directions, or he/she can move around, even on top of the moving path, in order to interact spatially with the path music and within the music-space. As previously mentioned, the grid music sounds are projected by the quadraphonic sound system, arriving at locations corresponding to the squares where they are visually located (see Section 5.2.3). The resultant spatial composition includes the grid music and the performer's contribution. Additional considerations regarding movement and choreography are discussed in Section 6.6.3.1.

The Active voice and Voice 1 may be switched to output single pitches. The Active voice by default comprises both treble and bass notes. Voice 1 may output single pitches, chords or arpeggios. Recording a path with single pitches renders a melodic phrase, like a cell motif or riff, which can become the first voice part of a canon. Early versions of the *HarmonyGrid* were aimed toward setting up a bass-line and cycling a loop of harmonies over that, and this feature persisted in later designs even while other options were added. This scheme works well for mid-range tempi, producing styles that include simple harmonic patterns, from minimal patterns, through "pop" and song patterns, to more atonal, angular patterns. One obvious application is loops or short riffs that set up "groove" patterns, suitable for adding percussion to and jamming over. Video 3 contains a single-note bass line under a harmonic pattern, accompanied by percussion (see analysis in Appendix 2.2.4 to explain the odd harmonic pattern). Video 7 plays single-note bass and treble lines, that provide a simple background to improvise with; which is then sped up significantly (at 1.22 minutes) to facilitate a much crisper rhythmic segment.

Using single pitch settings for voices allows the setting up of minimalist-style riffs that cycle around. There is a facility for offsetting a voice earlier or later by some number of steps.[47] The tempo may be smoothly adjusted up to very fast speeds. Video 15, at around 6.40 minutes, shows a single note pattern adjusted up to very fast tempi. Because recording of new paths may be started at any time (which resets the loop to step 0 on the next pulse), a continuous stream of musical material can be generated. This configuration also provides canonic music, in a similar vein. Adjusting the tempo to slow or even very slow, short phrases can provide bass

47 An earlier version experimented with tempo and delay offsets to provide "phasing", typical of Steve Reich and other minimalists. Another version provided five voices: the active voice and two sets of "treble" and "bass" voices, with offsets available. However these additions were not felt to be generally useful, and the controller placed restrictions on the number of functions available.

patterns, including such Baroque styles as passacaglia and chaconne bass lines. Modern use of the passacaglia effects a repeating bassline or chord progression. Longer phrases of more sonorous sounds looping slowly after one another can provide a languorous background for some introspective improvisation. Video 10 creates a "contemporary" soundscape by slow, offset paths playing chimes and cymbal splashes, providing for an exploratory improvisation using contemporary violin techniques. Generally, where a small change in the musical texture is desired, this can be effected by a change of scale or grid, altering the pitches of the bass line. Video 7 at 1.58 minutes, uses a change of scale to provide a small shift. Other musical styles suitable and accessible for this system include "techno" and other up-tempo dance music, and "ambient".

As indicated by its name, the *HarmonyGrid* is very suitable for exploring harmonies as sequences, continuous streams, or as interesting or pleasing patterns. An original aim for the system was to provide an adjustable harmony generator with which to improvise, which would be an advance on setting up a fixed pattern in a sequencer. To that end, I am very pleased with this function, and can happily spend time with this simple configuration. The *HarmonyGrid* has advantages over the sequencer, in that it is accessed spatially while the performer plays an instrument. Although both systems provide scale changes, the *HarmonyGrid* additionally provides a physical layout of harmonies. However, using the system well can take some experimentation and practice, in order to record paths and find patterns suitable to improvise with. An obvious starting point is to aim for simple patterns such as I-IV-V-I, and then to manipulate these. Patterns invariably end up being "flavoured" in idiosyncratic ways and sounding sufficiently interesting, as demonstrated by Video 3.

During trials with the system at *Ignite 08!,*[48] it was suggested that *HarmonyGrid* would be very useful for music students learning harmony, as it provided a visual layout and identification of harmonies, and an immediate sonic response to triggering them. This has yet to be tested. Section 7.2.2 discusses possible educational uses.

48 Postgraduate Research Conference, at Creative Industries, Queensland University of Technology, October 2008

6.5 Space, Music-Space and Immersion

As a scaled-up GMS, the *HarmonyGrid* allows for full body location on a grid large enough to accommodate the body on each square. Additionally, the system is a partially immersive one, in four related ways: spatially, graphically, sonically and musically. The performer stands on a two-dimensional graphical environment, and is bathed in the projected light from above, such that clothes and instrument may reflect colours. This bathing in light is immersive, in a graphical and spatial sense. The desire of some commentators (see Section 7.2.2) to see three-dimensional graphics arising from the grid, might indicate a wish for an extension of the currently perceived immersion to extend the sense of augmented reality.

Sonically and musically the system is more fully immersive. The musical components generated by the GMS are played through a quadrophonic speaker system so that music is heard and located where it is being made. Musical paths occur over the actual spatial paths. Despite using only a two-dimensional horizontal array of loudspeakers, variations in sound do occur over the three dimensions. In addition to the horizontal dimensions, differences in height will register variations in sound mainly due to boundary reflections (especially off the floor), and directional characteristics of the loudspeakers. The performer's ears move fairly much in the horizontal plane of the speakers, but the experience of sound is immersive. When considering an audience—the system is intended for a relatively small audience standing close to the projected grid—the speakers need to be spread out so the audience is within their spatial field, with the effect that the sonic exactitude of the spatial correspondence with the visual grid is diminished. However, audience members can clearly interpret what is happening, and it has been found that “near enough is good enough” to enable the audience to “read” the scenario accurately.

In order to enhance the spatial experience of the video performances on the accompanying DVD the sound was multi-channel recorded and rendered in 5.1 surround sound.

In this section I discuss how the *HarmonyGrid* draws on and contributes to this discussion of music and space, often referring to Holland's *Harmony Space* as a point of comparison.

6.5.1 Immersion and scaled-up GMSs

Holland reported on the results of scaling up his *Harmony Space* software to a prototype version. He writes of his system being “driven by whole body navigation” or whole body interaction. “All subjects unanimously reported finding the whole-body interface and tasks absorbing, attractive, demanding, and fun” (2009a, 4).

> The trial suggests that the whole-body version of Harmony Space offers several new opportunities compared with the desktop version. Key differences appear to be deeper engagement and directness, qualitatively different opportunities for collaboration, stronger memorability (in turn affording new opportunities for reflection), hands which are free for other simultaneous activities (such as playing an instrument), and deeper integration with rhythmically-felt, layered, time constraints. (Holland 2009a, 4)

Following Freud, Papert (1993) re-introduced the idea of body-syntonic learning: “the idea of understanding how some external object worked by thinking about your own body” (Fintel and Pate 1997). Papert applied these ideas to developing children’s understandings of geometry. Taking up this notion, Holland's team “were interested in whether participants could exploit their situated sense of space and how their bodies move to gain a deeper understanding of harmonic relationships” (Holland 2009b, 1). This idea points toward bodily learning of harmonic progressions via the spatial system. Additionally, it definitely speaks of immersion as embodiment.

Body movements also have rhythms, which are strongly felt on the *HarmonyGrid*, especially in the more free-wheeling Dance mode (see Section 5.1.8). In fact the sense of body movement, and the rhythmic and musical control engendered, combines to create a choreographic sense of performance. (Video 6 on the **DVD** shows the feel of this, as does Video 13, from 1.35 minutes.)

Continuing on from the detailed description of the *Harmony Space* software in Section 6.3.1, Holland describes its properties and functions as a:

- musical instrument,
- tool for musical analysis,
- learning tool for simple tonal music theory,
- learning tool for exploring more advanced aspects of harmony, (e.g. assessing the harmonic resources of other scales)
- discovery learning tool for composing chord sequences,
- notation for aspects of chord sequences not obvious in conventional notations (1989, 139).

This list could be re-written as:

- an instrument to play and compose with and-
- a tool for analysis, learning, and notation.

Part III of Holland's thesis proposes an intelligent tutor for music composition, to comprise of the *Harmony Space*, a Rhythm “micro world” and a Melody “micro world”;[49] terminology reinforcing the influence of Papert on his work.

Most of the list above applies equally well to the *HarmonyGrid*, but the *HarmonyGrid* relies less heavily on presenting the Longuet-Higgins or Bolzano harmonic schemes (see Section 6.3.1) due to its small grid size. Additionally the elements of harmonic analysis and notation don't apply equally well. However, *HarmonyGrid* is stronger as, and designed as, a generative music machine. In contrast, *Harmony Space* sends MIDI data direct to a synthesizer, without any algorithmic musical processing such as rhythm or phrase generation, or arpeggiation, as performed by the *HarmonyGrid*.

49 The latter two components were proposed, but have not been constructed as yet.

6.5.2 The performance space

Traditional staged art forms use a performance area on-stage that is delineated in obvious ways (see Section 4.4.3), e.g. by a raised stage, curtains, lighted areas and props. The *HarmonyGrid* defines its performance area with the projection. Additionally there is what might be termed an “equipment support space” around that, a concept similar to McAuley's concept of “practitioner space” (1999, 63) which includes the side monitor, sound equipment and speakers, and projector overhead. The audience space is less defined than in a theatre or concert hall, but similar to an installation or gallery presentation where it is appropriate for an audience to approach the work from any angle, but not to interfere with the equipment or actually encroach on the grid itself. These spatial arrangements are suggestions from some limited concerts with the *HarmonyGrid* given that, to date, no ritual contract between a stylised performance presentation and an audience has been established.

6.5.3 Music representative spaces

Both the *HarmonyGrid* and *Harmony Space* use music representative spaces (see Section 4.3) in their visual depiction of harmonic data. The *HarmonyGrid* also visualises data for the other musical parameters of volume, timbre and rhythm. This allows current and previous knowledge about musical materials to be utilised in navigating the space, and may also leverage innate knowledge of music in the brain (see Section 4.3.4). The system is designed for a trained musician who can access and use previous knowledge of musical materials (especially harmony) and map that knowledge to that current visual map of the grid. The concept of music representative spaces does seem to imply these two aspects: knowledge in the mind, mapped to visually displayed representations.

This is useful because, as Holland points out, “Musical harmony is considered to be one of the most abstract and technically difficult parts of music. It is generally taught formally via abstract, domain-specific concepts, principles, rules and heuristics” (Holland 2009b, 1). Benefits of the *Harmony Space* system, using the Bolzano layout, are itemised in Section 6.3.1 and Section 6.6.4.

Music representative space relies heavily on the visual representation of symbolic data, which is a huge area of research involving fields such as instrumentation, human-computer interaction, and data visualisation. However, for the present purposes of navigating a small grid of musical data, the needs are not large. The type of data is known beforehand, through selection of an interaction mode (although an easily memorable colour coding is called for). Then a simple mapping is chosen (e.g. size of disc represents volume level) that can be viewed from any angle. For large-scale grids that a person walks on, the issue of causing a shadow underneath one's body is a minor hazard because one may not be able to read the symbol one is on. Additionally, when the represented parameter requires a text label, as in harmonic symbols using Roman numerals, more issues of visibility and readability arise. This is because the text is orientated in one direction (an additional software module could re-orientate it for each movement of the performer!), and it needs to be sizable and sufficiently visible to read comfortably. Perhaps a bigger issue overall is the performer's ability to read in this new textual and graphical domain, in order to navigate and make music in the musical domain. Conventionally-trained musicians are used to reading and playing printed notation, but the large-scale GMS is unconventional as it becomes an immersive graphical score to read and play with.

Based on my interactions with the *HarmonyGrid*, it is an exciting experience to be bathed in colour and to move around in the field of light, navigating the icons or numerals. At normal tempi, animation on the *HarmonyGrid* generally allows sufficient time to read the symbols, as the grid tends to pulse as one-in-a-bar (see Section 5.2). However, becoming accustomed to the interaction flow is part of learning the system, as one would learn to use any piece of equipment or musical instrument.

6.5.4 Music-space

Of all current GMSs,[50] it appears that only the *HarmonyGrid* provides the kind of immersive experience, especially sonically and musically, to incorporate a sense of music-space. The performer is immersed in the spatial music and the body-scale

50 Known to this researcher, up to early 2010.

visual grid enhances the aural sense for locating musical elements, allowing the visual and aural senses to work synergistically. The audience may have a similar experience “by proxy”.

At the outset, the performer visually perceives the delineation of the space by the grid. The performer sees that the grid delineates the music representative space, and, by extension, intuits and senses the *functional* music-space—where it is interactive, manipulable, and “alive” in its responsiveness. Moving around in music-space on the *HarmonyGrid*, activating and shaping it in real-time, reflects Lefebvre's statement (see Section 4.4.1.1) that “there is an immediate relationship between the body and its space” (1991, 170). In Lefebvre's terms, the performer *produces* the space, which in turn produces effects in the material world—specifically, sounds. With the *HarmonyGrid*, this is achieved with the system and the live instrumental playing. Additionally, the performer generally engages with an audience, and works with them to make the space function performatively.

Considering music-space in terms of Smalley's work (see Section 4.4.4), circumspace is located over the grid and bounded by the loudspeakers. The musical entities or “spectra” are the musical components located on or over the grid squares,[51] that are shaped over time and connect with other spectra over other squares, as paths steps occur. The “delivery modes” of circumspace are mixed, comprising some of the “enacted mode” where the space “is actively diffused, expanded and rearticulated in real time” (Smalley 2007, 51), and some of “automated mode” where sounds are automatically spatially assigned to particular grid squares by the system. Smalley's “immersive space”, a sub-type of circumspace, is applicable as it incorporates the “perspectival space” (of the performer's perspective) filled with spectra, their qualities of density, scale and direction of movement, and where any one direction does not overly dominate—the grid system doesn't favour any direction (2007, 52). And lastly, Smalley's differentiation between a composed space and a listening space is interesting but not so applicable where the two activities occur together in music-making with

51 Centred at the level of the loudspeakers, rather than at ground level.

the *HarmonyGrid.* Perhaps the composed space are listening space could understood as blended.

Music-space is partially defined by a continuum or continuous spatial region (Section 4.4.4), discernible by variations in texture, although it may or may not acquire a “diffused ambience” as in ambiophony (Lotis 2003), where the instrument selections, volume levels and overall sonorities are more amorphous.

A practical comparison of a music production studio with the *HarmonyGrid* illustrates the use of, and access to, music-space. In a studio one can create sounds and place them in a three-dimensional environment and cause them to move around, in real time or by playback, but (i) one can't move oneself around physically at the same time, (ii) nor is the process so convenient and systematised, (iii) and the locations, and icons describing paths of sounds are not visible.

Music-space can be experienced by a listener, but actively making the music within the music-space heightens the experience. A musician playing in a space with good reverberation understands this. As with other types of interactive systems, interactivity is the key to the in-the-moment experience, shaping the medium directly as events unfold.

6.6 Performance considerations with the *HarmonyGrid*

An original design idea for the *HarmonyGrid* was for it to be a simple hands-free arpeggiator and pattern accompaniment, and this function is fully developed. With the addition of the multi-parameter path capability, the system has grown into a moderately sophisticated music generation tool, somewhat unique for its visual display directly mapped onto the music generation and performance area. This section explores the performative aspects of the system in use including audience reception, observations from the video analyses, performance issues, movement, and harmonic schemes on the grid.

6.6.1 Audience reception of *HarmonyGrid*

Viewers are stimulated firstly, by the initial visual impact of the system, and secondly, by the design concept of direct music triggering over a graphical environment. In one demonstration,[52] I allowed participants onto the grid whilst I controlled the system from aside. Participants enjoyed themselves, and one small girl danced on the grid for a full ten minutes. Viewers seem to enjoy a walk-through explanation. Many people need to be informed that it is a live interactive system, or to have that confirmed.

