Composition : pure data as a meta-compositional instrument

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COMPOSITION:
Pure Data as a Meta-Compositional Instrument

A thesis submitted in fulfilment of the requirements for the award of the degree

Doctor of Creative Arts

from

UNIVERSITY OF WOLLONGONG

by

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I, Michael Barkl, declare that this thesis, submitted in fulfilment of the requirements for the award of Doctor of Creative Arts, in the Faculty of Creative Arts, University of Wollongong, is wholly my own work unless otherwise referenced or acknowledged. The document has not been submitted for qualifications at any other academic institution.

Michael Barkl

22 January 2009
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Finally, thanks are due to Miller Puckette, the writer of Pd as an open source program, without which life would be a whole lot less fun.
To my grandfather, Leslie Cum Chow Cook (1900-1977)

- audio engineer, inventor, inspiration-
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One of the consistent features of electronic music is the absence of a “score”, and while this attribute is often regarded as a “freedom”, it has also inhibited the study of electronic works, especially their process of composition; indeed, at different times composers, most notably Karlheinz Stockhausen, have attempted to produce “study scores” of their electronic pieces.

The desire to document the compositional process has also been a longstanding personal interest of mine, and the electronic works in this folio, described in the thesis, are a creative response to this interest. The original works take the form of MP3 files that are provided on the companion CD in the sleeve of this volume. All works except one have been composed using an open source musical patching language called Pure Data or Pd, which was initially developed by Miller Puckette.

The personal motivations for the compositions on the accompanying CD are explained in chapter 1. It describes the types of pieces composed for the folio and the means and resources used to develop and produce them. The notion of “reading” the graphic layout of Pure Data (Pd) patches is proposed as a way to document compositional process and structure. The poetry of John Gracen Brown provides a contextual “vision” for an extension and development of the sounds of The paradox of Pythagoras into the series of three highly structured works that comprise Music of Grace. My interest in pure sine tones, used in this case for an extended harmonic
series based on a significant fundamental, is discussed in relation to these pieces and, finally, the whole project is reframed in “research” terms.

In chapter 2 *The paradox of Pythagoras* is discussed in detail (together with a variant of this piece entitled *Music of the spheres*). The discussion not only describes the work in terms of its structure and function, but addresses a range of aesthetic choices that are maintained throughout the rest of the folio, especially with regard to pitch (frequency) and the particular use of the harmonic series. For the purposes of reference and comparison the appendices include a table showing the relationship between all Pd patches created specifically for the work.

Chapter 3 briefly describes a series of three works collectively entitled *Music of Grace* and discusses the compositional development of each of these works. Though the works were inspired by the poetry of John Gracen Brown their musical origins lie in a Bach chorale. A detailed examination of every one of the 1025 patches I developed in the process of composing *Music of Grace* can be found in the appendices, together with reference tables that show the structural relationship between all Pd patches created. This was intentionally organised so that technical detail essential to the composition process is made available without deterring a reader who is less conversant with the intricacies of Pure Data from understanding the musical character of these works.

Chapter 4 finally deals with the central question of my thesis—the inherent problem of electronic music composition and its inattention to the documentation of compositional process and structure. The programming and layout conventions of the Pd patches are reassessed in the light of the works discussed in the previous chapters and the specific solutions devised for each individual piece. Difficulties are acknowledged and deviations from programming conventions are accounted for.
Chapter 4 concludes by recognising the capacity of Pd to suit large scale multi-sectional projects, and the value of the programming conventions as a benchmark for readability.

Chapter 5 serves as an epilogue, revisiting instrumental composition in the light of the electronic works composed using Pure Data and reviewing some of the special characteristics of instrumental writing. It describes the process of composing a chamber work entitled *Here…*, a work written concurrently with *The crystals in the cave*, discussed in chapter 3. As an epilogue to the project, after an intense period of composing purely electronic music, this piece allowed a return to the issues identified at the beginning of the project with a widened vision of composing. The strictures and human limitations of instrumental music, which are acknowledged as “special” in their own way, may now take their place alongside the “freedoms” of electronic music in a complementary manner.
Abstract

The aim of “Composition: Pure Data as a Meta-Compositional Instrument” was to compose a folio of original electronic pieces that used Miller Puckette’s open source program Pure Data (Pd) as a “meta-compositional instrument”: that is, as a vehicle for documenting the creative process in a graphical way as a type of analytical notation.

The pieces extended and explored creative aspects of my previous compositional research into binary processes, symmetry, and complementary pairs, using only sine tone frequencies based on the higher partials of sub-audio fundamentals.

Published Pd programming conventions provided a standard benchmark with regard to “common sense” signal flow conventions, and were only adjusted when significant differences between purposes and methods were encountered.

Despite the “composition of the composition” being evident in the graphical layout of the patches, it became clear that further “interpretive” commentary was necessary to explain the artistic or musical purposes of different patches.

Nonetheless, it was shown that a composition in Pd can explicitly show its own construction and interrelation of compositional elements, providing a kind of descriptive analysis of the work. Moreover, Pd was shown to be suitable for large scale, multi-sectional projects.
Chapter 1

Developing Meta-Compositional Strategies

1.1 Background to the Project

My introduction to electronic music in 1977 was through the traditional, and sometimes laborious, techniques of recording, tape splicing and mixing as one of Martin Wesley-Smith’s students at the NSW State Conservatorium of Music. Later, while studying with Warren Burt, the Moog Modular V offered a dizzying array of possibilities. Finally, the new Fairlight Computer Musical Instrument (CMI) arrived and I earned the tiniest footnote in the history of electronic music in Australia by producing what is presumed to be the first so-called “serious” piece for it.¹

Working with the CMI was exciting, but my undergraduate years were complete and, in 1980, a Fairlight cost close to the equivalent of a small house in Sydney. I devoted the next decade to orchestral and chamber music, and the decade after that, to musicology and education.

However, in 1988 I had a brief experience that stayed with me. I was invited to IRCAM in Paris for a lecture and performance of one of my chamber works² by the resident Ensemble InterContemporain. As part of the visit a tour of the facility was arranged and the place seemed to be abuzz with the word “Max”. There is nothing like a visit to IRCAM to rekindle an interest in electronic music and I began to fantasise how I could return there.