At another casual presentation of the system,[53] the overall impression of the grid system was favourable, with comments on the visual appeal and more than several musical moments. Adults enjoyed trying it, but technical difficulties including tracking lag and alignment made it difficult to understand. They also asked if more than one person could trigger the grid. Several children were intrigued and excited by the setup, and spent quite some time on the grid and around it, but continually asked to play a version of *Twister* (Foley and Rabens 1966) on the grid. One media professional was very keen on its application to VJ/rave performances as an interactive enhancement to performances. For this presentation there were more than several technical issues (see Appendix 1).

Viewers of the video segments have had varying responses, partly dependent on technical setup at the time, i.e. screen size and sound quality. Responses have been generally quite positive, along with some more varied responses including those who simply enjoyed the visuals and ignored the music, a sound engineer who ignored the visuals, and one respondent who simply wanted to hear me play the violin! Musicians tend to concentrate on the musical output. It is apparent that the video segments (other than the explanation video) don't simply and quickly reveal the mechanisms underlying *HarmonyGrid*, and viewers may quickly give up understanding it and engage in their preferred domain.

52 At Ignite08!, Postgraduate Research Conference, Queensland University of Technology, October 2008.

53 At a gathering in Mundaring, W.A., December 2010.

6.6.2 Observations from the analyses, and performance issues

This section refers to the analysis of the video examples presented in Appendix 2, where events are listed for each video, followed by analyses in table form. Content analysis was undertaken (Appendix 2.2.1 covers the *rationale* in detail) using five viewpoints: musical, spatial, visual, musical motivations and system affordances.[54] Examining the performance data from several perspectives produced new observations, revealing the order and motivations of various events and patterns of interaction, between actions taken and their effects. Details elucidated included how musical material is selected and controlled with the system, how the improvisation proceeds, and how the performer interacts with the spatialised music and concomitant graphics. The visual and spatial observations identified visual and theatrical effects that occurred. Results and observations from the analyses are listed below.

Musically the *HarmonyGrid* provides sufficient and varied textures to improvise with, ranging from carefully selected and organised textures to more general or loosely organised ones. Additionally the system technically facilitates music-making. Simple textures work effectively, e.g. live rhythm patterns actively selected, or drone and rhythms. A sustained musical environment is successfully created to improvise with (Video 10). The range of instruments provides combinations that sound well together (Video 1), or provide a variety of sounds for an atmospheric palette (Video 10). Some scale patterns sounded modal (Video 7), and the arpeggiators work to provide sufficient variety and musical interest, stimulating melodic exploration with the violin. Modulations can be performed effectively (Video 1), and tempo change can dramatically alter the musical scene (Video 7), as can a change in percussion selection (Video 5). Overall, the DVD sounds lively and the spatiality is effectively conveyed, so that listening within the zone of the four speakers places one within the music-space of the grid.

My movement on the grid is generally for the purposes of live triggering of active

54Briefly, affordance is a quality of something that allows someone to perform an action, or the "action possibilities" latent in an object or the local environment.

squares or for recording a path. Other types of movements appear to serve particular functions. Moving to a selected square can be seen to be a highly intentional manoeuvre (Video 10) and to build theatrical tension in holding the location. Moving to a square and then starting a new musical phrase (Video 1) works dramatically. In several instances I move into middle area of a currently playing path, seemingly to be visible amongst it, interacting with it, and to be in the centre of the music-space. This illustrates the immersive nature of the system. In some cases I appear to be addressing the activity of the grid, by moving to a location and looking down at the grid (Video 13). Moving around the entire grid (Video 14) at varying speeds resembles and carries the potential of a choreography. The activity can get quite physical where, for example, I run around to record a path (towards the end of Video 9), or I appear to chase the icons (Video 6). Practically, I can move at speeds from very slow to quite fast whilst holding onto my equipment, although more complex manoeuvres would not be possible.

Visually, colour schemes with the grid colours and the icons created an ambience that could be enhanced with suitable music (Video 4), and with suitable costumes and lighting. Shadows occurring on illuminated shapes further enhance the visual impact (Video 2), revealing unexpected and intriguing patterns and shapes. The biggest visual change possible is to change the displayed grid. The most colourful grid is the Timbre grid, but the Rhythm grid appears to provide the highest intensity of mood with its all-orange display, whilst the Volume grid corresponds to a sombre and moody setting.

6.6.2.1 Performance issues

For a solo musician, using the system presents a different kind of performance. Traditionally solo performers and musicians on stage are fairly static, and do not walk around beyond a few steps. The *HarmonyGrid* requires that the performer move around freely, use the grid space of two metres squared, and often turn away from spectators on one side to face another direction.

Currently the system is still in early development and quite some practice and experience with it is needed to present a smooth performance. As mentioned earlier, use of the controller and control display screens are somewhat "clunky", and the design paradigm itself takes some digestion and consideration. Spatial determination of volume and timbral paths is simple, yet for harmony it is seemingly a new experience.

As an interactive music system, the *HarmonyGrid* acts as an extended instrument by making music as an extension of the musician's will and direction. The conception of media as providing extensions of human capabilities has been around at least since Marshall McLuhan's writings in the 1960s, and is often raised as important in discussions of new electronic instrument systems, for example:

> 'Hyper-instruments' consist of large scale musical systems which can be designed to respond to performance control in a complex manner. A complex sonic response may thus be generated by a musical performance which can involve unconventional combinations of gestures and modes of control. Such a system is acting as a new, more complex instrument. (Anderson and Hearn 1994, 1)

Hyper-instruments are electronically enhanced instruments or software modules that function as instruments, operable via computer inputs (Machover 2009). Although *HarmonyGrid* doesn't require combinations of gestures or complex movements, it does function to "extend" the performer's instrument by playing additional musical material.

6.6.3 Movement

As discussed in Section 3.3.1, movement is appreciated by performers and perceivers alike. In particular, rhythm, patterns and precision can be understood in relation to a performer's movement on a GMS. The performer's movements can be further understood in Jensenius's terms of their role in sound production or appreciation.

6.6.3.1 Movement and the grid

The performer may move around on the grid in any way he or she pleases, but the tempo will determine when cells are activated. For example, running around rapidly with a very slow tempo setting is not effective. A particular feature is Dance mode, where single pitches are triggered in free time by "dancing" around the grid (see Video 11). In this mode the main pulse is switched off but the triggering is quantised to maintain some rhythmic integrity. The mode can work effectively as a creative interruption, and then one can return to the previous situation. Naturally, using Dance mode adds more of a choreographic quality to the performance, and further consideration of more dance-like movement in the ordinary modes is the subject of future development for the system. The possibility of moving in other ways on the grid, rather than upright standing and walking, have yet to be considered and tested. Movement options may also depend on the particular instrument being played by the performer.

During system development, various sizes of grid squares were tried, and fifty cm^2 felt like a comfortable size to occupy, cover, and make a small shadow over (including one's instrument). Optimal square size might depend to some degree on the size of the performer. Whilst holding an instrument, the performer needs to see the neighbouring grid squares around him or her. It was assumed that larger grid sizes would incur excessive movement to cover the grid, especially when speed is required.

Movement on the grid at first carries with it the sensation of being a piece on a gameboard, akin to a toy soldier or marching piece. Stepping along the grid and making reversals of direction or sudden backwards manoeuvres are reminiscent of this, in addition to bearing some relation to dance steps. As a performer on the grid, and especially where the music calls for dance, it seems that more than merely moving around on the grid is called for. Experiments have yet to be conducted placing a dancer on the grid, but this will be a future investigation.

Whilst it is traditional in dance that dancers *follow* the music, for a live interactive system the dancer must *lead*, which may take some adjustment. However a quantity of work has been done in this area in Australia, including the works of Garth Paine (2000), and works of Lindsay Vickery (2010) that use the *miburi* suit (Yamaha Corporation 1994) e.g. *Scan* from 2002. Dancers using a grid system must accommodate several different constraints, including the clocking and triggering the grid itself.

Dance mode calls for gestural interpretation, which suggests that further system development should include gesture recognition and tracking, in a feedback system — currently there is no feedback system in the *HarmonyGrid*. One suggestion received during PhD supervision was for musical feedback of the acoustic instrumental output to affect the grid's musical output, via some intelligent processing.

The performer's movements can also be understood in Jensenius's terms of their role in sound production or appreciation. The performer's movements can be classified as indirect sound-producing movements because the sounds are triggered remotely, and as sound-coordinating movements like a conductor's movements that influence rather than directly producing music. Moving around on the grid triggering squares can be seen as sound-coordinating. The use of the controller is a supporting action and is termed an ancillary movement. The performer's movements therefore have multiple roles, and further include sound-accompanying movements, similar to a dancer following the musical sounds, and communicative movements, such as performative gestures to communicate with an audience.

6.6.3.2 The use of motion-tracking

The use of motion-tracking (see Section 3.3.1.1) allows the performer to move around freely and naturally, unencumbered by equipment. The use of touchpads on the floor, whilst reducing some issues such as an overhead projection system and causing shadows, may engender a somewhat robotic movement to activate them. The use of motion-tracking allows a natural movement; crossing the boundaries between squares is mechanically even, making for a fluid process, because software deals with the switching. Part of the appeal of the system is to try out natural movements e.g. simply walk around, and to hear the translation into music.

6.6.4 Harmonic schemes on the grid

In performance testing of the *HarmonyGrid*, the layout of harmonies did not seem critical at all. In fact the process involved either (i) thinking of the next suitable harmony and then locating it on the grid, (ii) sighting a harmony on the grid and considering its suitability, or (iii) just trying the next one that comes to hand. There was a slight difficulty around the design of the initial setup of the system, in which somewhat eclectic choices had been made for harmonies on the scale degrees.[55] This was due to originally building a system around only one scale and needing it to be interesting.

Starting from the initial idea for the *HarmonyGrid*—of being able to form workable and pleasant chord progressions whilst moving around the grid—several layouts or harmonic schemes were constructed, and are selectable via the controller. The first scheme, Grid 3 on the program, is an easy distribution of intervallic distances made by hand. Grid 4 simply uses a pitch spiral ascending from the centre, to obtain both close and larger intervals near the active square.

55 This included more diminished seventh chords than one would usually encounter.

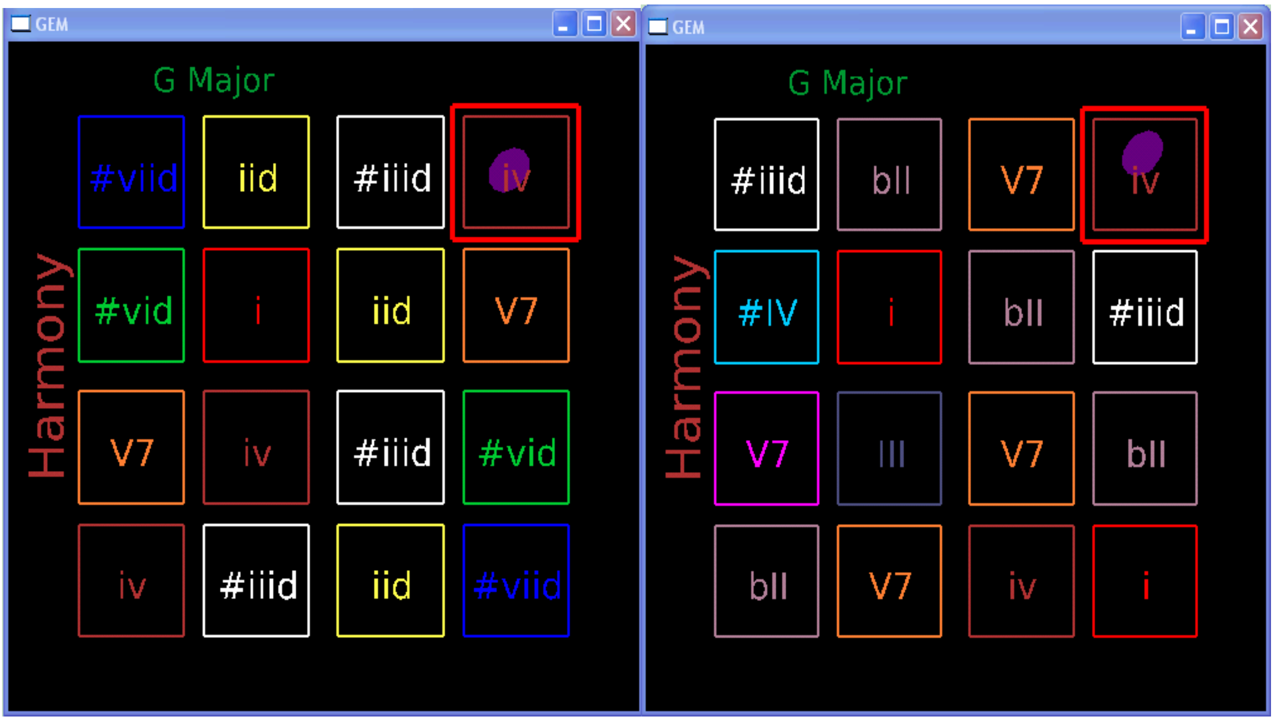

Figure 33. Grid 2 and Grid 3 of the *HarmonyGrid* as selected by the controller. Current scale is 'G Major'.

Grid 1 (Figure 34) is Euler's scheme from the 18th century (see Figure 20), with intervals of thirds running horizontally and sixths running vertically; and grid 0 is after Lerdahl's (2001, 57) scheme.

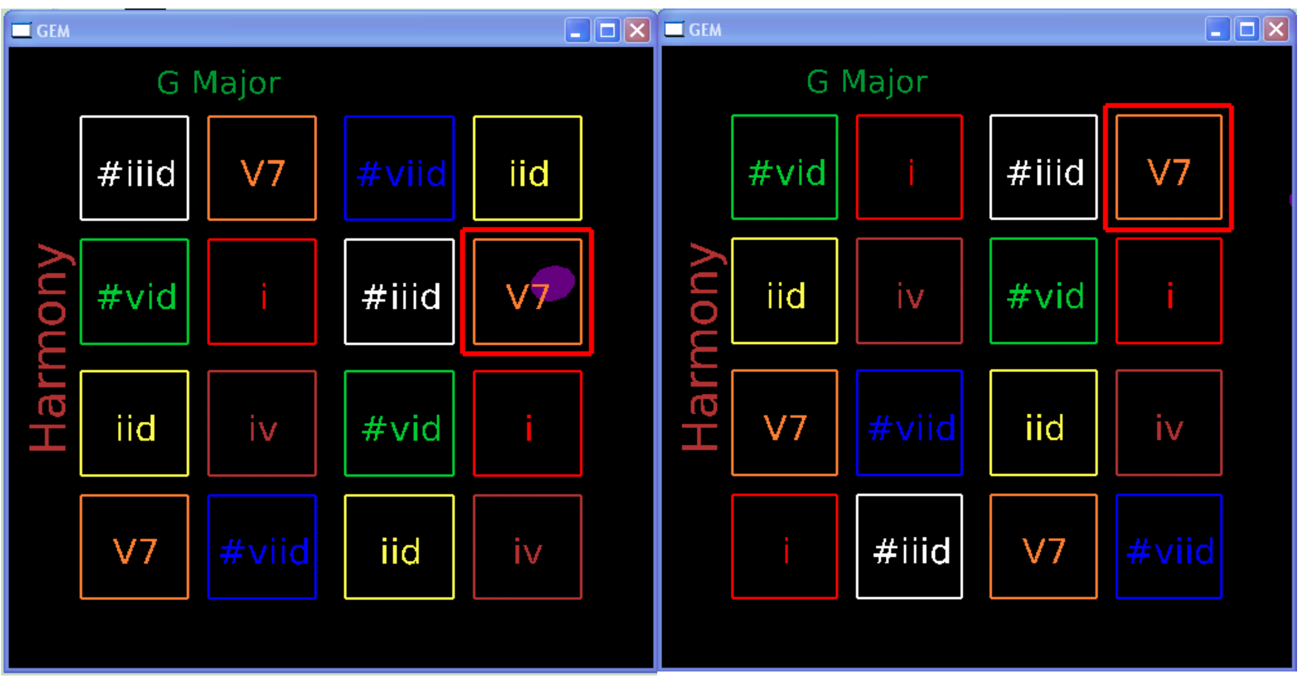

Figure 34.Grid 0 and grid 1 reflect Lerdahl's and Euler's schemes.