¹ Rosalia (1980), using sampled drum sounds, was first performed on 29 November 1980 at the NSW State Conservatorium of Music and was subsequently featured in a performance at the International Music and Technology Conference, University of Melbourne, on 28 August 1981.
² Ballade (1984) for flute, clarinet, vibraphone, piano, violin and cello.
Domestic and vocational activities, though pleasurable and satisfying, intervened for the next 17 years and I eventually moved to Wollongong in 2005. After getting settled, one of my first actions was to contact the Faculty of Creative Arts to discuss the possibility of studying electronic music.

There were two provisos:

1. Did I have sufficient background to resume the study of electronic music composition at this stage?
2. Was it possible to run the required software on a laptop computer?

Firstly, I brought to this project a four-year undergraduate background in electronic music combined with a thorough post-graduate background in both composition and music analysis. At that level, my preparation for this project was reasonably good. However, I did not have a background as a computer programmer. When I discussed with Greg Schiemer my interest in using accessible technology (a laptop computer) to develop algorithmic structures using a user-friendly program, Miller Puckette’s Pure Data (Pd) was suggested. When I discovered that Pd was similar to Max the project was irresistible from my point of view.\(^3\)

In terms of “limits” to the project, it had to be acknowledged from the outset that this was a composition project and not a software-development one. I did not expect to add to the world’s knowledge of computer synthesis or even of Pd; I expected only to add original music to that created using Pd. However, I did expect that the music I created would not only use Pd but be integral to Pd. This is not to say that the music would not be able to be realised by another program such as Csound, for example, but that Pd was to be used for a particular purpose.

\(^3\) Puckette was working on Max at IRCAM during the late 1980s. I met a number of young Americans there and Puckette may have been among them.
The second proviso was a personal and pragmatic one. Having once experienced separation anxiety from the Fairlight CMI after enrolment at the NSW Conservatorium ceased I did not want to have that happen again. The project had to be able to be realisable in my home studio, which, because I lived in a very small apartment, consisted of a laptop on a collapsible table beside my bed.

1.2 Composition: Pure Data as a meta-compositional instrument

My proposal was to create a folio of electronic pieces using the program Pure Data (Pd) as a “meta-compositional instrument”.

By “instrument” I meant using the program as a machine or tool to make music. By “meta-compositional” I meant using Pd to explicitly close the gap between analysis and composition (the two subjects which have engaged me for the last 30 years): that is, the “notation” of the composition in Pd (taking advantage of its graphic qualities) was intended to explicitly show its own construction and the nature of its interrelations—in effect, the composition of the composition would become evident. Pd already has a widely acknowledged value in real time synthesis. My intention was to exploit its less acknowledged value by using its inherent graphic qualities as a means of documenting the thought processes of the composer.4

1.3 Progress

Initially, I proposed that I would work with MIDI only, and compose a folio of works for quasi-piano in the tradition of Conlon Nancarrow’s Studies for Player Piano

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4 This expectation was thought to be reasonable since Pd was designed essentially as a “real-time” computer music system useable by so-called “non-computer scientists” (Puckette 1997). Significantly, Pd’s user interface is a screen-based patching language that imitates the modalities of a patchable analogue synthesiser through a graphic representation (not altogether unlike the Moog Modular V, for example).
through to Warren Burt’s *Music for Microtonal Piano Sounds* (1992-1998)\(^5\) and Kyle Gann’s *Studies for Disklavier* (1997-2004).\(^6\) However, after six months learning Pd and composing a short quasi-piano piece I decided to expand my perspectives and a number of types of music emerged:

1. Two short MIDI pieces that functioned as experimental “studies”\(^7\);

2. *The paradox of Pythagoras*: twenty-seven pieces of variable duration that are clouds of slowly changing oscillator sound;

3. *Music of the spheres*: a work derived from *The paradox of Pythagoras*, consisting of nine pieces based on the orbits of the planets;

4. *Music of Grace*: a series of three gentle, but still austere, compositions\(^8\) consisting of chains of “panels” that are re-readings of previous panels;\(^9\)

5. *Here…*: A single movement chamber work for clarinet, piano and cello, serving as an “epilogue” to the electronic works and a re-engagement with acoustic music.\(^10\)

### 1.4 MIDI Studies

The purpose of the MIDI studies was to separate the control functions of Pd from the synthesis, at least for the purposes of personal experimentation. The main issue that

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\(^{7}\) Recordings of the short MIDI studies, Study#1 and Study#2, are considered preparatory work and have not been included in this folio.

\(^{8}\) Each one of these compositions has its own title: 1. *The cat dances and the moon shines brightly*; 2. *The heavy dark trees line the streets of summer*; 3. *The crystals in the cave absorb the light as if they have not seen it in a million years*.

\(^{9}\) “Panels” is a description and application adopted from the Italian composer Franco Donatoni (1927-2000). “Panel construction” refers to composition that graphically (and often aurally) creates section breaks” (Haber 2004: 16). The significance of the use of this terminology is that my previous musicological research concentrated on the music of Donatoni (Barkl 1985) and Donatoni’s student Riccardo Formosa (Barkl 1994). My own composition techniques, both for instrumental music and for this Pd project, derive from that research.

\(^{10}\) The number series 27-9-3-1, articulated by the pieces in this folio, is not accidental; it is intended to subtly tie the pieces in the folio together.
arose surprised me by its intensity. Clearly, when writing for MIDI piano, the limitations of a human performer are of no consequence, let alone the foibles of an individual pianist. The efforts of louder, softer and faster mean nothing. My surprise was the realisation of just how much my personal compositional approach was entwined with the “physicality” of individual instruments, each imbued with a kind of historical “catalogue” of repertoire or idiomatic figures. In the past my compositional craftsmanship involved establishing a musical meaning through the connection of the instrument to the human performer, and then from the performer to the human listener in live performance.

My approach to composition technique meant nothing in the electronic music context and I was devastated.

And then I saw this devastation as the most extraordinary opportunity. I had previously researched composition and music-making from a social-economic and psychological viewpoint (Barkl 1992) and had been struck by its transactional component. Performers (including conductors) and audiences generally wished to feel “rewarded” for their investment of effort and time. Even more directly, concert producers required an economic return. As a composer I had been sensitive and accepting of this and had consciously attempted to provide rewards via idiomatic writing (for the performers) and astonishing sounds (for the audiences). I had no sense of “selling out”; this was just my approach as a composer and my interpretation of craftsmanship. The corollary of this point of view was that my music was essentially demand driven: the live performance was the authentic music (a recording
being something else) and, if performers did not wish to perform the work, then there was little point composing.\textsuperscript{11}

The opportunity was that, while I had previously seen these strictures as stimulating (to the point of being the foundation of my compositional approach), the removal of them would allow a totally “free” music. For the first time I could create music that I did not have to “sell” to a performer. I could create music that I, even if it was only I, wished to hear.

Significantly, by acknowledging the authenticity of a recording of an electronic work, as distinct from its live performance in a concert setting,\textsuperscript{12} the music remained unbound by the economic context of live performance and became available for distribution via electronic means, such as web radio, whilst remaining in authentic form.\textsuperscript{13} While live interactivity remains one of the most outstanding and attractive features of Pd, my interests are in the structuring of compositions in time and not in interactivity or improvisation.\textsuperscript{14}

\subsection{1.5 The paradox of Pythagoras}

The initial purpose of \textit{The paradox of Pythagoras} was to concentrate on sculpting sound; that is, to experiment with synthesis with minimal interference from Pd’s control functions. The concept was to create complementary (A-B) panels of sound using slowly changing sine tones based on higher partials in the harmonic series.\textsuperscript{15}

\textsuperscript{11}The aesthetic problems of electronic music and live audiences have been discussed at length (see Emmerson 1986, Davis 1996 and Holmes 2002). Cf the communicatory intentions behind Steve Reich’s “documentary” approach to electronic music (Reich 1996) and the research into speech synthesis (Chowning 1989).

\textsuperscript{12}Here I take my cue from Morton Subotnick, \textit{Silver Apples of the Moon} (1967) (Wergo 2035, 1994), the first electronic composition conceived and recorded specifically for release as a commercial recording, as apposed to “live” or concert performance.

\textsuperscript{13}See Cosentino 2004 for web radio and Duckworth 2005 for other web based distribution.

\textsuperscript{14}As a jazz player, my improvisatory urges are well satisfied elsewhere.

\textsuperscript{15}Because the music in this project is constructed solely from exact harmonics, for the purpose of this thesis, “partials” and “harmonics” have the same meaning, with the fundamental being counted as the first partial or the first harmonic. However, it is recognised that the word “partial” is often used to
These synthesis studies have taken on a life of their own, engaged my interest, and have grown from “panels” to “walls” of sound that vary from resembling various sounds ranging from tanpura drones to industrial noise.

1.5.1 Complementary binary structures

My interest in complementary structures as a compositional determinant is a personal one relating to my previous research into binary form and balance, and the notion of creating complex structures from simple binary opposites. The current project serves to further that research.

1.5.2 Sine tones

Sine tones have an audible clarity where beats, difference tones and even residues may be expected to be heard. I experimented with FM synthesis and, while the timbres were interesting for The paradox of Pythagoras, I found the sidebands distracting for the more “pure” intentions of Music of Grace and chose to leave the sine tones pure and unadorned for that series.

Additionally, sine tones have and maintain, for me, a strong aesthetic dimension, as expressed by Stockhausen in 1953: “It is unbelievably beautiful to hear identify harmonics that are not exact integer multiples of the fundamental. For a similar reason, the word “overtone” is avoided, as it is commonly used to describe partials that do not have a relation to harmonics.

The use of the word “noise” here is not intended to imply any connection to Russolo’s (1986) concepts or ideas. Indeed, as I will show later, these pieces have very little in common with the more random frequencies associated with “noise”. Rather, they are more closely associated with notions of “purity”.

See Barkl 1994.


I also experimented with reverberation (in order to control the “depth of field”), but found it significantly interfered with the pure timbres. Additionally, a subtle control of proportional left-right placement of sounds (panning) tended to be lost in the blend of pure harmonics, while moving panned sounds left and right was too overt for my taste. After some experimentation I was content for the left-right stereo image to reflect the sharply contrasted complementarity of the rest of the work, and, indeed, to allow the identification of complementary pairs. See Appendix N for examples of the reverberation patches.
such sounds, which are completely balanced, ‘calm’, static, and ‘illuminated’ only by structural proportions. Raindrops in the sun…”

1.5.3 The use of the harmonic series

Initially I did not have an interest in tuning systems. However, working in equal temperament with sine tones made the tuning anomalies of equal temperament distractingly apparent and seemingly out of place. Using higher partials in the harmonic series (and the equivalent partials in the sub-harmonic series) placed all frequencies, including summation and difference tones, in their “correct” relation. The results enhanced aural clarity.

1.6 Music of Grace


Music of Grace uses the lessons learnt in the MIDI control studies and The paradox of Pythagoras to make a series of pieces of some length and scale from basic Pd principles; that is, without using externals developed by other composer-programmers. Certain Pd programming conventions, as proposed by Trevor Agus (2004), are acknowledged in order to document the composition process.

1.6.1 John Gracen Brown’s poetry

There is no special reason for the choice of this poet except for personal preference. The notion of “The Return” is metaphorical (from my point of view) for my return to

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20 Letter to Karel Goeyvaerts 7 September 1953, quoted in Toop 1979 (translation by Richard Toop). Stockhausen was writing of his experiences composing Studie I.

21 The use of externals is discussed later, in the Pure Data Literature Review.

22 See Appendix D. Agus’s conventions will be briefly described in the next section.
composition after a decade of near silence. It is through the “grace” of the computer (that is, inexpensive hardware and open source software) that has made this return possible.