Holland's *Harmony Space* (1992) uses an altered Bolzano scheme for the layout of harmonies (see Section 6.3.1). The scheme is found to be highly efficacious in the following ways:

1. for playing music, and exploring music (note—this system only plays chords, selectable for type, e.g. major or minor)
2. for finding chord sequences, for instance to accompany well-known songs or pieces
3. for modifying these sequences and exploring new sequences
4. "to carry out various musical tasks, such as to recognise and distinguish chord qualities" (Holland 1989, 223).

Complete beginners can be taught very rapidly to play accompaniments to pieces in the major or minor mode in any key using typical two, three and four chord patterns, with a clear idea of where to find tonal centres. More extended "classical harmonic movements" involving establishing a tonal centre, jumping to some non-tonic triad and then moving back to the tonic in a straight line through all intermediate triads along the cycle of fifths axis are equally easy to play (Holland 1992, 3).

Harmony Space allows the user to understand chord sequences in trajectories: "the chord sequence for John Coltrane's Giant Steps, which modulates every two chords or so, is typically considered hard to play and to memorize. The Harmony Space trace reveals its to be a very ingenious but essentially simple sequence of V I and II V I chords (i.e. straight lines) modulating 'westwards' down in major thirds every two or three chords" (Holland 1992, 3). Following from that implementation, the participant found it quite simple to alter the progression and explore alternatives. The altered Bolzano scheme does "Reduce cognitive load by representing explicitly and uniformly relationships that would otherwise have to be learned or calculated" (Holland 1992, 4).

The altered Bolzano scheme was tested on the *HarmonyGrid* using a specially adapted 8x8 grid version. The scheme was found to be highly suitable for improvising with, given its selection harmonic progression by minor thirds, major thirds, perfect fifths, or semitones. I personally didn't feel the need for the extended grid size, tending to use one area closely related by key, and physically close as well. Modulation with the *HarmonyGrid* can also be effected by selecting the scale with the controller.

6.7 Issues and limitations with GMSs

This section presents a collection of issues and limitations around performing with, working with and designing GMSs. The intent is to cover all the outlying issues before the final section of this chapter compares the *HarmonyGrid* with other GMSs, in order to highlight the original contribution to knowledge made by this system.

6.7.1 Limitations of GMSs

The most obvious limitation is in the very nature of GMSs: their discrete or quantised locations, and how these relate to discrete and quantised musical parameters. It is not explicitly necessary that grid positions relate to discrete musical values, and locations could refer to other functions such as, for example, an increasing volume. However, all the surveyed systems make use of the discrete quantities to affect discrete musical parameters.

There are size limitations, depending on the scale of the GMS. Hand-held devices may be small enough to cover any selection of buttons with one's fingers simultaneously. Large systems have different size issues, e.g. the ability to fit the participant's body on one square, or to cover many squares at once or cover them quickly, akin to playing a game of *Twister*. Another limitation may be the size of the performance space available.

Holland (1993, 4-5) lists some more advanced limitations for *Harmony Space* of interest to the current discussion, including: (i) vertical components of chords are not independently manipulable (ii) rhythmic playing is restricted by the response speed of the system (iii) no provision for adjustment of patterns, e.g. Alberti or arpeggio patterns (iv) lack of a visual record playback facility. Earlier, Holland (1989, 225) had listed other limitations, including: (i) lack of menus displaying all options (ii) speed of response to input commands was then around 250 ms (ii) no control over the position of the octave break, determining the placement of root notes (iii) user-defined chord qualities (iv) switchable grids for Bolzano and Longuet-Higgins layouts.

There is an issue of rhythmic expressivity that extends to GMSs generally, where finer subdivisions of the pulse are not controllable or recordable. This contrasts with the degree of control achievable by a proficient instrumentalist. However the *HarmonyGrid* is designed more as a musical accompaniment to a solo performer, who is free to use any rhythmic invention. An instrumentalist playing a portable instrument may play one line, or possibly several implied lines, of music at once. The *HarmonyGrid* system plays up to three lines of music, including percussion, that may be controlled by a small amount of input (a spatial location and any controller messages), but sacrifices the fine degree of control for any one line.

6.7.2 Difficulties in developing and constructing an interactive system

There were and are many issues and difficulties relating to developing such systems. Starting from a particular set of skills, deciding what was possible and what was not really achievable was the first step. Then came the slow process of locating interesting ideas and techniques or technologies, and then deciding which to embark on (particularly where a learning curve is involved), as for example with programming languages or large applications.

In the development of physical components, there are issues of cost, time and effort to make items that can be a significant investment and risk. Some development processes lead to unexpected results. As a small example, the making of the lighted hat used with the *HarmonyGrid* was a process in itself. The device was initially a party hat with reflective cardboard taped on top. This was followed by substituting aluminium foil on top, but the results were dubious in both cases. A torch was tried next, followed by a bicycle headlamp, which came with a head-strap attached. Finally, it was surmised that a broader light source was needed, to differentiate it against the projected background. LEDs were considered the cheapest, most energy efficient light source, as batteries would have to be located nearby, and preferably on the hat itself, for ease of taking on and off. The most convenient bunch of LEDs was a string of light clusters, leading to the somewhat comical design of the "halo hat", which proved workable with the system. It was only intended as an initial workable solution, but remained as there were many other more pressing issues to develop, and somehow the appearance tied in with the theatrical, mixed-reality look.

6.8 Comparison of the *HarmonyGrid* with the other systems

This section details the comparison of the *HarmonyGrid* with other GMSs. The first subsection offers an overall view of the comparison. The second subsection looks at a comparison by relevant components of the categorisation introduced in Section 3.1. The aim of these sections is to reveal the gains and insights produced by the design and performance with the new system.

6.8.1 General comparison and differences

HarmonyGrid is different to other GMSs in the following areas and ways. *HarmonyGrid*:

- uses whole body movement on a projection
- is sonically immersive in a quadraphonic field
- is graphically more engaging than smaller devices with lights or buttons
- requires an improvising musician who understands and can play with written

harmonic symbols

- is designed to be an accompanying musical system to live improvisation
- provides an electronic (remote) controller
- provides separate “grids” for musical parameters
- provides spatial access to connecting harmonies, or plotting harmonic paths spatially
- caters for layering up of paths from different musical parameters
- features Dance mode, which is “unclocked”
- is custom-made, not manufactured.

The most significant differences include the use of whole body on a projection, the sonic and graphical immersion, the display and access to different musical parameters, the use of a remote controller, and the system acting as a musical accompaniment to a solo performer. The use of generative techniques is also unusual for a GMS; often they represent an event-by-event score. *HarmonyGrid* doesn't provide the following functions sometimes found in other GMSs. It does not:

- operate in step-sequencer mode
- display path direction-switching icons
- play different length paths simultaneously
- provide output to other computer applications such as DAWs,[56] e.g. *Ableton Live* (although this could be easily patched).

None of these factors is of much significance, although the use of varying path lengths may be lead to interesting results in future versions of the system. Most GMSs don't provide variable path lengths, though *'M'* and *Nodal* do.

6.8.1.1 The projected display

The most obvious difference with other music systems, apart from an experimental version of *Harmony Space*, is that *HarmonyGrid* uses projections on the floor that are walked around *on*. Some commercial projection systems, described in Section

56 DAW – digital audio workstation

3.3.2, also use floor projection but, apart from providing visually appealing graphical "tricks" and displays, none of these systems provide access to an underlying creative system. The advantage of floor projections lies in the appeal of the immersive nature of moving in and through the graphics. Vertical projections may be visible and have more impact from a greater distance, and therefore may be suitable for use with a larger audience.

HarmonyGrid and other larger systems with dynamic displays are graphically more engaging than smaller devices where the output is via LEDs or backlit buttons. The *HarmonyGrid* uses a matrix of squares with circles or other graphical symbols within the squares. Most other systems simply have buttons or lit squares forming the cells of the grid. *HarmonyGrid* shows an appropriate symbol for the grid representing the musical parameter and, in addition, represents a level of that parameter or a descriptive symbol of it. This is an advantage for grid systems. An extra addition is the minor animation of the symbols, which could be developed further.

6.8.2 Comparison by the categorisation

Each item in the categorisation below will provide a means to compare the *HarmonyGrid* with other GMSs.

Activation of a square occurs when a tracked location coincides with a square on a metronome pulse, as determined by the software. This is a more complicated arrangement than the pressing of a button or click of a mouse on a location, and is located further down the chain of events (causing a slight time delay), but is sufficiently robust in execution. The advantage gained is hands-free activation and a large degree of bodily freedom, allowing the playing of a musical instrument or other activities. This similarly applies to other systems mentioned in the next paragraph. Naturally the size of the system creates some limitations on activation. For instance, a user may quickly move a finger around the screen of a hand-held device such as the KAOSSPAD or iPhone. However *HarmonyGrid* is large enough to allow a body to stand on a square, play an instrument, and move comfortably around the grid. There is a minor issue of obscuring the projection, which constitutes only a very minor aesthetic infringement for the audience. A solution to this is to use projection from below, or from two or more projectors at forty-five degree angles, but this increases equipment. Currently the single projector system can to be set up easily in most venues or rooms, where the projector can be rigged four to five metres overhead.

Detection is by location tracking with a webcam. Some systems of this size use contact switches or pads, such as dance games. Systems outside the domain of GMSs may use location tracking or motion tracking via webcam, for installations or some performance systems. The advantages of using location tracking include:

1. no specific platform or screen or engineered surface is required, beyond a flat area two metres squared, with a semi-reflective pale coloured mat or surface
2. the use of projections allowing controlled and synchronised animations of relevant displays
3. the use of a small-sized tracking device conveniently mounted on or near the projector (whereas ultrasound or infra-red or other systems require further equipment to be deployed around the space).

Outputs of the *HarmonyGrid* include audio from the software synthesizers as well as video projection. Software synthesizers may be replaced in the *Pd* patches labelled “VSTunits” for each voice, but the instrument selections and timbral controls have been preselected for the *Zebra* synthesizers. This audio output provides a good variety of high quality synthesizer sounds. The choice of synthesizer certainly influences the style and palette of available sounds. Obviously, by way of example, if a more classical sound were desired, the samples of the Vienna Symphonic Library (Vienna Symphonic Library 2002-09) would suffice. Or, for more dance music styles, a dedicated synthesizer may be selected, such as Rob Papen's *Predator* (Rob Papen Inspiration Soundware 2004-08). Smaller hand-held GMSs may output music protocols such as MIDI which then require connection to a computer system. Some devices such as *Tenori-On* provide a limited range of built-in sounds, with a small pair of on-board speakers, but with MIDI and headphone line outputs. The video output of *HarmonyGrid* is more in line with a larger installation system, with its dual screen output, sent to the projected image and the monitor screen.

Grid cells visually are somewhat unique with their semi-animated projection. Their size of around 50 centimetres squared makes them the largest currently in a GMS. *HarmonyGrid* also probably has the fewest number of squares (sixteen), with sixty-four cells being common for portable devices. The grid itself is static, whereas with software systems they may scroll horizontally, as for the *Paklsound 1* iPhone application, or be expandable, like *Nodal*, in any direction.

Paths are displayed by one icon for each path, with the icon moving from cell to cell in synchrony with triggered and generated musical sounds. In portable devices, paths are typically displayed as a "trace" or moving sequence of lighted cells, as with the *Tenori-On*.

With **modes of operation**, *HarmonyGrid* is quite unique in providing separate grids for musical parameters, although *M* allows access to parameters. *Tenori-On* operates in many modes, generally adjusting pitch and time axes for each mode (detailed in Section 3.1.9). *Nodal*, and *Al Jazari* maintain only one mode of operation.

6.9 Summary

This chapter has integrated music, space and GMSs, to discuss the complete performance system and all its aspects from musical, technical and presentational perspectives. With the *HarmonyGrid* system musical data is visibly mapped to the grid space, and movement on it creates paths and shapes displayed by the graphics. Although the small grid presents a reduction in decision space, there are some benefits including that paths are simple, yet may have any topology such as crossing over. The choices for path presentation and selection through the musical data is trivial for most parameters, but is more complex for harmony. Holland showed with his *Harmony Space* system that both the update of the Longuet-Higgins grid and the similar Bolzano grid are a sophisticated means for playing with and exploring harmony in a spatial array. The altered Bolzano scheme was satisfactorily tested on the *HarmonyGrid*, as were several other designs, where the arrangement of harmonies seems less critical on the small grid.

The DVD videos present an engaging experience that both demonstrates the musical and technical capabilities of the system, and shows music-making as a combination of composition and improvisation. Because the *HarmonyGrid* provides more than a musical blank slate upon start-up, it is fairly easy to assemble a musical segment. Examples on the DVD demonstrate various musical affordances, including arpeggiation, drone effects and rhythmic patterns to improvise with. These musical capabilities produce various styles, so that single pitches allow for canons and minimalist processes, and a bass-line with harmonies facilitates “pop” and song patterns, some more atonal and angular patterns, up to “techno” and dance music.

Because the scaled-up GMS uses full-body location on the grid, the performer is situated within the graphically augmented reality and the surround sound of the system, thereby experiencing partial immersion both sonically and graphically. This heightens the interactivity of the space. Body movements on the grid have and produce rhythms, and help form an understanding of harmonic relationships. The visual display of musical parameters forms the music representative space, and the concept of these spaces does seem to imply that the performer uses stored musical knowledge in the mind, and maps it to the displayed structures. For the performer, immersion in the colours of these structures is an exciting experience.

The performer *produces* the space in Lefebvre's sense, and subsequently intuits and senses the functional music-space, as it is interactive, manipulable, and “alive” in its responsiveness. Although it is possible to define and discuss music-space in terms of Smalley's work, this does not lead to further understanding at present. As with other types of interactive systems, interactivity is the key to the in-the-moment experience and, in this case, shaping the medium of music-space directly as events unfold.

The use of motion-tracking allows a natural movement on the grid, and the *HarmonyGrid* requires that the performer move around freely. However, it takes some practice and experience to operate effectively with the system as a whole. Movement on the grid can resemble moving on a gameboard, or imply dance steps and, by extension, choreography. This is a subject for future exploration. Using the *HarmonyGrid's* Dance mode encourages gestural interpretation of musical and spatial events. Movements may also be understood in Jensenius's terms of their role in sound production or appreciation. Overall, audience reception of both live and video presentations has been largely positive.

Limitations of the system include its size, some issues of rhythmic expressivity, and that spatial locations and musical data are treated as being discrete or quantised. In comparing and contrasting the *HarmonyGrid* with other systems, the most significant differences include the use of the whole body on a projection, the sonic and graphical immersion, the display and access to different musical parameters, the remote controller, and the system acting as a musical accompaniment to a solo performer. Functions that are not available seem inconsequential except perhaps the simultaneous playing of different length paths.

Chapter 7. Conclusion

In this conclusion I sum up the research findings, with emphasis on GMSs and space, where GMSs are musical systems that provide a visual grid or matrix on a screen or physical interface to spatially construct and play music. The next section considers possible future development of the system, including ideas for applications. The final section discusses ideas for future research of a broader nature, stimulated by this exegesis.