The titles of the three individual pieces that comprise *Music of Grace* are the complete text of three short poems by John Gracen Brown (2005: 5). These poems, which take the form of brief “visions”, create a general context for the musical works:

1. *The cat dances and the moon shines brightly*\(^\text{25}\)
2. *The heavy dark trees line the streets of summer*\(^\text{26}\)
3. *The crystals in the cave absorb the light as if they have not seen it in a million years.*\(^\text{27}\)

### 1.6.2 The use of primary material: a Bach chorale

As did countless music students, I spent a decade of childhood and adolescence emulating Bach chorale style, and tonal harmony became something of a personal strength. The particular chorale I have chosen, *Befiehl du deine Wege*,\(^\text{28}\) is the only one in the Riemenschneider collection to have a flute obbligato.\(^\text{29}\)

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\(^{23}\) John Gracen Brown gave me permission to use his work in a letter dated 26 April 2006. Upon completion of *Music of Grace* I was concerned that the result may not meet with his approval, so I sent him a CD copy. After listening to the pieces, and with characteristic warmth and generosity, John Gracen Brown reaffirmed his permission in a letter dated 13 September 2008.

\(^{24}\) This is how John Gracen Brown described them (personal communication 13 September 2008).

\(^{25}\) “The Cat and the Moon”.

\(^{26}\) “Streets on a Summer Night”.

\(^{27}\) “Cavern Crystals”.

\(^{28}\) “Entrust thy Ways”, otherwise known as the melody of “Herzlich thut mich verlangen.” In this harmonisation it closes Cantata 161 “Komm, du süße Todesstunde”, suggesting the awakening and resurrection of the body.

\(^{29}\) See Bach 1941: 66. Additionally, the melody from this chorale has been used for popular songs, notably Paul Simon’s “American Tune”, from *There Goes Rhymin’ Simon* (Warner Bros 1973/WEA 2004).
The flute obbligato became my licence to do my own troping. The extracted pitches from *Befiehl* became numbers (as per standard MIDI assignment) and were allocated to harmonic numbers.

1.6.3 The use of numbers: an analogue between MIDI note numbers and harmonic numbers

In essence, I viewed MIDI number assignment as an ordering or ranking system, placing one (available) pitch in relation to the next (where the actual numbers themselves are of little significance). One may imagine that composers who typically work with scales\(^{30}\) could view MIDI numbers as a chromatic scale and the harmonic series as “just” another scale. The assignment of numbers from one parameter to another is not unusual. See, for example, Stockhausen’s analogue of durations to the harmonic series in *How Time Passes*.\(^{31}\) My use of numbers in this fashion is focused on the relation between pitches rather than the pitches themselves.

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\(^{30}\) Such as Warren Burt and Kyle Gann.

\(^{31}\) Stockhausen, Karlheinz, “…how time passes…” *Die Reihe 3*, Bryn Mawr: T. Presser (1959): 10-14 (p.16). Cited in London 2002: 716, Fig.22.10. Stockhausen’s article also includes an equivalent duration-pitch diagram for the sub-harmonic series. See also Xenakis 1992 and Gozza 2000 for number-sound relationships.
1.7 The application of programming conventions

The first thing that struck me about Pd’s patching language was its ability to document compositional algorithms. It seemed to me that, with a little care, Pd patches would be easily readable, not so much as a finished or publishable “score”, but as a documentation of a composer’s sketches and evidence of process; that is, serving as a kind of descriptive analysis of the piece. Using sketches or examples from a musical score, with minimal annotations, as an analytical tool is well known. Schenker is perhaps the most obvious example of this.\(^{32}\)

Initially I intended to develop my own set of patching conventions, since patches can easily become impenetrable. However, within a few weeks of literature review I discovered that Trevor Agus (a British researcher into hearing science) had raised similar ideas, though from a rather different point of view, and had published his own set of conventions. Agus’s brief conventions, comprising approximately half a dozen pages, recommend concise comments, consistent data flow, consistent naming of sub-patches, and avoidance of “sends” and “receives” and inline monitoring or “debugging” objects. As a starting point it seemed sensible to apply Agus’s conventions as far as possible and extend them if need be.

Examples of patches from The cat dances and the moon shines brightly follow, which show some basic aspects of the principle in action. In Figure 1.4 data

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33 “This is intended to apply to situations where Pd patches are being shared between users. … Specifically it is for a project in which 4 of us will be working on the same potentially large-scale patch.” (Agus 2004, 19:09:16 CET)
34 “Sends” and “receives” are connections that are not visible on screen.
35 That is, functional components should be “inline” and non-functional monitoring components should be offset.
36 See Appendix E “Pd Boxes” for a description of how Pd objects, messages, GUIs and comments are rendered in this thesis.
flows down the page from panel 1 to panel 5. The [bang] GUI signals that the previous section is complete as well as initiating the next section.

Figure 1.4 *The cat dances* Panels 1-5

Figure 1.5 shows what is inside the [pd panel_1] sub-patch. Again, data flow is down the page and shows that panel 1 comprises two subsections.
Figure 1.5 *The cat dances* Subsections 1a and 1b within Panel 1

Figure 1.6 shows what is inside the [pd p_1a] sub-patch. Here the data flow is more complex, with feedback to [pd high_control_1-22].
Opening further sub-patches, such as [pd high_control_1-22], [pd rests], [pd axis_50], [pd high_1-22], [pd low_1-22], [pd mixout_x6_d] and [pd no_of Voices_playing], would delve deeper into the structure down to the level of elemental operations.

The bulk of the written component of the thesis (and appendices H, J and L) will be concerned with the description and explanation of these kinds of patches. *The cat dances* has 50 different such “canvases” (as Pd calls them), some of which are
elementary (such as Figures 1.4 and 1.5) and some of which are more complex (such as Figure 1.6); *The heavy dark trees* has 257 and *The crystals in the cave* has 718.

### 1.8 Research question

Insofar as a folio of compositions can be thought of as “research”, the research question could be expressed as follows: ³⁷

Do Agus’s conventions provide a viable method of plotting creative processes in large scale Pd projects?

#### 1.8.1 Aims

The aim of the project is to compose a folio of electronic pieces that, as far as possible, use Pd as a vehicle for documenting creative process in a graphical way; that is, as a kind of analytical notation.

#### 1.8.2 Significance

Agus’s conventions have been proposed and discussed amongst Pd users, but as yet there has been no documented specific implementation and therefore no consensus on the matter. ³⁸ However, such an approach to Pd would not only be of use for collaborative projects, as flagged by Agus, ³⁹ but for “archival” benefit to scholars, students and, most importantly, composers themselves.

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³⁷ The “thesis” is the “submission of creative work (research)…supported by written documentation…focusing on aspects such as origins of the work, structures and techniques used, and artistic theories underpinning the work.” See University of Wollongong. *Creative Arts: 2006 Postgraduate Course Guide*: 16.

³⁸ See Barknecht 2004, 5 March 00:24:09 CET. The complete discussion on the subject may be found at the “Pure Data Mailing List,” last accessed 8 August 2005, [http://iem.at/mailinglists/pd-list](http://iem.at/mailinglists/pd-list).

³⁹ See Agus 2004, 4 March 22:50:17 CET. The issues are, in fact, a little more complex than outlined above. One of Agus’s principal concerns, for example, is that software is unlikely to be maintained for its whole life by the original author, and conventions allow later engineers to understand new code more quickly (Agus 2004).
1.8.3 Approach

The approach to this project is creative. There is no intention, for example, to produce pieces that illustrate Agus’s conventions.\(^{40}\) Rather, the intention is to produce pieces that will conform to Agus’s conventions insofar as the conventions remain useful.

1.8.4 Originality

The project is original in the sense that the compositions are original. However, three aspects are worth considering in this context:

1. The use of “standard” Pd (as distinct from “extended” Pd)
2. The use of sine tones and higher partials (harmonics)
3. The application of Agus’s conventions

Firstly, the use of the “standard”\(^{41}\) version of Pd is not original in itself. Rather, it represents a particular value system and point of view of the composer (as discussed previously).

Secondly, the use of sine tones and higher harmonics is also not original in itself, but it does represent a particular aesthetic held by the composer. Sine tones have been used since the birth of electronic music and their use in this project reflects the tradition of the Cologne studio and *elektronische Musik*\(^{42}\) rather than, for example, recent Japanese so-called onkyo music.\(^{43}\) One of the most well known contemporary uses of higher sine tone harmonics is by La Monte Young in his *Dream House* project

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\(^{40}\) Such a practice is not unusual. Compare, for example, Nattiez’s analysis of Varèse’s *Density 21.5* for solo flute (Nattiez 1982). The purpose of Nattiez’s analysis was more to provide an example of the semiotic method of analysis than a response to the desire to analyse this particular work (see Barkl 1994: 34-5, 45).

\(^{41}\) “Standard”, as distinct from extended versions of Pd that include externals developed by other composer/programmers.

\(^{42}\) See *Cologne—WDR: Early Electronic Music*, CD. BVHAAST 9016.


in New York. I became aware of the *Dream House* only after working on *The paradox of Pythagoras* and making the presumption that there must be other music like this. Unfortunately from my point of view, the *Dream House* is an installation and there are no commercially released recordings to listen to. However, descriptions and reports are quite detailed and it would appear that, among other things, the tones in the *Dream House* are static. Apparent changes and effects are perceived through either changes in perception over time, or changing one’s physical position in the room. Two major points of difference between the *Dream House* and *The paradox of Pythagoras* and *Music of Grace* are that the pitches and amplitudes do change over time, and they are conceived as recordings, not live performances or installations.

Lastly, while applying Agus’s conventions is certainly not an original idea, the particular purpose for which they are applied may be. Notation for electronic music has been a point of interest for many composers, and has recently become a focus for Miller Puckette and Pd users. Additionally, the notion of Pd’s “compositional” qualities, as opposed to its more celebrated “performative” ones, has recently attracted Puckette’s attention. Scoring and notation have become topical subjects for Pd. As far as my own interests are concerned, using Agus’s conventions to document the creative process extends and develops my previous research using graphical analytic techniques.

In summary, it would be fair to say that, leaving the creative originality of the compositions aside, the individual contributory components of “standard” Pd, higher

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45 I would like to thank Warren Burt for bringing the *Dream House* to my attention.
47 See, for example, Iannis Xenakis’s *Mycenae Alpha* and Cornelius Cardew’s *Treatise*. Cf also Stockhausen’s attempts to create, in retrospect, a “study score” of *Studie I* (Toop 1981).
50 See Barkl 1985 and Haber 2004.
sine tone harmonics and Agus’s conventions are not significantly original in themselves. However, my claim is that, when taken as a whole and combined with creative work, this project represents an original approach and an original contribution.

1.9 **Pure Data Literature Review**

1.9.1 **Published findings**

Significant milestones in Miller Puckette’s development of Pd are documented in his published papers, a list of which is included in Appendix A. Of particular interest are “Pure Data” (1996) and “Pure Data: Another Integrated Computer Music Environment” (1997) as they describe the early developmental aspects of the program. Later papers, such as “Synthesizing Sounds with Specified, Time-Varying Spectra” (2001), “Low-Dimensional Parameter Mapping using Spectral Envelopes” (2004) and “Phase Bashing for Sample-Based Formant Synthesis” (2005), are concerned with more recent problems that may be applied to Pd. Another is notable for its application to a practical outcome, “New Public-Domain Realizations of Standard Pieces for Instruments and Live Electronics” (2001), and two others for what appear to be a particular interest of Puckette: “Using Pd as a Score Language” (2002) and “A Divide between ‘Compositional’ and ‘Performative’ Aspects of Pd” (2004).


\(^{51}\) Although the date is given as 2003 (the version used during this project), Puckette considers the text to be a “work in progress”, intending to improve, upgrade and extend it as required. Its free availability in soft copy on the web makes this approach possible.
a comprehensive textbook on electronic music that uses Pd to illustrate the concepts. As an additional feature, the patches used in the book are included in the Pd program download.

“Bang: Pure Data” is a web based publication of a selection of the papers presented in the First International Pd Convention in 2004, and thus makes available a number of papers in a convenient source. The papers range from the technical to the sociological and any attempt to make a summary description of them here would be a distortion. Part of their significance is that they provide a window to the wide range of serious research interests related to Pd engaged in by academics and artists from Europe and the USA. While no paper raises the notion of Pd being used as documentation of the creative process, of particular interest is one that identifies and describes the Pd community, giving numbers of members of various subscriber lists, geographical spread, types and modes of communication, and motivations (Mayr 2006).