7.1 Summing up the research findings

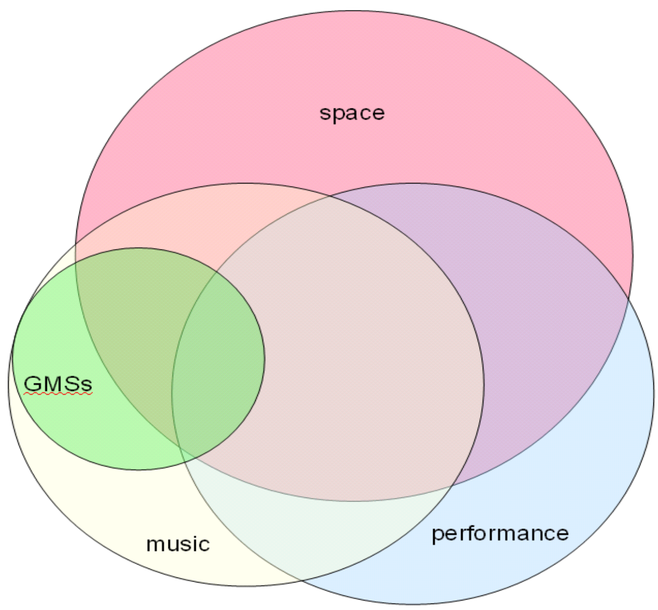

Figure35. Overlap of research areas.

The diagram above represents visually the overlapping areas relevant to this exegesis (the dimensions and ratios of these have no statistical basis, and are only a guide). Starting from the smallest, GMSs are a subset of musical activity, and both part of performance but may not include other aspects of performance such as theatre, lighting and staging among others. There is a large area of cross-over between music, performance and the domain of space, although space encompasses other aspects not relevant here.

During this research it became apparent that space was an essential component of the systems under investigation, and that space is vital component of live performance presentation. The relationship of music to space is the central idea underlying the whole research project. This relationship may be divided into several areas: (i) the mapping of one to the other, and the subsequent problem of visual and informational representation of that mapping; (ii) the physical facilitation of this by design, composition, technology and performance; and (iii) the experience of music, of space, and of music in space.

Performance on the diagram refers to a cluster of considerations about performance ranging from the experiential to the practical. These include immersion, body movement and location as input to the system, and conceptual design incorporating elements of an extended instrument and of augmented reality. The GMS is simply the physical vehicle to access the other areas on the diagram, and contains the grid that is the spatial matrix in which to locate versions of musical spaces.

The investigation began with the understanding that GMSs are an effective and viable means of music-making. These systems were categorised and their properties examined and discussed in detail. These typically small-scale devices incorporate the facility for triggering of musical elements by positions on a grid, and as such provide a simple technological solution to the problem of spatialised music-making. This concept was extrapolated to whole-body triggering on a large-scale grid, to provide a performance medium of music-making that allows hands-free control so one can play an acoustic instrument whilst using it. The function and components of a GMS were expanded in space to produce a human-sized playability.

The research has produced a new performance system called the *HarmonyGrid*, which is a full-scale GMS implemented on a computer and some additional hardware as an interactive system for music and graphics. Software designed in *Pd* allows controller and motion-tracking input to affect musical parameters, and then create generative music to produce synthesised sound. The software also creates live animated graphics that are projected as the grid. The *HarmonyGrid* inherits characteristics from earlier GMSs, but goes further than previous systems by facilitating the performance to be immersive in a full-scale environment. The system provides for a certain degree of graphical and spatial immersion, and a greater degree of musical and sonic immersion. By moving around the *HarmonyGrid*, equipped with motion tracking and a controller, a musician can spatially engage and control an immersive GMS.

The research has opened up the area of a performance system that provides a vehicle to embed knowledge of musical structures and elements, using discrete geometrical and musical elements. The display of musical parameters is an area that overlaps with those of data visualisation and graphical notation. The use of discrete elements facilitates the spatial mappings of musical components, and makes for a relatively simple system design and functioning.

The *HarmonyGrid* has allowed me as a performing artist to broaden my domain from musician to a musical artist within a multimedia performance work. This had provided support for my creativity, in utilising space as a musical performance medium, and working within a colourful immersive environment that is theatrical and performative. The ability to traverse a landscape of musical components provides stimulation and support, not to mention music, to improvise with. The system as a flexible musical accompaniment provides a wealth of opportunities to explore diverse musical terrains, and to develop my musical and improvisational skills.

The creative product formed out of the research process was found via cycles of practice-based experience and performance, through external space, virtual space, and combined external and virtual space. These types of space combine in a kind of augmented reality shown by the performance system. The animated, semi-virtual space of the grid, projected out of the data-scape of the software, combines with the live performance aesthetic to enable the performer to become immersed in the space and to be perceived as such. Using the *HarmonyGrid* is an activity that blurs the lines between performance, play, art participation and experience.

7.1.1 Summing up GMSs and music performance

The *HarmonyGrid* has proven to be an engaging and viable means of music-making in a larger-scale GMS. Using a grid as a template to overlay representations of musical data and knowledge structures, has been shown to be musically effective, and is a new format for spatially presenting music. The *HarmonyGrid* and to a lesser degree, Holland's *Harmony Space*, demonstrate that spatial control by body location is a viable means to navigate the musical data space. In this way a GMS can be operated as a musical system to improvise with. Moving on the grid to produce music, as a scaled-up version of hand-held devices, has been shown to be a performative means to access music representative space. This is supported by the work of Holland and his *Harmony Space* system, and he details the benefits extensively (1989, 220). The *HarmonyGrid* is a unique music system with its interactive grid as an animated projection to walk around on, operated by remote control. The animated computer graphics produce visual and theatrical impact, and heighten the experience of immersion.

Effective and satisfying music-making is created with this GMS by simple procedures, and then by overlaying material for more complexity. The active triggering of grid squares and the recording and playing of loops of musical material forms the basic output, and the playing of additional loops on other parameters may be layered up to add complexity. While simple textures work effectively (e.g. arpeggios or rhythm patterns actively selected and improvised with, or a drone and rhythms), more complex musical environments can also be created to improvise with (see Section 6.6.2).

By using paths created and recorded on a grid in a variety of ways, a GMS can produce satisfyingly complex musical results, and can be quite flexible in its methods. Notwithstanding the small data set of paths and the significant constraints of small grids, GMSs are capable of generating sophisticated musical outcomes. The

HarmonyGrid (along with *M*—see Section 3.2.2) has extended the range of GMSs, by providing path access and recording capability for multiple parameters independently, so that a musical segment may have independent volume, rhythm, timbre, and harmonic or pitch contours.

As Holland stated, "Musical harmony is considered to be one of the most abstract and technically difficult parts of music" (Holland 2009b, 1). Holland's update of the Longuet-Higgins grid and the similar Bolzano grid are sophisticated means for playing with and exploring harmony, and have been proven useful for aiding beginners to find, learn and even improvise basic harmonic patterns. The *HarmonyGrid* provides this capability and, in addition, uniquely provides a range of Harmony grid layouts.

The central issues in designing a performance practice for an immersive GMS include firstly an initial system design that is functional and performs effectively. Secondly, there is a requirement for suitable mapping and implementation of musical data to the grid space, with suitable visual representation so the performer is able to move knowingly around the grid. Other issues include designing the controller so as to navigate its menus and select grids or instruments, for example, or to structure the musical composition. In addition, the system needs to be fairly transparent in its operation for other users and for an audience to understand and enjoy viewing. Finally the performer needs to practise using the system, just as an instrumentalist needs to rehearse, not just to be able to operate smoothly but to compose and structure compositions in real time.

The concept of a GMS has been further extended, in that the *HarmonyGrid* provides a musical accompaniment to improvise with, rather than being a stand-alone musical device. Naturally all GMSs *could* be improvised with, but a full-scale GMS equipped with motion tracking allows hands-free triggering of the grid, and the *HarmonyGrid* also provides a controller. Musically the *HarmonyGrid* becomes a partner in music creation and performance.

7.1.2 Summing up space and music performance

The study of space has been increasing in the last decade or so, particularly in relation to geography and urban research (Soja 1996), and to a lesser extent in performance studies. Some psychological aspects are under investigation, for example, in relation to story generation and imbuing place with space.[57] However, few researchers have paid attention to real time psychological experience, which is crucial toward understanding art forms that inhabit time and space.

The *HarmonyGrid* presents multiple musical parameters visually arranged in space, to be accessed, triggered and used musically via the spatial domain. These spatial presentations allow effective organisation and selection of musical elements via the grid. Previously, in acoustic musical compositions of the Twentieth Century featuring instruments in spatialised layouts (Brant and Xenakis among others—see Section 4.1.4), various musical parameters such as pitch, timbre and volume were arranged spatially, but not also presented visually. These spatial arrangements were not easily altered. It could be argued that certain ensemble layouts like the Indonesian *gamelan*, provide sufficient visual information. The percussion instruments' type and use may be observable, but percussion ensembles do not provide labelled pitches observable by the audience. The advantage of an interactive grid-based music-making system lies in its ability to provide automated and flexible layouts of multiple musical parameters, which are also highly visual. Furthermore, animation provides additional real time information and heightens the visual impact of music representative space.

Musical data for the *HarmonyGrid* is accessible via the parameters of volume, timbre, rhythm and harmony. Arrangements of values and parameter types are assigned to grid squares in design layouts. Both the volume levels and rhythms are arranged by simple schemes. Timbre types are assigned to each of the grid rows (dependent on the instrument playing) and varying levels to the rows, and harmonies are designated by the five layouts discussed in Section 5.2.1.4.

The *HarmonyGrid* provides an immersive experience of music space, that is overlaid

57 This relates to ambience, atmosphere, memories, and other more ephemeral place data.

with music representative space. The system sounds musical elements at specific locations that can move around on paths, actively spatialising the music. This is enabled by the surround sound system in alignment with the grid. The spatialisation is discrete, by location, and concurs with the graphics or visual information. The performer spatially engages with the system by exploring the musical terrain, finding suitable patterns and recording paths. These elements are combined, using the spatial and electronic controls, to create a musical segment. The performer may produce space, and with the system, by association, may *produce* music-space.

7.2 Possible future development of the system

Possible future developments of the *HarmonyGrid* include further development of the current performance system, and development towards use in education and with disabled or impaired people.

7.2.1 Further development of the current system

Under its present research direction, the system is designed for music-making and performance. Some observers have suggested the possibility of enhancing the graphics to more extensive animations, but also to further spatialise these using new technology such as holographic projection. The intention is to have an immersive graphical environment in three-dimensions, as well as the immersive audio environment. Observers at Ignite 08![58] suggested animations could rise up from the grid squares which the performer may move through.

The current system allows a child or musically inexperienced participant to don the lighted hat and play on the grid whilst an experienced operator controls the system. For example, at Ignite 08!, a young girl danced on the grid whilst I controlled the system, and played violin from behind the grid.

A frequent request is to add further performers or participants onto the grid. This was

58 Postgraduate Research Conference, at Creative Industries, Queensland University of Technology, October 2008

felt to be too difficult to achieve, until recently I located a software library patch for tracking multiple objects. The software program will require extensive re-writing to handle two or more participants, although a prototype may certainly be attempted at a later date. The idea of two duelling musical participants, or even combatants, is appealing, and may add to the expressive qualities of a performance, in addition to providing collaborative support and creative input.

Another extension would be to add a dancer onto the grid, either alone or with a musician. This would greatly extend the current concept of the system into gestural and choreographic territory. However, the engaging graphical environment calls out for some more interactive, performative, or possibly systematised activity on the grid. I intend to pursue this direction in the near future.

As mentioned in Section 6.6.3.1, the idea of adding additional feedback to the system is intriguing, although complex to achieve. This might be done to provide musical feedback of the performer's output, or possibly for movement—gestural or choreographic—beyond the current location data.

Additional functionality could be added to the system, such as a recording and replaying facility for the whole of the *HarmonyGrid* activity—rather than just 'Preset' starting conditions (see Section 5.1.7). Following this a “demo” file could be made, to run the system as a demonstration.

A range of path manipulation tools could also be provided, such as tools for transformations commonly applied to musical phrases. These might include inversion, retrograde, and diminution or scaling for each path, and *stretto* or staggered entries or path entry lists for the collection of paths. Additionally paths could be constructed to have differing lengths, to play simultaneously and then phase in and out relative to each other.

7.2.2 Future applications

HarmonyGrid has appeal as an educative device for music-making. Playing on the

Harmony grid, in particular, has application as an aural perception tool to students learning harmony, where they see the harmonies and learn to connect them in meaningful patterns. Students can test out and play with the conventions of Western harmonic language; for example, simple patterns of I-IV-V can be played and then passing harmonies or substitutions can be explored between these. Indeed, even the software, without the whole projection and performance setup, can be used for this purpose, although the immersive quality of the environment would be lost.[59] Holland describes the benefits of a scaled-up GMS for learning and understanding musical elements and how they go together (see Section 6.4.1 and 6.5.5).

Although it has been stated that the *HarmonyGrid* was built to be used by an "expert" performer, any musician can use it in tandem with a skilled operator using the controller or the computer controls, or any person can play with it while a skilled operator such as myself controls and improvises with the system from beside the grid. The system is a fun and accessible way for people to play with music while learning about musical structures, and could be set up or modified to encourage or facilitate music-making activities for disabled or impaired people.

Interestingly, Anderson and Hearn notice this possibility as well, when they speak of Hyper-instruments: "This makes them highly suitable for use by disabled musicians who typically have different combinations of musically precise movements to a non-disabled performer" (1994, 1).

7.2.3 Further research into music-space and music representative space

There is much room for experimentation with graphical representations of music, to be applied as music representative space. Research is required to determined which parameters are accessed effectively, and how they may be displayed for the best musical access. This research will include the testing of symbols and graphical icons, in various designs and colours, and with varying grid sizes.

59 A request to use *HarmonyGrid* was made by a harmony teacher at Queensland University of Technology, in October 2008.

Experimentation and research with music-space, and other formulations of musical spaces, may be carried out using ethnographic studies by performers and participants. Future experimentation will need to try various styles of music and musical textures, to test with and without music representative space, and similarly with music-space. Further work includes testing different grid layouts for the current parameters, and trying other parameters, e.g. metre. Further testing may investigate other grid topologies, using firstly discrete regular layouts, for example, using a hexagonal-based honeycomb pattern; and secondly, using irregular layouts and/or less discrete and less defined layouts, e.g. a selection of different shapes perhaps overlapping or fading into one another, or with gaps between them.

As suggested elsewhere, the addition of music feedback from the performer into the computer system, may enhance the interactive experience of moving through, and playing with, music-space. Various methods of applying the feedback to the software system may be tested. Other technological solutions may arise to heighten the interactivity with music-space.

7.3 Future research

Performing within music representative space is an interesting and convenient platform, and perhaps points to a similar usage in relation to other real time forms—e.g. using a representative space for other forms such as visual artwork or training for other activities such as dance or sport.[60] There is much more exploration, experimentation and development to be done with spatialised music performance, and many formats to be explored. Even with the current system and its technologies, there is much that can be explored. Moving within a projected animation and using motion tracking provides much scope for performance systems in general. Although discrete systems prove very convenient and easy to comprehend and work with, the use of continuous systems (although this is done in installations) within formalised

60 To some extent this is being developed with augmented systems e.g. military head-up displays and surgery (eHealth Insider: "Augmented reality surgery" in Prospect 2005).

frameworks (such as interfaces for software applications do).

Much more work can be done in the area of experiential space involving interactive artworks. Other further research may involve the combination of dance and movement with interactive music systems.

7.4 Conclusion

Music improvisation, composition and performance are aspects of music-making, which in the present case access multiple musical parameters to create paths and loops, and combine them to form musical textures. This music-making is facilitated by the new performance system, a scaled-up GMS, the *HarmonyGrid*, which provides access to music representative space, graphically presented on the grid. That is, it provides visual access to musical knowledge structures that can interact with the musician/performer's stored musical knowledge.

The new system provides the facility to produce, access, and create music in music-space. The concept of music-space, developed by the research process, is similar to other musical spaces including soundscape, acoustic space, Smalley's circumspace and immersive space (2007, 48-52), and Lotis's ambiophony (2003), but is perceivable by its “texture” made of spatial patterns of tensions and relaxations formed by musical elements changing over time. Music-space is interactive and therefore conducive to live improvisation. In this system this property is enhanced by its co-existence with music representative space, aligned and overlaid onto the grid. To sum up, the *HarmonyGrid* is an effective vehicle for music-making because it provides access to music-space overlaid with music representative space.