The “Pd Help and Tutorials” section of the program is another significant source of information. All “Help” files use working examples from Pd to illustrate objects and functions. Extensive example patches, such as additive synthesis, FM and reverberation, are also included in the Help download. Websites, associated with the Institut für Elektronische Musik und Akustik at Graz provide further access to tutorials and mailing lists.

52 General sources on computer music are more available than one would perhaps think. Until quite recently, authors of doctoral dissertations in electronic or computer music felt the need to include full descriptions of synthesis and underpinning theory before describing the actual doctoral project; see for example Ashton 1971 and Malouf 1985, which include sections describing general waveform generation and control. For this Pd project Roads 1996 was also consulted.


54 See Appendix B “Pd Help and Tutorials”.
1.9.2 Externals developed by other composer-programmers

The resource of a world wide community of Pd-users sharing patches is an exciting and stimulating prospect, and for some period of time I worked with Olaf Matthes’s MaxLib externals (2004). However, for the purposes of this project, I reverted to the “standard” release of Pd, as provided by Miller Puckette, for two reasons.

Firstly, I found myself drifting from my objectives and methods. My objectives included exploiting the opportunity to produce the music I wish to hear, irrespective of external aesthetics or economics. My method to achieve this objective was to draw the music from my imagination, and to use Pd to construct the music in a planned or architectural sense, rather than be distracted by adopting an exploratory “trial and error” approach to available materials that had been created by others motivated by a different aesthetic. More specifically, my objective at this stage was not to “learn” Pd per se, but to use it to achieve my compositional aims. Indeed, it is likely that learning Pd thoroughly would take significantly longer than the time allocated to this project.

Secondly, after adopting a freely available program designed for widespread use, I had no wish to personalise it to the extent that my patches would not load without special compiling. My intention was to ensure that my work would always load on the “standard” version of Pd; complexity will be developed through the building up of basic processes.

56 See <http://crca.ucsd.edu/~msp/software.html>. An extended package of Pd may be downloaded from <http://pure-data.info>. The version of Pd used for this project is 0.38.3.
57 This is not to cast an implicit judgement on the “trial and error” approach, but to make a distinction between it and a “planned” approach.
58 Some advice in this regard has been offered by Frank Barknecht, journalist for Deutschland Radio and the computer magazine c’t and an experienced software developer and Pd programmer: “I gave myself a span of 4 years in which I would not even try to do any real music with Pd but instead just invest time to learn it” (2004, 5 March 00:57:42 CET).
1.9.3 Areas requiring original research

There has been some general doubt expressed by Pd practitioners as to the ability of Pd to “scale up”; that is, its ability to be effective in larger scale projects.\textsuperscript{59}

The extension of Pd practice and documentation into larger scale compositions has not specifically been addressed in the literature and was consequently chosen as a focus for this project. The first stage in this process was to explore and develop the general sound world of the project through manipulation of multiple oscillators. This is discussed in chapter 2.

\textsuperscript{59} See, for example, Steiner: “Graphical programming languages don’t scale well into larger projects. Their strength is in getting highly customized things done quickly and instinctively. From what I’ve seen…they are generally not the right tool for creating large, general purpose, modularized applications” (2004, 23 March 14:29:19 CET) and Barknecht’s reply pointing out patcher languages’ relation to scripting languages (2004, 23 March 17:07:00 CET). Agus remains confident of Pd’s capacity to “scale up” (personal email 2 November 2006, see Appendix O).
Chapter 2

The paradox of Pythagoras

Chapter 2 discusses The paradox of Pythagoras in detail. In addition to describing the work’s structure and function, it identifies significant aesthetic choices that are maintained throughout the rest of the folio, particularly with regard to the choice of fundamental pitch and use of the harmonic series. MP3 recordings of the 27 “movements” are included on the companion CD to this volume. Also included on the companion CD, in order to facilitate cross referencing, is the related Appendix F.

2.1 Origins

The origins of The paradox of Pythagoras lie in the experiments I did in synthesis, building up banks of oscillators that will behave in interesting musical ways. The rather presumptuous title for this patch comes from a self-published book “composed” (as he writes on the cover) by Michael O’Halloran: Revisiting the Ancient Musical Scale and the Paradox of Pythagoras (2004). My intention was to choose a frequency on which to base the harmonic series used for this patch as well as the subsequent Music of Grace. One option was to adopt something approximating the legendary Chinese huang chung (hwangjung) tone that was said to maintain ancient Chinese civilisation in harmonious alignment.60

My choice, however, came from O’Halloran’s book, as a kind of tribute to him as an enthusiast for the proportions articulated by ancient measures and as proprietor

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60 I had been introduced to the huang chung tone, the “yellow bell” or “primal sound”, some twenty years ago through the rather polemical book The Secret Power of Music (Tame 1984) and remembered it as an attractive notion. For a more contemporary review of Tame (1984) and the huang chung see Gray (“Frequently Asked Questions: The Secret Power of Music, <http://www.wangchung.com/faq/secrets.shtml>). For a more scholarly approach, see Kuttner 1965.
of the Old Goulburn Brewery. If his book was “composed”, then my piece may be considered a “variation” on his composition, and I chose a fundamental of “D” in the fifth octave below middle-C, or 9.13125 Hz, tuned according to O’Halloran’s calculations.

The fundamental can also be represented as D,,, using a convention adopted in this thesis. In this convention specific pitches are given in the text using apostrophes and commas or strokes: c’ =middle-C; an octave below c’ is c; an octave below c is C; and an octave below C is C,. D,,, is therefore four octaves and a minor seventh below middle-C.