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Appendix 1. Equipment specifications

1.1 Components, layout, and setting up the system

1.1.1 Components

Components are:

• a computer (with Bluetooth, double-headed graphics card, 4 channel sound output)

• webcam or video camera

• video projector

• *Pd* software program

• VST synthesizers – presently set up with *Zebra*

• Bluetooth dongle (if not build-in)

• custom-made controller incorporating *Arduino* Bluetooth controller

• custom-made lighted hat

• 2x2m (semi-reflective) white mat

• sound system (preferably in four-speaker array around the grid and audience) and mixer if necessary

• improvising performer with portable instrument (I used a radio pick-up system for amplification and recording of the violin but this is not strictly necessary.

1.1.2 Set up

Setup takes one to two hours, provided that the placement of the projector and webcam four to five metres overhead, is relatively simple. The projector needs to be that height, in order to gain an image two metres squared.[61] On starting the computer, the screen display needs to be set on dual display (horizontally), and the GEM output window for the grid must be resized and moved to the right screen that is projected. The projected image probably requires enlarging at this point. A grid of 2x2 metres is large enough to comfortably place one's body over the grid square, and

61 Expensive projectors have the ability to spread the image at a greater angle, and therefore wouldn't require such a height.

not block the others.

Once installed, and software is running sufficiently to see the grid graphics, the projected grid must be placed centrally on the floor mat, fairly much directly underneath the projector, and resized if needed. Then the program must be run, to check that the alignment of the webcam detection is mirrored by the graphics output (i.e. the 'blob' follows right underneath the tracked performer). The angle of the webcam may need to be adjusted, to point exactly at the grid. There is a software zoom control for the webcam.

The sound system must be setup, with mixers where necessary between the computer audio output and the speakers. The speakers need to be placed around the grid, depending on the size of any anticipated audience. Some basic sound testing, and level setting may be done at this time, including a testing of the sound alignment on the grid, i.e. grid squares should sound at the square's location.

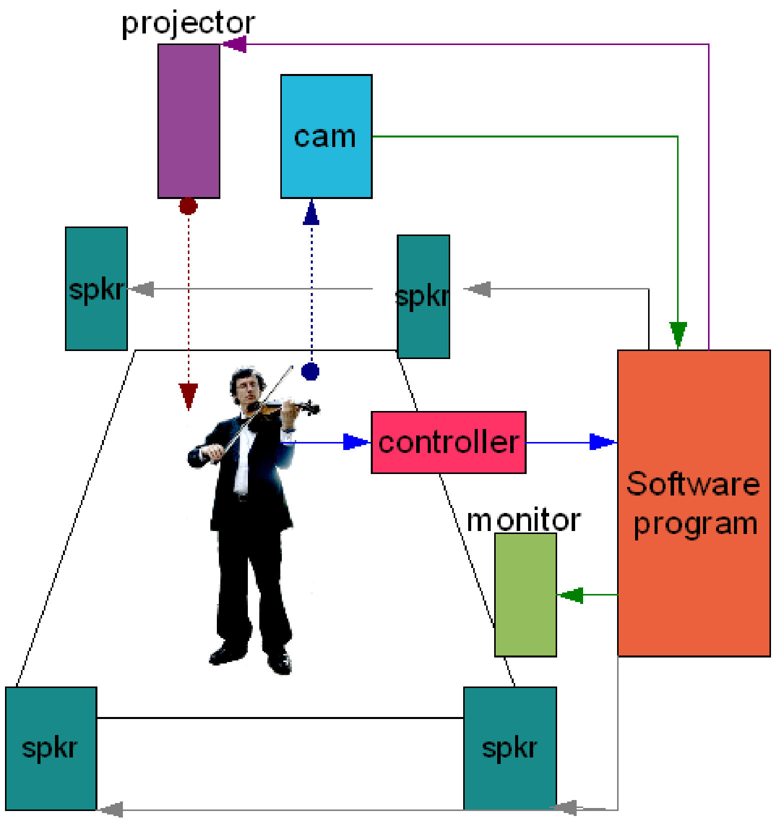

Figure 36. Components and layout of the system.

The controller must be supplied with batteries, tested to provide between 5 and 5.5 volts (I have yet to put a voltage limiter on it), as too much voltage can damage the *Arduino*. Then the slightly "finicky" sequence of starting the software components is to be done. Generally, the sequence is:

1. switch on the controller
2. switch on the Bluetooth software, and connect to the *Arduino*
3. open the *Pd* program (if not already opened) and set up the *Arduino* in the *Pd* patch for it.

1.1.2.1 Known issues

As mentioned above, the software setup is somewhat unreliable, but once it has run, it tends to continue to do so; i.e. may be restarted repeatedly. The "finicky" part is getting the Bluetooth software to communicate with the *Arduino*, and then be successfully started in the *Pd* patch. Once that is accomplished, all will be fine. Additionally, once the battery voltage drops below five volts, the system goes into chaos, and fresh batteries must be tested and installed. A voltage limiter connected to a nine-volt battery is presently being fitted[62] to overcome the frequent draining and re-charging of batteries.

Webcam motion detection does have some time-lag or latency. This is partly to do with the detection algorithm and partly due to the type of camera used (the webcam used operates at 25 frames per second). A video camera reduces latency, and a camera running at much higher frame-rates would do even better, but the improved quality uses valuable CPU on the host computer, and I elected to leave processing power for the synthesizers. A video camera runs with less latency on FireWire, but the webcam is lighter, more convenient, and consumes less CPU load. In addition, the five metre USB extension required to reach the computer on the ground should be an active USB extension[63] or further latency is encountered. The five metre (or ten metre) video cable entails negligible latency.

62 As of March 2011.
63 These devices use an amplifier to maintain signal strength

Motion tracking may be improved using infra-red LEDs and detectors, minimising the need for a sizable hat. Bongers (2006, 237) reports more accurate tracking in his *Protospace* project using infra-red LEDs and an optical filter in front of the camera lens.

1.1.3 Equipment detail

1.1.3.1 Audio

A soundcard capable of delivering quadraphonic sound is required. Once installed in the computer, further adjustment within the *Pd* environment is necessary, and usually required on re-opening *Pd*. Naturally, in early development work, much use was made of Windows level MIDI sounds, to lessen CPU load, and ease of program opening and closing.

1.1.3.2 Video

This configuration uses a computer with a double-headed graphics card i.e. with two graphics output sockets. The screen display of the computer must be set on double (horizontally), and when the *Pd* program is running, and the GEM output screen opened to show the grid, this must be moved to the right screen, which becomes the projected image. Once the projected image has been enlarged, one may loose visibility of, and access to icons on the bottom right corner of the PC desktop, mainly the Bluetooth icon.

1.1.4 Extras

Additional lighting may be desired, although the light level (at head height) must not be too high so as to overwhelm detection of the lighted hat. Lighting is best placed off the floor a bit, and pointed downwards.

It may be desired to amplify the acoustic instrument of the performer, via radio miking, and send the audio signal through the sound system. It that case the sound won't be spatialised, unless some direct sound is heard as well.

1.2 Software Program flow

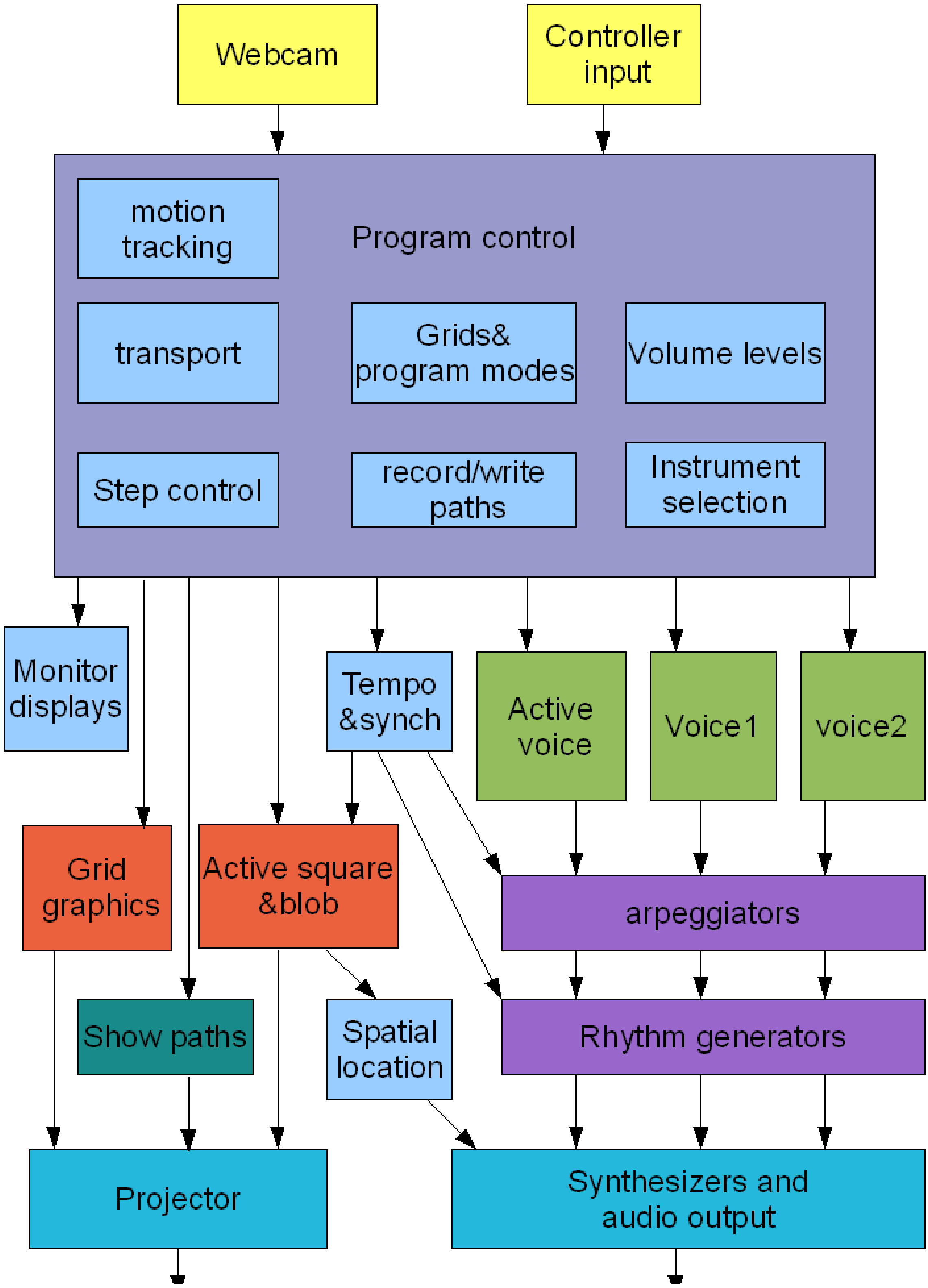

Figure 37. Software schematic.

Above is the software schematic of the *Pd* program. Below is a screenshot of the *Pd* program and its layers of sub-patches (only one group shown). This screen has its own controls, built before the controller was made, and useful as backup, and for programming development.

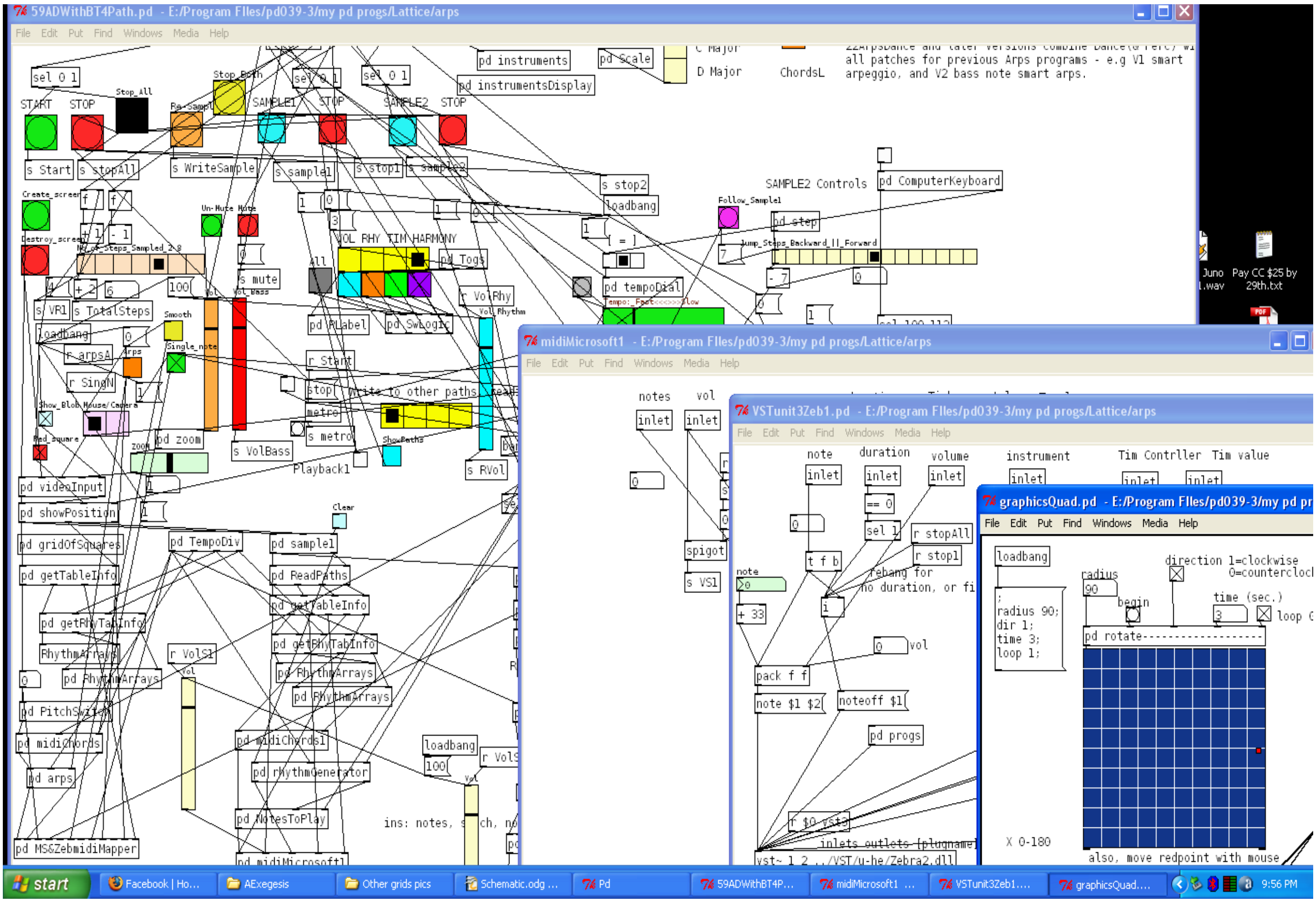

Figure 38. *Pd* main program and (some) sub-patches:- around 4-5 layers deep is workable.

1.2.1.1 The Manual

A manual is being compiled for the *HarmonyGrid* program. Topics include the Display Panel, paths and instrumentation, where data flow is detailed for these; rhythm, percussion and tempo treatment, and using the 'Preset' files. Other information includes the Arduino pin assignments, controller buttons and data flow from these to the display screens.

1.2.1.2 Icons

The following Figures show the icons for Voices 1 and 2, which often functionally play the role of treble and bass parts, as well as performing the canonic path-following behaviour.

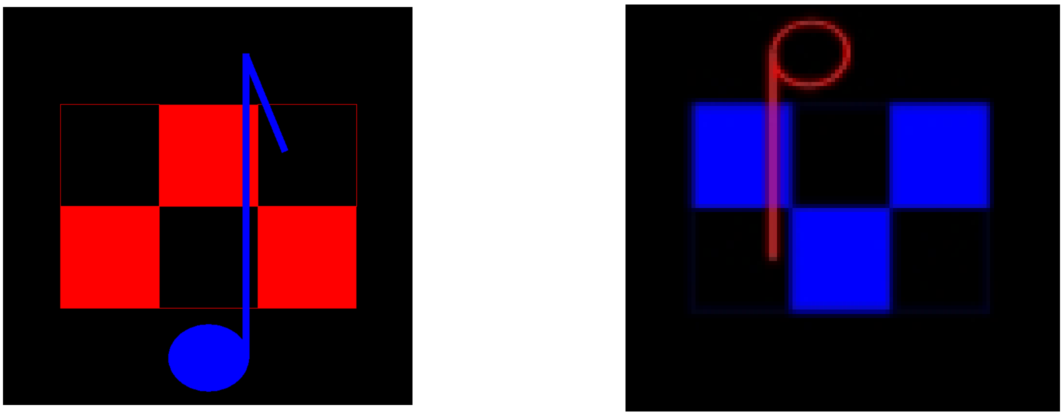

Figure 39. Icons for Voices 1&2.

1.2.2 Control display and Instrument display screens

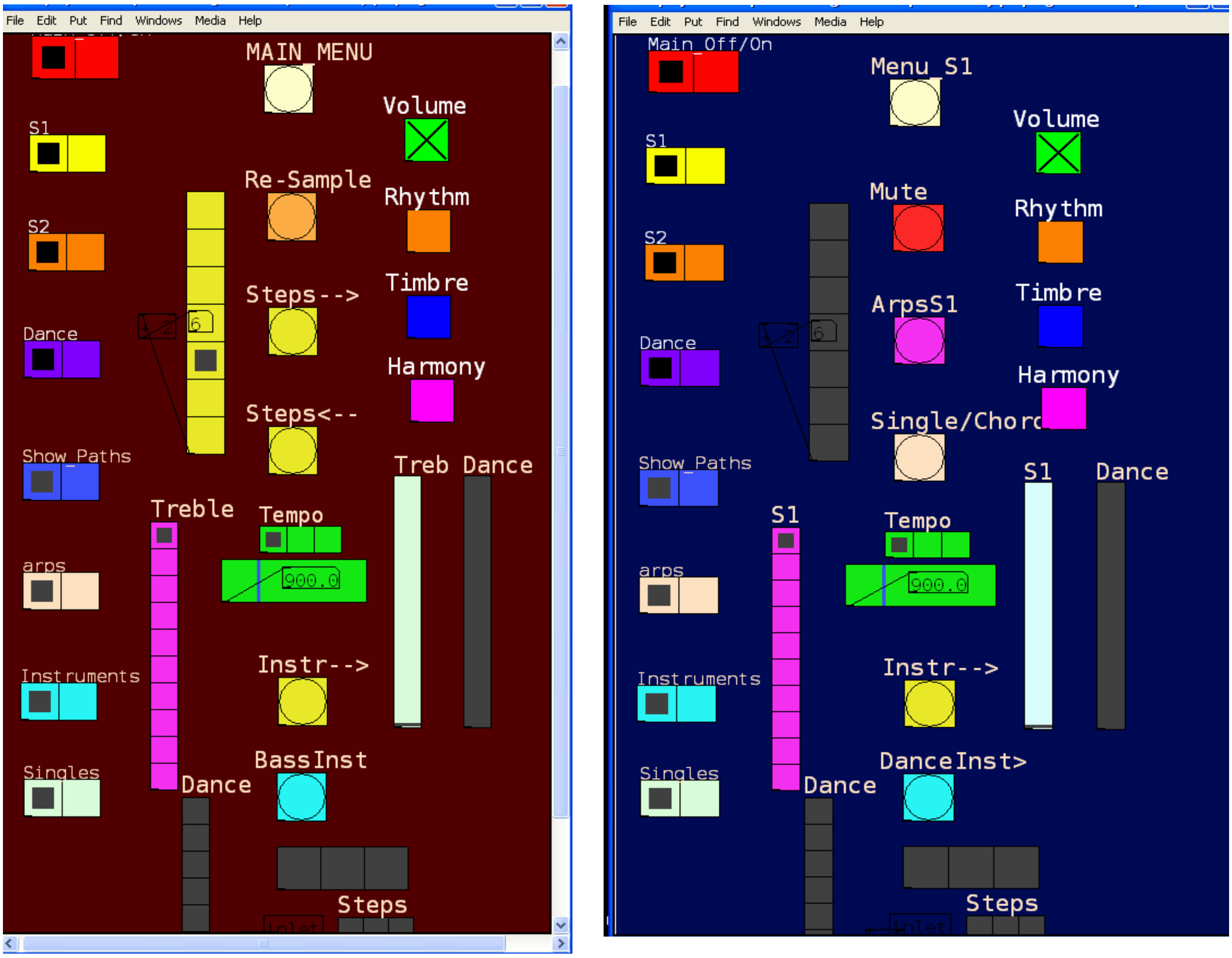

Figure 40. Control display screens 1 & 2 (Menu S1& S2 refer to Voices 1&2).

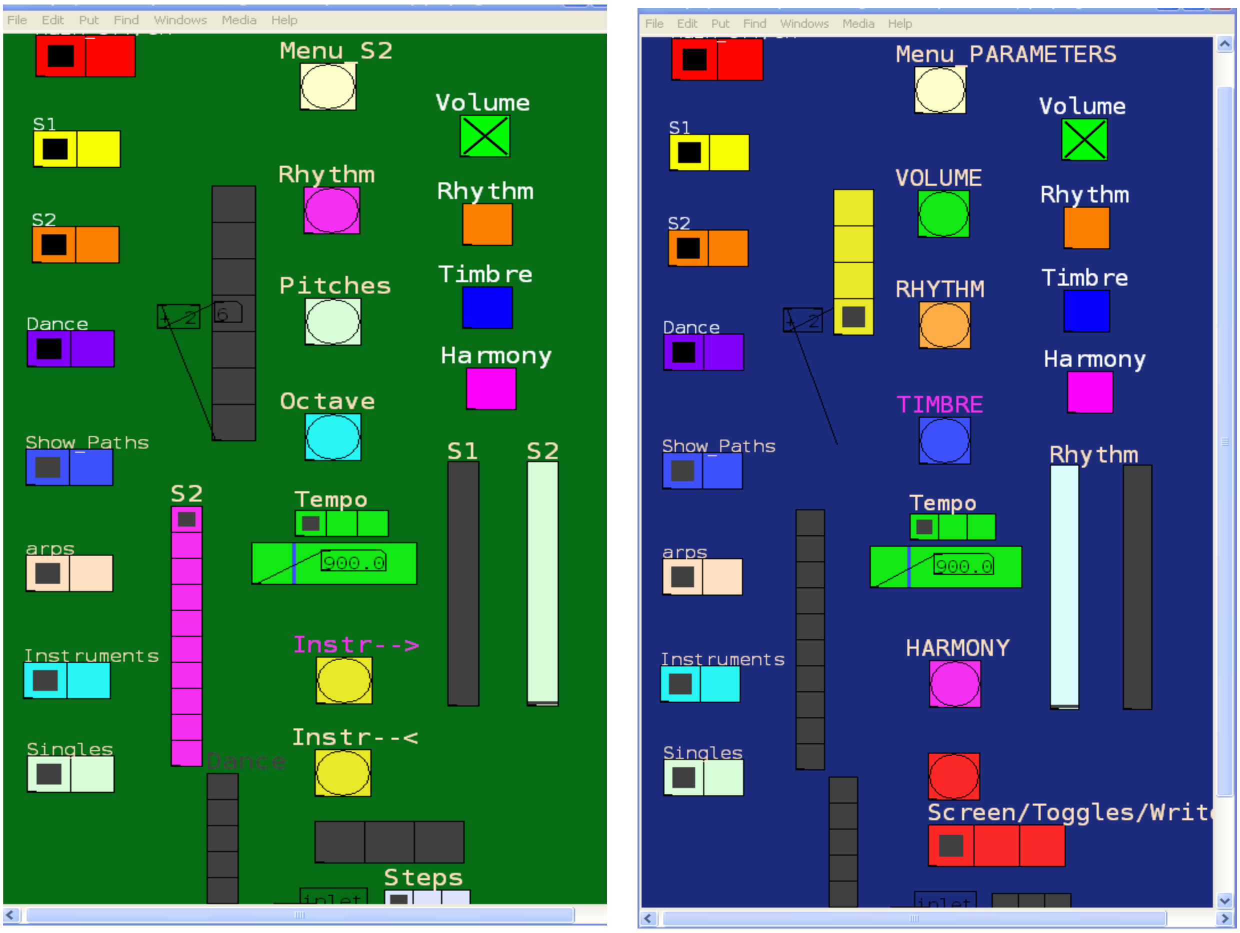

Figure 41. Control display screens 3 & 4 (Menu S1& S2 refer to Voices 1&2).

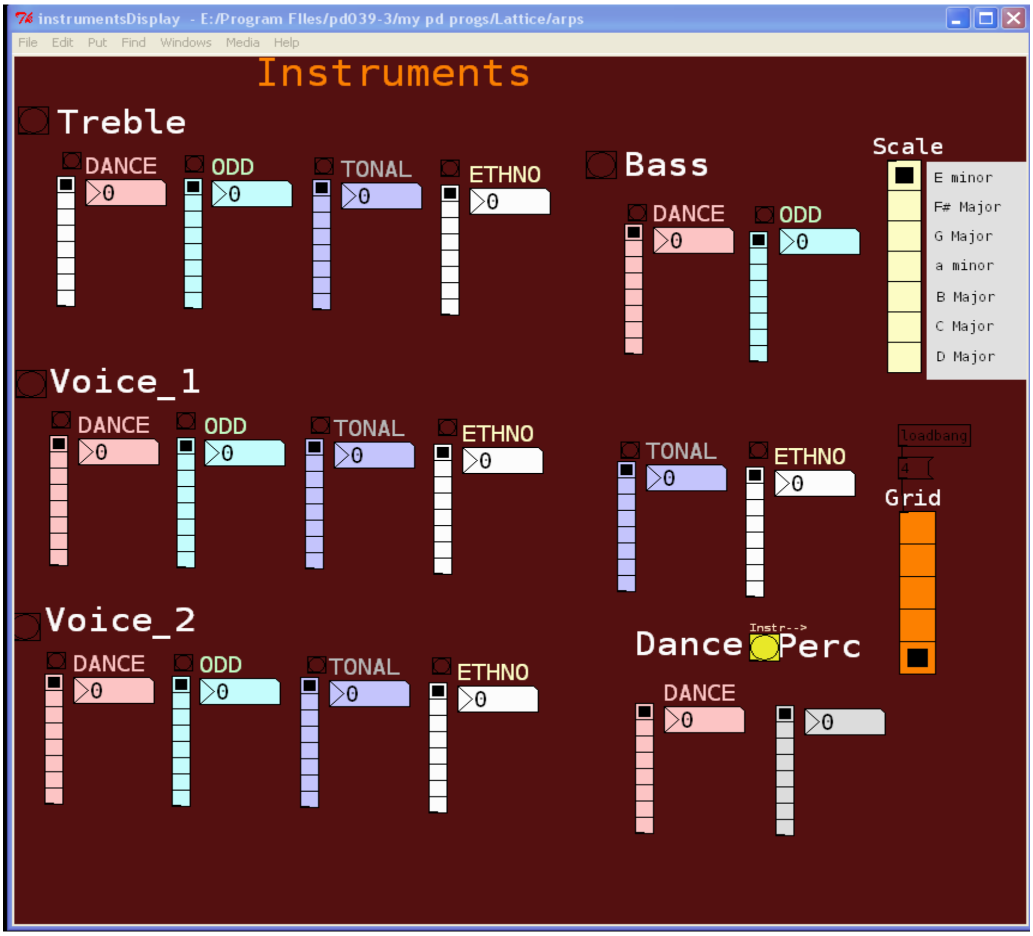

Figure 42. Instrument Display.

1.2.3 Additional equipment

The 'halo hat' consists of a string of LEDs powered by a nine volt battery and a on/off switch. The batteries last for days.

Figure 43. The 'halo hat'.

Figure 44. The *Arduino* controller, with battery pack worn in the performer's pocket. The written functions are for the toggle switches, whilst the push buttons and knobs have functions determined by the layer of the menu display.

The operation of the *Arduino* controller has been sufficiently described in Section 5.3 —Control of the system. This controller is still a prototype. A rather revised and more effective version may be built in the future. Apart from the job of determining a suitable number of knobs, switches and push buttons, the main difficulty is in marrying the designated controls through the software modules to the menu display screens. There are currently four menu display screens, with one button dedicated to cycling through them.

Appendix 2. Video Examples on the DVD

These video examples are to be found on the accompanying DVD of the *HarmonyGrid.* The first section provides a listing of events on all the videos, in the order they occur on the DVD. The second section provides an analysis of an extended listing in table form, of the videos.

2.1 Index of Video Examples

This section presents a listing of events, to be noted, when watching the videos, and may be used as a guide to locate examples of particular aspects or functions of the system. For instance, all the grids can be viewed, and subsequent technical transitions and effects appear, as discussed in the exegesis. Video 15 provides an "talk-through" explanation of the system. The "Photographs" selection provides around ten still photos from the videos detailing the *HarmonyGrid* in action.

Technical notes: –

(a) all but five videos have the surround sound orientated from the front—i.e. what you see is what you would hear standing on the grid. However, Videos 8, 9, 10, and 11 are rotated, to sound as they are mostly viewed, from the left (house left). Video 13 is the other way, viewed from the right (house right).

(b) in some videos the motion tracking was not accurate and a delay and offset are visible. This was re-calibrated and improved on the second day of filming.)

2.1.1 Video 1. Spacey Timbre

Best looking! Timbre grid in action showing changes of timbral effect and shifts in intensity, via the animated grid graphics. The arpeggiators are selecting optional chord qualities.

1.38 adjusting controller, shows control display on monitor

1.42 change to Harmony grid, showing Active voice moving over grid.

2.1.2 Video 2. Graphics Timbre

Timbre grid similar to above.

2.1.3 Video 3. GrooveHarmony&Timbre

Harmony grid, with a (pre-)recorded path playing Voices 1&2, offset

0.32 change to Timbre grid

0.41 shows Timbre path playing (whilst I mistakenly move around the grid trying to activate squares)

2.1.4 Video 4. Tambura Volume

Volume grid with a path alternating between two similar volume levels, provides a meditative backing for a violin solo. Near the end the volume of the instrument is reduced, and the octave switched to low to end.

2.1.5 Video 5. Lyric Harmony

Harmony grid, with a 4-step path, playing both Voices 1&2 part and a percussion path.

0.58 selection of percussion instruments is adjusted.

2.1.6 Video 6. ZangZang Rhythm

Rhythm grid plays a path on Voice 1.

0.09 Harmony path is switched on (to make a pitch play) as well as a Volume path being audible, Voice 2 is switched on and Voice 1 switched off

0.35 Voices 1&2 are switched off, so the Active voice triggers rhythms live on the grid

0.45 Voice 2 switched on again, and the Timbral path becomes audible

1.13 percussion selections are changed

2.1.7 Video 7. Americana Harmony

Voices 1&2 play a simple tonal pattern on Harmony grid. Voice 1 plays single notes, with subtle alterations of pitch choices.

0.11 Voice 2 instrument is changed.

1.22 tempo is sped up

1.58 scale is changed

2.22 grid (layout of harmonies) is changed

2.1.8 Video 8. ArpsVol Rhythm

Volume grid, with Voice 1 playing a Volume path

0.16 Voice 1 switched off and Active voice plays (with arpeggiator)

0.34 Rhythm grid switched on, changing Active voice to play percussion patterns live on the grid

0.58 Timbre grid switched on, with Active part playing timbres.

2.1.9 Video 9. AugLyric Harmony

Harmony grid, playing both Voices (with no offset), and a Rhythm path.