O’Halloran’s complete calculations and description of the “paradox” are rather complex and require some clarification before they are of any use in this context. In summary, O’Halloran relates the musical scale to the architectural referent, the 2x2 geographic-foot “mason’s module”, two modules being analogous to what are normally referred to as two tetrachords (O’Halloran 2004, 3). The proportions are applied to the dimensions of the Great Pyramid of Giza and the frequency of a’ =438.30414 Hz is derived (2004, 47), where the scale passes from a’ to g’’. When the mason’s module is “tweaked” with reference to the Sothic Great Year

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61 It should be made clear that O’Halloran is not a scholar in the academic sense, but an enthusiast, and there has been no attempt on my part to challenge his writings in a systematic academic manner (though it can be seen that questionable results may have been the result of judicious rounding of decimals). The Old Goulburn Brewery, claimed by O’Halloran to be designed by Francis Greenway and imbued with significant architectural and structural proportions (see also O’Halloran 2002), was the venue of many musical events during my 18-year residence in Goulburn, and the source of many happy memories. His pronouncements are accepted in good faith and their technical or historical accuracy (or otherwise) has no bearing on the nature of this project.

62 This is the so-called “Helmholtz pitch notation” because of the use of it in his Die Lehre von den Tonempfindungen als physiologische Grundlage für die Theorie der Musik (Brunswick 1863). Commas, or strokes, change to Roman numerals for five and above. The apparent awkwardness of assigning c’ to middle-C is explained by the assignation of the pitch C for the bottom note of an 8-foot stop on organ manuals. Helmholtz’s notation is used as a conventional standard in the Grove’s Dictionary of Music and Musicians (Grove [ed.] 1878, 1880, 1883, 1899, Fuller-Maitland [ed.] 1900, Colles [ed.] 1927, 1940, Blom [ed.] 1954, Sadie [ed.] 1980, 2000) and the Harvard Dictionary of Music (Apel [ed.] 1944, 1969, 1970, 1976). It is, perhaps, particularly relevant to use it here in acknowledgement of Helmholtz’s analysis of overtones (including combination and summation tones and beats).
the proportion becomes 2:2.0292186 (2004, 54) rather than 2:2. That is, according to O’Halloran, the fundamental, characterised as 2, has a Sothic twin formed from the addition of 2 to the “gnomon” residual 0.0292186 expressive of the Great Year (2004, 54), the twin being the “foundation of all measures” (2004, 62).

With $a' = 438.30414$ Hz, O’Halloran derives all notes except $d''$ from whole number multiples of 12.1751, and then derives $d''$ from the difference between $c''$ (44 multiples) to $d''$ (52 multiples): that is, 48 multiples of 12.1751 (2004, 64). The note $d''$ becomes 584.4 Hz and “therefore resonates with the fundamental tone. … ∆ or D represents ‘nothing’ and ‘everything’. Like the very name of God in ancient thinking, it reverberates in and through everything, yet is utterly and ultimately inexpressible” (2004, 64).

Whether true or not, such assertions were more romantically compelling than the prospect of my choosing a fundamental frequency at random. The frequency $d'' = 584.4$ Hz was not, however, an appropriately low frequency on which to base a harmonic series. I chose, therefore, to divide the frequency by the required number to reduce it to an approximation of the lowest MIDI $D_{,\ldots}$, which I was gratified to note was MIDI number 2, and therefore coincidentally referential to the notion of the 2x2 mason’s module and the “foundation of all

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63 The Sothic Year refers to the fixed year of the ancient Egyptians, determined by the heliacal rising of Sirius and equivalent to 365 ¼ days.
64 $12.1751 \times 36 = a''$; $40 = b''$; $42 = c''$; $46.66 = d''$; $54 = e''$; $57 = f''$; $63 = g''$.
65 $\Delta$ (Delta) is also the Egyptian sigil (signet) for Sirius (O’Halloran 2004, 62).
66 According to O’Halloran, the significance of the number 584.4 is that it is double 292.2: “This is immediately recognised as the numeric of the Great Year of 29,220 years; and as a simple multiple of the residual component of the fundamental Sothic tone, 2 plus 0.02922…” (2004, 64).
67 Additionally, without ever mentioning the huang chung tone, O’Halloran had arrived precisely at the pitch, if not the exact frequency, of the huang chung for the last Chinese dynasty (suggested by fixed pitch instruments and identified by J.A. van Aalst in 1884): $d'' = 601.5$ Hz (Aalst 1933). By comparison, at the “Stuttgart Pitch” of $a' = 440$ Hz, the equal tempered $d'' = 587.33$ Hz. O’Halloran’s $d''$ is therefore 8.65674 cents lower than Stuttgart Pitch.
measures” referred to above. My D, , , fundamental therefore became 9.13125 Hz\textsuperscript{68} instead of the standard equal temperament D, , , of 9.17702 Hz.

The second stage of my thinking was to choose how many numbers of the harmonic series to include as the patch was running. The lowest MIDI D, , , suggested the use of 128 harmonics to further reflect the MIDI note system (and this is, in fact, the number I have adhered to in *Music of Grace*). I noted that the theorist Joseph Sauveur\textsuperscript{69} claimed to hear up to the 128th harmonic (Cook 2002, 85) (a remarkable coincidence, in comparison to the 128 available MIDI notes from C, , ,=0 to g\textsuperscript{VI}=127) and was initially quite content with this.

However, as time progressed, I wished to hear further harmonics and so halved the fundamental frequency more and more times, allowing higher and higher harmonics. Hypothetically, the fundamental could be almost infinitely low, allowing an almost infinite number of harmonics. At present, when performing the patch, I tend to favour using a fundamental of 9.13125/2\textsuperscript{16}, that is 9.13125/65536=0.000139332 Hz, and up to the 1,000,000th harmonic.

The general effect of *The paradox of Pythagoras* is of overlapping chords slowly changing over time. The chords are comprised of random selections of odd numbered harmonics above the fundamental, ensuring that there will be no “octaves”. Each frequency will therefore be “unique”. The choice of fundamental and the choice of the number of harmonics are up to the initiator of the patch: that is, the “performer”. Additionally, the envelope of each frequency (duration of attack, duration and dynamic of sustain, and duration of decay) is random within prescribed limits, making each articulation unique. Finally, the timbre of each frequency,

\textsuperscript{68} Halved six times.
\textsuperscript{69} Joseph Sauveur (1653-1716) is famous for devising the logarithmic method of pitch calculations.
modified by frequency modulation (FM), changes or moves between two randomised control frequencies making each timbre unique.