0.05-0.08 changes of grid (layout of harmonies), produces the augmented harmonies of the title

0.22 Voice 2 instrument changed, then Voice 1 is changed

1.04 offset introduced between Voices, and adjusted again

2.20 percussion adjusted

2.24 Tempo increased

2.35 Voices 1 switched off, percussion changed

2.40 Harmony path is switched off, leaving a single pitch iterating. (An unexpected result where the icon is still present - the Voice is still on)

2.1.10 Video 10. Contemporary Harmony

Paths play a contemporary soundscape at a slow tempo on the Harmony grid. Voice 2 plays repeated flabby bass notes whilst Voice 1 plays quiet chime notes, with a percussion path accompanying with splashing cymbals.

1.48 switch to Rhythm grid

2.1.11 Video 11. Dance Question

Dance mode is activated on the Harmony grid, playing live whilst I move across the grid. I treat this as question and answer phrasing.

0.19 Dance mode switched off, reactivating paths from earlier

2.1.12 Video 12. Falling Harm&Rhythm

Voices 1&2 play together (no offset) on the Harmony grid, along with a percussion path.

0.55 percussion instruments changed

0.58 Rhythm grid switched on, and harmony paths off leaving a drone note hanging.

1.08 percussion instruments changed, playing a path of two squares

2.09 path switched off

2.1.13 Video 13. Tomtom Rhythm

0.01 switch to Rhythm grid, actively playing tomtoms

0.06 Voice 1 path switched on, and timbre or volume path switched on to play notes

0.39 path switched to harmony path to play chordal patterns, and then back to previous setting

1.09 Voice 2 on, Voice 1 off, to play. Percussion instruments changed.

1.27 paths off (arpeggios left overhanging), and the Active voice freely triggers rhythm patterns on the grid

2.28 Voice 1 path on to play notes.

2.1.14 Video 14. Tracking Rhythm

Active voice freely triggers rhythm patterns on the Rhythm grid.

2.1.15 Video 15. Explanation

A complete walk-through explanation of the system, and its functions

0.00 basic system overview on Volume grid

1.46 Timbre grid, software, instruments

2.19 Rhythm grid

2.52 Harmony grid, harmonies and grids

3.56 recording steps for paths, playing paths, icons

6.18 tempo control

7.04 the controller

8.07 paths on multiple grids

10.50 Allpaths display mode

2.2 Analyses of Videos

2.2.1 General video analyses

Analyses of video or film of performance, or general life as in documentary or ethnography, have been carried out for most of the last century and up to the present, using a variety of techniques. Videoed performance can include performance arts, ethnographic performance, or more general activities such as work practice or sports. Various work or industrial processes may also be videoed and analysed with a view to processes, task analysis, event analysis, and interaction order among others.

Videoed performance, usually involving person(s) moving around in a space, is quickly categorised by observation and then certain aspects may be addressed with the relevant techniques to the particular field, for example, addressing choreography for a dance video. Content analysis is a systematic observational method that starts with a hypothesis or question about well-defined variables. In the newer technology of automated content-based analysis of video, content is sorted at three levels. It is firstly sorted into "topics" such as news report, action sequence etc., then into "events", and finally into "sites" such as single locations or objects (Hanjalic 2004, 113). However, "the question of how to analyse video data is still a particularly difficult and underdeveloped area in qualitative research" (Dicks et al. 2005, 152).

Video analysis of learning and education may use content logs, and investigate interaction approaches and their order, to compile a timeline of events or "event maps". Where verbal communication is a major component of the video activities, a transcription is often made, using the basic unit of a "message unit" (Goldman et. al. 2007). Analysing work and everyday events on video, is carried out by finding the interaction order and instances of social interaction, to "discover patterns of interaction" (Heath and Luff 2008, 495). Methods are currently being sought to transcribe bodily conduct and talk in many studies, especially in ethnography. For example, the chart "Fragment 1: Transcript 2" (Heath and Luff 2008, 500) shows a series of photo stills from a video sequence, displaying a person's gestures, that are lined up by arrows with the transcribed words below.

In Vernallis's (1998) analysis of a Madonna music video, observations are categorised from both musical and filmic structures, including song verses and film sequences. Later, various aspects of film are examined, for example, narrative, space, and Madonna's performance. Some correlations are made between the music and film, e.g. an arch contour occurs in both. In an appendix, the film narrative is annotated within the song structure. By way of comparison, sports performance analysis using video usually has quite specific aims, such as refining effective movements for players or player/team strategies (Hughs and Franks 2008). It uses movement analysis, usually via a form of notational analysis, and biomechanics. Results may then be quantified, tallied up, computerised and analysed statistically.

2.2.1.1 Analyses of the *HarmonyGrid* videos

The analyses observes and interprets the video performances, to investigate spatialised music-making. I decided to proceed traditionally by observing the videos and classifying observations from several viewpoints, as selected by the research questions, and in line with content analysis. Further analyses, in particular with music, uses techniques from that field.

In the main the exegesis sets out to explore the composition, facilitation and performance of music in space, via these research questions:[64]

(a) how can a musician spatially engage and control an immersive GMS?
(b) how can a GMS operate as a musical system to improvise with?
(c) what spatial presentations will allow effective organisation and selection of musical elements on a grid?
(d) how might one best engage in music-making with a GMS in a way that meets the targeted aesthetic aspirations?
(e) how can an experience of immersion in space, graphics, sound and music, be facilitated using existing multimedia equipment, with some adaptation?

64 Selected as appropriate from the list in Chapter 1.

From these questions the five viewpoints are selected: Musical, Spatial, Visual, Musical motivations and System affordances. Although not frequently considered in the exegesis, the Visual category is present as a means to observe the video, and more specifically from a theatrical audience perspective. This category does include graphics, but also the performer's movements, appearance and activities. The Visual crosses over with the Spatial, as all activities are both visual and spatial in this case, but some observations are more relevant to one category than the other.

I de-constructed the videos into events at specific times, to closely observe what occurred in the relevant categories. Examining from several perspectives produces new observations, and can reveal the order and motivations of various events and patterns of interaction, between actions taken and their effects.

The details presented include how musical material is selected and controlled with the system, and how the improvisation proceeds. The analysis also examines how the performer interacts with the spatialised music and the concomitant graphics. The visual and spatial observations tease out visual and theatrical effects which had not been considered prior to the analysis.

[Technical note:- to view some parts of the video, I accessed the raw video data to obtain the front camera view that contained all the action. Three cameras were used to film the videos, from which the DVD assemblages were made.]

2.2.2 Video 1. Spacey Timbre

	0	0.06	0.17	0.38
musical	“space synth” sounds with high arpeggios and deep squelchy bass	I am actively triggering timbres. Arpeggios move through a range of harmonies	I play violin in E harmonic minor, and avoid the upper root “E” for “spooky” effect	
spatial		I move around,		
visual	Timbre grid, active red square flashing	I move around, actively triggering		I walk across to the R and stand facing in
Musical motivations		Lots of minor 1st inversions create “spooky space” sounds		
System affordances	Sounds that sit well together			

	0.48	1.1	1.23	1.3
musical	End of phrase, then new high phrase	I find the augmented 4th interval to finish the phrase on – more “spookiness”.	After a very high lyrical line, I arrive at a square of a softer timbre	Repeated bass quavers when I stop playing
spatial				
visual	I move to front L corner	I move slowly to the middle	I move to L and to R	
Musical motivations		I have to listen carefully to follow the harmonies		
System affordances				

	1.43	1.53	
musical	Modulation up to A minor, then I actively trigger harmonies. Bass note changes	Arrive at a climactic sounding F Major	
spatial	I actively trigger squares		
visual	Harmony grid appears	I move to the rear	
Musical motivations		I find a suitable and interesting harmonic place to rest	
System affordances			

2.2.2.1 Notes and Discussion

This video looks very colourful with the swirling discs of colour.

Musically, a satisfying combination of synthesizer sounds and moving arpeggio chords creates the "space synth" sound-world, which becomes a bed for a lyrical exploration on violin of various intervals in e harmonic minor. Various musical tricks are employed – avoiding the root note in the harmonic minor scale, and using augmented fourths. A suitable modulation is engineered – up a fourth to A minor, and then via the live triggered progression to a dramatic drop of a minor third to F Major. The bass note remains on E until the change to the Harmony grid. This piece not only accomplishes a successful sound-world and suitable harmonic movements, but also achieves decent and appropriate modulations.

At 0.48 I take a new corner position to start a new high phrase, which looks like theatrical intention.

At 1.23 after a very high lyrical line, I arrive at a square of a softer timbre – combining a theatrical movement with a suitable musical outcome.

2.2.3 Video 2. Graphics Timbre

	0	0.19
musical	Live triggering timbres. High, loud synth arpeggio, and bass drone in e minor	I play a lyrical exploratory violin line in e minor
spatial	I move around	
visual	Graphics grid. I get really nice shadows of the violin scroll and 'halo- hat' on the coloured discs	
Musical motivations		
System affordances	There is sufficient variation in the arpeggios to sound well	

2.2.3.1 Notes and Discussion

This is probably the best looking video! Of interest are the interesting shadows cast by the violin and its scroll, and the “halo-hat” over the swirling coloured discs.

When on the Timbre grid, the bass note cannot be changed, unless a path for the Harmony grid is played. Otherwise, one needs to switch to the Harmony grid, to alter pitches being sounded, and then return to the Timbre grid.

2.2.4 Video 3. GrooveHarmony&Timbre

	0	0.02	0.21
musical	4-step chordal pattern with bass, offbeat percussion	Violin starts with pizzicato on diminished chord	Violin settles on semiquaver repetition of a minor 3rd chord
spatial	Paths offset		
visual	Harmony grid with blue and red icons		
Musical motivations		To explore the odd note/chords	
System affordances	Percussion is quite crisp, offbeat and variable		

	0.32	0.41	
musical	Pattern changes, then stops, leaving repeated 'C' bass quavers. Violin imitates quavers	4-step 2-timbre path of 'C' quavers	
spatial		I move around	
visual	Timbre grid appears	I mistakenly move around the grid trying to record a path	
Musical motivations	New section, stripped back sound	Set up a timbral path?	
System affordances		Copy paths from different parameters	

2.2.4.1 Notes and Discussion

The Harmony grid looks colourful, with the red and blue icons interacting with it, along with the purple dot. The 'halo-hat' gleams nicely in this dark video (we later realised that having more lighting was possible). The switch to the Timbre grid, and subsequent change in the way the paths sound, makes for quite a change, like a sectional change of compositional structure. (Paths can be kept similar, by judicious management of paths switches.)

The odd note pattern E, $F^{\#}$, A $D^{\#}$ has occurred, due to several chords of flattened scalic degrees, and no root chord being sounded. A diminished sound is the result, which the violin exploits to explore the intervals.

At 0.41, I appear to mistakenly attempt recording when a path is already playing. This occurred many times during the filming, and is a system behaviour that needs to be learnt.

2.2.5 Video 4. Tambura Volume

	0	0.05	0.26	0.4
musical	Alternating bass notes on 'sitar'	Violin commences long rising line, from home note	Answering phrase from high note descending	Violin stops, volume reduced on 'sitar', and then falls to low octave
spatial	4-step, 2 position path			
visual	Volume grid with one icon alternating with active icon, and then moving			
Musical motivations	meditative			An ending
System affordances	A lyrical serene mood			

2.2.5.1 Notes and Discussion

The Volume grid, with its serene pulsating blue discs helps set the serene mood for meditative violin lines over alternating "tambura" bass notes. The violin plays E, F, G, $G^{\#}$ over the E root note, and then an answering phrase: high B, A, $G^{\#}$, $F^{\#}$.

2.2.6 Video 5. Lyric Harmony

	0	0.1	0.34	0.41
musical	a slow 4-step path, bIII-I-V^7-V^7 'accordion' and 'reverb' keyboard sound, simple beats	Violins starts a slow plaintive melody over the harmonic pattern		A new more active phrase from low, moving upwards, uses minor and major 3rd scale degrees
spatial	Both icons together, I stand at the rear		I move forward a few steps, then pause	I move back
visual	Harmony grid, girl with clapperboard starts, camera girl visible. I wear gold.			Moving back whilst going up in pitch, then static whilst a sombre line flows downwards
Musical motivations	Ending on repeated V^7 gives a languorous feel			
System affordances	A good musical progression with nice instrument combination			

	0.58	1.1	1.42	1.52
musical	I stop and select new percussion instruments, trying several, sounding more active		some lyrical and impassioned playing	I finish slowly at high pitch
spatial				
visual			I move or sway around	
Musical motivations	A change	More forceful percussion with tabla stimulate new intervallic exploration		
System affordances	Trying new percussion			

2.2.6.1 Notes and Discussion

The chord progression noted at the outset, ends on two dominant sevenths, leaving a reclining and languorous end to the phrase, which allows for a slow, sensitive and lyrical violin exploration. There are several squares with the same chords, depending on the selected grid. This results here in spatial movement without chord change, although the vertical arrangement of the chord generally changes. The benefits of this situation would have to be evaluated on a case-by-case basis. However, it was set up initially like this, to allow many chord sequence selections that contain dominant sevenths, or to play a longer sequence (up to steps) including two dominant sevenths). At 0.41 mins. I step backwards whilst slowly rising in pitch – a timeless theatrical gesture from music-hall or opera (stepping slowly forward or backward whilst rising or lowering pitch, or rising or diminishing in intensity, has dramatic effect). At 1.42 mins. I start moving and start playing a new, more active phrase, like any musical performer might do.

At 1.10 mins., I react to the new percussion environment, by exploring new intervals and adding glissandi up to notes, to generate a new style for this section. A fresh selection of percussion changes the music considerably, as it does in other musical situations.

2.2.7 Video 6: ZangZang Rhythm

	0	0.09	0.14	0.35
musical	Simple percussion rhythm	Repeated bass synth quavers	I play a rhythmic violin line, starting and ending on home note Bb.	Voices switched off to activate 'live' percussion
spatial	6-step (five positions) Voice 1	Harmony path takes over		
visual	Rhythm grid – orange, I have gold shirt, and stand on the R. Red icon moves rapidly	Blue icon takes over, with a period of overlap (offset)	I step around the grid casually	
Musical motivations	Simple rhythm is a blank slate to add to	A home note provides a rhythmic drone as a solid basis for any improvisation	A soaring yet rhythmic line that curls and weaves seems called for	The solid bouncy percussion allows for re-emphasis of violin lines, or new material
System affordances	Simple rhythm is a blank slate to add to	As a harmony path has not been previously added, there is only 1 pitch		In 'active' mode, no other paths can be sounded

	0.41	0.46	0.53
musical	Percussion section finishes with some pitches, and then restarts	Bass synth quavers restart, and then I play violin, similar lines to before	
spatial			Stepping around, I may be seen to be chasing the icons
visual			I step around, some rhythm in my legs
Musical motivations			
System affordances			

	1.06	1.15
musical		Percussion changed
spatial		
visual	I adjust controller, attend display	I'm looking at display and grid icons
Musical motivations	I'm looking for something new to do	
System affordances		

2.2.7.1 Notes and Discussion

The Rhythm grid and its icons probably presents the *HarmonyGrid* at its most colourful. Combining loud and active percussion with my movement around the grid, shows the system at its most theatrically engaging.

2.2.8 Video 7. Americana Harmony

	0	0.22	1.22
musical	Slow synth crotchets over simple bass with similar phrases. The IV-I-V-IV pattern (on A) makes the tonality confusing, perhaps Hypophrygian mode.	I play violin broadly and lyrically, slowly expanding phrase lengths and complexity, then stop	Tempo increases, slowly at first and then up to a fast tempo
spatial	Both icons together		
visual	Harmony grid. I stand at the rear	I move a little	
Musical motivations	Sounds like added 6^{th} and Major 7^{th} chords, giving an "American" sound.	These chords provide scope to explore the intervals.	
System affordances			Same material sounds quite different

	1.3	1.58	2.22
musical	I play violin crisply, adding quavers and syncopation	Scale changed – like a modulation down a 4th. After a while I become lyrical and fall to lower pitches.	Harmony grid changed, adding a harmonic minor flavour. Violin starts at low pich and works upward
spatial			I go off the grid
visual	I move around		I use the computer mouse to make the change
Musical motivations	Exploration of rhythmic quaver patterns and syncopation	Repeat exploration in new key	The new intervals provide material to play with
System affordances		Modulation by changing scale	

2.2.8.1 Notes and Discussion

The confusion of tonality is provoked by the four-step three-note pattern, that starts and ends on chord IV. Taking IV as the home note makes this a Hypophrygian mode. This situation could have been altered by changing the setting for the number of steps, and reducing to three-steps to make it a IV-I-V phrase. However, it provided intervallic interest to improvise with. A modulation was effected by changing the scale. Later a change of Harmony grid provided new intervals to work with, including an augmented second.

Adjusting the the tempo from slow through to fast allowed the same musical material to sound differently (synthesizer string sounds lost their "tail"), and to provide an upbeat basis for rhythmic improvisation with its quavers and syncopation.

2.2.9 Video 8. ArpsVol Rhythm

	0	0.16	0.34
musical	Solo 'clarinet' note sounds a volume path	Active voice plays arpeggios	A tone overhangs as a rhythm starts
spatial			
visual	Volume grid with red icon on blue circles. I stand at the rear		Rhythm grid appears, icon appears and goes. I move around
Musical motivations			Live triggering of rhythms
System affordances			

	0.58	1.11
musical	Arpeggios return, modulated by timbres	I play violin, lyically in e minor, using augmented 4th
spatial		timbres heard distinctly spatially
visual	Timbre grid appears	
Musical motivations		
System affordances		

2.2.10 Video 9. AugLyric Harmony

	0	0.13	0.22	0.31
musical	Aug. triad and delayed bass, simple percussion. I change Harmony grids twice - modulations	Change instruments several times	Bass voice changes, upper voice to strings	Free lyric violin line
spatial	5-step medium-fast loop across L to R	static		
visual	The Harmony grid, both icons together. I change harmony grids twice	Nothing new to watch in these periods	I look at controller and its display	I play violin
Musical motivations	Exploring harmonies by different grids			
System affordances	Modulation and differentiation by grid change	Sufficient instrument choices to find a good pairing		Purple dot wandering around in this session, not tracking well, a visual distraction

	0.45	1.04	1.24	1.53
musical	Violin line plays with accidentals as passing notes or appoggiaturas	Voices separate in time. Violin stops	Short phrases on violin, getting longer and more connected	Accidentals used to play around with harmonies, play chords
spatial		Offset paths		
visual		Offset icons move separately. I adjust controller and watch		
Musical motivations			Short phrases sit over the pattern well, as do longer lyrical ones	
System affordances			Improvise as long as I like over any pattern	

	2.08	2.14	2.24	2.26
musical		Stop violin	Tempo increased, new more varied percussion	Rhythmic violin line
spatial	A different visual viewpoint for me		Tempo increased	
visual	I move across to R corner and return to L	Stand still and adjust controller	Tempo increased	I move a little
Musical motivations	A different musical/spatial viewpoint for me		It has been a long time on the previous pattern	
System affordances	To hear phrases from different spatial perspectives		Tempo change is available any time, and the knob calibration feels right	

	2.35	2.37	
musical	Mostly percussion, violin stopped	Repeated bass quavers on one note	
spatial		I trot around grid	
visual		I trot around grid, purple dot follows, wandering a little	
Musical motivations	Splashy percussion makes a new scenario	Repeated bass notes provide rhythmic impetus to run around	
System affordances		To change the musical scenario quite radically, easily	

2.2.10.1 Notes and Discussion

Some notes relate to only one row in the tables, whereas “Tempo increased” related to all three rows.

System affordances are often musical, e.g. I take a decision point at a phrase ending, to prepare a new musical segment: at 2.24 mins. with the tempo increase, a shift to percussion is followed by the bass being released from its path to play a repeated note.

2.2.11 Video 10. Contemporary Harmony

	0	0.1	0.22
musical	Offset paths at v. slow tempo play a contemporary soundscape, with flabby bass and splashy percussion	Violin starts playing, at the bridge, mixing odd intervals, tremolo, chords, rests, and then lyrical phrases	Tremolo - bowed and slurred, chordal sequences
spatial	I stand at the rear		I move to a square (V^7)
visual	Harmony grid, seeing both icons. Silver shirt matches white 'halo-hat'		
Musical motivations	Making a contemporary soundscape		
System affordances	Very slow tempi and widely varying volume levels. It's possible to create colour schemes		

	1.17	1.36	1.46
musical	Artificial harmonics	I stop playing violin	splashy percussion remains
spatial			
visual	I move to another square (I), then slowly step back	Stop playing and step back to the rear	Rhythm grid appears
Musical motivations			A change
System affordances			A change

2.2.11.1 Notes and Discussion

In this video a very different sound-world is created, by using a very slow tempo and sounding chimes and cymbal splashes, and by playing the violin with the bow near the bridge (*ponticello*). A broad range of violin techniques are used—various tremolos, chordal sections, trills, artificial harmonics etc.—to create a contemporary sound-world. These resonate well with the musical texture of the *HarmonyGrid*. The musical scene is sustained for nearly two minutes, with an intimate presence. At times some violin detail contrasts with the 'splashy' texture, and pulls in the audience focus.

A colour scheme can be created, between my costume and the grid colours (and the lighting). Standing on a particular square creates an attitude of intention. Slowly stepping to another square with this slow soundscape has dramatic effect. This scenario isn't further developed here, but has potential.

2.2.12 Video 11. Dance Question

	0	0.04	0.09
musical	3 rising notes on chimes. The voice is not arpeggiated but plays 2-3 note chords	Silent, then 4 note phrase, first 3 notes doubled on violin	A few chime notes, then a short phrase violin solo
spatial	I move across, a few steps	I move back	I move across
visual	Harmony grid		
Musical motivations	Asking question	Answering question	
System affordances	Dance mode!		

	0.15	0.19
musical	More notes followed by violin chords	After a silence, notes and a percussion rhythm start up
spatial		
visual		
Musical motivations		A new section after the question and answers
System affordances		Dance mode is switched off, to re-activate paths recorded earlier

2.2.12.1 Notes and Discussion

On the Harmony grid, Dance mode is used to spatially and temporally play phrases on the grid. It is very demonstrative after the regular triggering in ordinary mode. By stopping moving, and ceasing to trigger notes, I can respond on the violin in the ensuing silence. The system can then be reinstated from where it left off before, with previously recorded paths, by switching off Dance mode. Dance mode provides a very different rhythmic and gestural performance to the other modes.

2.2.13 Video12. Falling Harm&Rhythm

	0	0.27	0.57	0.59
musical	3-note 4-step pattern of falling phrase with varying sounds, striking bass& percussion	Violin starts on the 3rd and 4th degrees of F dorian mode	Percussion changes lead to Rhythm grid selected.	New path for both icons together: 2-squares, 6-beats/steps
spatial	I stand on rear R corner			
visual	Both icons, visible yet together, loop together on Harmony grid. Purple dot away from me.		Rhythm grid presents its orange colour scheme, offset by my white reflective shirt	I move around, but not triggering, as in counterpoint to previously active grid and music
Musical motivations	One phrase can have several instrument-ations, plus percussion.			
System affordances	Different Harmony grid patterns present different colour schemes, here combined with icons	Where only several notes sound, the performer can determine which scale suits or fits	A lingering note, left over before a grid change, becomes an effective drone	

	1.08	1.19	1.27	1.54
musical	Percussion stripped back to light cymbal, with drone	Kick drum added, with odd back-beat	Violin starts low to build a rising phrase over drone, then playing on FM[7] using chords	Violin starts low again to build to a "grand" style
spatial				
visual	I wander back and forward on the rear row like an animal			
Musical motivations			A drone and simple percussion provides a basis for a musician to build an epic solo	
System affordances			It is simple to build a scenario for an extended solo break	

	2.09
musical	Violin stops, drone stops. Percussion changes several times
spatial	I appear to wander around the icon loop
visual	Icons disappear, and reappear, I wander around
Musical motivations	Stopping the drone and violin, leaving percussion, leaves a state which can end, or go on somewhere else.
System affordances	Its usually simple to strip back events to bring a close

2.2.13.1 Notes and Discussion

At 0.59 mins. I move around the grid, not actively triggering it, as a movement counterpoint to the previous grid and musical activity.

At 1.27 mins. a drone and simple percussion provides a basis to build an epic solo. It is easy to create a musical scenario with this system to set up an extended solo break.

Whenever the icons move in a close loop and I move around the grid, it appears to be around that zone and in relation to it, i.e. the most visible moving components are perceived to move in relation to each other.

A change of grid displayed is probably the most dramatic effect achievable with this system. A corollary to this observation might be that, as it is quite often visually static, the audience's perception is drawn to details.

2.2.14 Video13. TomTom Rhythm

	0	0.06	0.23	0.29
musical	fast quavers on tom-toms, loud	Voice 2 on, takes a while to sound volume path on bass rhythm	I play violin march-like line in D major.	
spatial	I start at the rear			I move to L side and face in, addressing grid
visual	I'm standing still with purple dot wandering and red active square flashing	Blue icon appears		
Musical motivations			Loud active music requires a crisp definite response	
System affordances				

	0.39	0.49	1.09
musical	Bass replaced by oscillating high synth, new snare pattern added to perc. Violin modulates to B Major	Bass rhythm returns, back to D Major	Complete change: Voice 1 with clanging synth 4ths rhythm, and new simple percussion minus tom-toms
spatial			
visual	I move to front edge, face in	I move to R side edge, face in	
Musical motivations	A fresh section, contrasting, yet still with tom-toms	Return to 1st statement, and extend it with hooked rhythms	Losing the toms brings a new melodic clarity, in C# Major!
System affordances	modulation		

	1.27	1.58	2.28
musical	Voices switched off, leaving the oscillating high synth. I play pizzicato on violin, in $G^{\#}$ minor (relative minor of B Major from 0.39). Active part plays different percussion patterns	I play, with the bow, legato phrases around $D^{\#}$	Voice 2 returns to play low notes of less intensity, in D
spatial	I wander around, plucking the violin, triggering flashing red squares		
visual	I wander around	I stand on the rear edge, and then continue to move	
Musical motivations	A steady crotchet drum-beat and high synth provide a chance for a new texture - pizzicato	Its time to expand the "B" section and play with it a while	Return to familiar ground, and home key of D Major
System affordances	Switching on the harmony grid (but not displaying it or playing a path) leaves an oscillating synth pattern running – a handy textural function	Active triggering of percussion is expressive and engaging, and has the appearance of a dance game	Switching paths back on has the effect of returning to musical sections, and system scenarios

2.2.14.1 Notes and Discussion

Some physical placements and gestures may be interpreted by the audience. For example, at 0.29 mins. I move to left edge and look down at the grid whilst playing, seemingly to address the grid action, directing music to spatial/visual icons, as it were. At 0.39 mins. I move to the front edge and address the grid, and again move at

0.47 mins. to the final side, like a square dance with each musical section facing one direction.

In this example and many others, the system is used frequently to create musical sections of a composition by up to three actions: by switching items on or off or adjusting one – e.g. percussion instruments. Often two actions are sufficient for a significant change, given that some paths have been set-up previously. Since adjustments are made whilst not playing the violin, the pattern of action is to make some and then play violin with the new texture. This seems a comfortable and musically natural way to proceed.

2.2.15 Video14. Tracking Rhythm

	0	0.12
musical	Simple percussion sounds, then tom-toms	
spatial	I walk around it	I arrive at the rear, stop a moment, and then move clockwise around more quickly
visual	Rhythm grid. I walk around it triggering live	As above
Musical motivations	Active rhythms as solo music	
System affordances	Moving around and actively triggering, can be enough activity	Moving on the grid is theatrical action

2.2.15.1 Notes and Discussion

Moving around and actively triggering the grid squares can be sufficient activity—musically, spatially and visually. The emphasis in this video appears equally split between the percussion sounds and the visual activity. Here I move around in a circle on the grid, first at a medium pace, and then faster. This could develop into a choreography.

2.2.16 Concluding Notes

The rows labelled Visual and Spatial in the tables largely covered the same information. Only details of colour schemes and shadows strictly belonged to the visual domain. Musical motivations covered the musical intention and potential of the segment, beyond the reporting of the musical events in the Music row.

2.2.16.1 Visual

Colour schemes occur with the displayed grid and the icons selected. These grids have their own ambience and mood, which may be quickly heightened by creating suitable music (Video 4). Colour schemes may be added to by appropriate use of costume and lighting. Shadows occurring on illuminated shapes can be delightful (Video 2), revealing patterns and shapes that become another parameter to become involved with. The biggest visual change possible is to change the displayed grid. The most colourful grid is the Timbre grid, but the Rhythm grid has the highest intensity with its all-orange display, whilst the Volume grid looks quite sombre and moody.

2.2.16.2 Spatial

Moving around on the grid is generally for recording a path, or for live triggering of active squares. Additional motivations are revealed via the analysis. Moving into the spatial zone of the currently playing path, I appear to want to be seen in the middle of it, interacting with it, and to get into the centre of the music-space. In Video 6 I appear to be chasing the icons.

Moving to a particular square can be seen to be a highly intentional manoeuvre (Video 10) and to have theatrical tension in holding the location. A next move carries equal focus. Moving to a square and then starting a new musical phrase (Video 1) works dramatically. In some cases I appear to be addressing the activity of the grid, by moving to a location and looking down at the grid (Video 13). Moving around the entire grid (Video 14) at varying speeds, resembles and carries the potential of a choreography. Practically, I can move at speeds from very slow to quite fast, whilst holding onto my instrument and equipment. However quite athletic manoeuvres would not be possible with the current equipment.

Repeating a chord within a pattern or path, may mean playing the same chord at several locations (Video 5). On a sequencer or instrument this may be trivial or of no consequence, but on the grid a particular spatial path is formed. The benefit of having several squares with the same chord would need to examined on a case-by-case basis.

Dance mode allows spontaneous triggering of squares, rather than the rigid pulsed synchronisation of the usual mode (Video 11). Dance mode highlights, and makes a feature out of, the central mechanism of the system: the motion tracking and spatial music triggering.

On the negative side, triggering by moving the whole body around might be seen as a clumsy method. A musician's fingers can play a sampler or keyboard very fast and accurately and do multiple things simultaneously. However, the *HarmonyGrid* provides hands-free operation, in an immersive graphical and musical/sonic environment.

Overall, the videos sound lively and the spatiality is conveyed well by the DVD, so that listening within the zone of the four or five speakers (the centre one is unnecessary) places one within the music-space of the grid.

2.2.16.3 Music

Overall the *HarmonyGrid* provides sufficient and varied textures to improvise with, from the specifically selected and organised, to the more general or loosely organised. Simple textures work well, e.g. live rhythm patterns actively selected, or drone and rhythms. Instruments can be selected to sound well together (Video 1), or to provide a variety of sounds for a palette (Video 10). Some scale patterns sounded modal, providing (Video 7) further melodic interest.

A sustained musical environment can be created to improvise with (Video 10). This ambience stimulated a range of colouristic violin techniques such as *ponticello* and artificial harmonics.

The arpeggiators work to provide sufficient variety and musical interest. I found I was motivated to explore unusual note patterns on the violin, within the largely diatonic harmony; for example, by using augmented fourths.

Modulations can be performed effectively (Video 1) with the system. Tempo change can dramatically change the musical scene (Video 7), as can a change in percussion selection (Video 5) which stimulates further improvisation.

On the negative side, bass notes can get “stuck” unless shifted by a Harmony grid path.