It will be noticed that, when moving one’s head while listening, the sensory experience changes, different pitches becoming more or less apparent. The reason for this is not clearly understood, but it is presumed to be the effect of masking or residual tones in the ear *(cf. Pierce 1989 and Parncutt 1989).*

One of the first things that will be noticed is that, for ease of operation, I have provided a simple performance interface (see Figure 2.1 *The paradox of Pythagoras* top canvas), despite my intention not to “hide” the processes behind GUIs. While sophisticated GUIs are an area of research in themselves, quite outside the scope of this project, this simple example facilitated experimentation.

Secondly, upon opening the first three pd objects on the top canvas, it will become apparent that Agus’s convention has not been strictly adhered to, since each uses the [send] object. When attempting to provide choices as to the fundamental, the number of harmonics (the “range”) and the duration, it was found that avoiding [send] was impractical. This is one instance where, in effect, Agus’s convention would have obscured clarity. If the three criteria were fixed, a [loadbang] on each oscillator would have been sufficient, with a [bang] to start. However, with variable criteria, “beaming” the values to each oscillator remains a simple and consistent method to adopt, without unduly diminishing the clarity of the signal path to the reader.*

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*71 From the point of view of this project, it is important not to fall into the trap identified by Barknecht: “…in my newer patches, there still are messy things, but those are in ‘unimportant’ areas. Generally my stuff now is much more organized and modularized, while the early stuff now is very hard to even understand (‘what did this number box do, and where does this send lead to?’)” (Barknecht, Frank.)
A discussion of the patches in detail follows. The complete patch structure of *The paradox of Pythagoras*, showing the placement of all embedded sub-patches in relation to each other, is given in Appendix F on the companion CD to this volume. MP3 recordings of the 27 “movements” in the piece are also provided on the CD.

### 2.2 *The paradox of Pythagoras: screen prints*

The top canvas (Figure 2.1 *The paradox of Pythagoras* top canvas) provides three pd objects from which to choose the parameters of the patch. Firstly, the frequency of the fundamental may be chosen from 27 options as listed in the pd object [pd fundamental_of_9.13125Hz_/…]; that is, the fundamental 9.13125 Hz divided by each of the numbers given. The default frequency (if no other fundamental is selected) is 9.13125 Hz (D,, , ).

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72 The names of the first two objects on the top canvas have been truncated for the purposes of the discussion in the thesis. [pd fundamental_of_9.13125Hz_/…] and [pd number_of_harmonics_128_/*…] have lengthy names in order to document the actual denominators of 9.13125 Hz and the number of harmonics used. Additionally, they allow for the length required to differentiate 27 inlets along the top of the objects.

73 Dividing by 0.015625 is equivalent to multiplying by 64; likewise /0.03125=*32; /0.0625=*16; /0.125=*8; /0.25=*4; /0.5=*2. The 27 actual fundamental frequencies are: 584.4 Hz, 292.2 Hz, 146.1 Hz, 73.05 Hz, 36.525 Hz, 18.2625 Hz, 9.13125 Hz, 4.56563 Hz, 2.28281 Hz, 1.14141 Hz, 0.570703 Hz, 0.285352 Hz, 0.142676 Hz, 0.0713379 Hz, 0.0356689 Hz, 0.0178345 Hz, 0.00891724 Hz, 0.00445862 Hz, 0.00222931 Hz, 0.00111465 Hz, 0.000557327 Hz, 0.000278664 Hz, 0.000139332 Hz, 6.96659*10^-5 Hz, 3.4833*10^-5 Hz, 1.74165*10^-5 Hz, 8.70821*10^-6 Hz.
Choose a fundamental: 9.13125Hz default

Choose the no of harmonics above fundamental: 128 default

Click on the desired maximum duration (minutes)

Secondly, the number of harmonics may be chosen from the pd object [pd number_of_harmonics_128_*…]. Again, there are 27 options, with 128 being the default number. The multiples of 128 have a complementary function to the fundamentals so that the upper frequency limit remains stable if the corresponding [bang)s are clicked. That is, if the first [bang] is clicked of both the “fundamental” and the “number of harmonics” pd objects, the result is

$9.13125/0.015625*128*0.015625 = 1168.8$ Hz as the upper limit. Similarly, clicking the 27th [bang] of both pd objects results in

$9.13125/1.04858*10^6*128*1.04858*10^6 = 1168.8$ Hz.

The actual number of harmonics selected for each [bang] 1-27 are as follows: 2; 4; 8; 16; 32; 64; 128; 256; 512; 1024; 2048; 4096; 8192; 16384; 32768; 65536; 131072; 262144; 524288; 1.04858*10^9; 2.09715*10^9; 4.1943*10^9; 8.38861*10^9; 1.67772*10^10; 3.35544*10^10; 6.71089*10^10; 1.34218*10^11.
1168.8 Hz.\textsuperscript{75} Of course, this arrangement is merely for orientation, and quite different effects can be gained by assigning different fundamentals to different numbers of harmonics.\textsuperscript{76}

The desired [bang] enters [pd fundamental_of_9.13125Hz_/…] (Figure 2.2) via the [inlet], and the calculation is made and sent to every appropriate receive object [r fundamental] inside [pd oscillators]. Note the [loadbang] connected to [9.13125( to provide the default setting.

![Figure 2.2](image)

[pd fundamental_of_9.13125Hz_/…] (Figure 2.2) shows the calculations made when the chosen [bang] enters via the [inlet] in order to establish the frequency range. The result is sent via [s range] to [pd oscillators]. Note the [loadbang] connected to [128( to provide the default setting.

\textsuperscript{75} 1168.8 Hz is MIDI note 85.9134 (that is, MIDI note 86 due to the lower D,, fundamental) which is d’.’.’.

\textsuperscript{76} The 27 movements recorded on the companion CD to this volume match the 27 fundamentals to the “equivalent” number of harmonics in the normal manner.
Figure 2.3 [pd number_of_harmonics_128_ *…]

[pd duration_1_2_5_10_15_20_30_40_50_60] (Figure 2.4) sends the approximate duration, calibrated in minutes, to [pd oscillators] via [s duration].

Figure 2.4 [pd duration_1_2_5_10_15_20_30_40_50_60]

[pd oscillators] (Figure 2.5) receives the selected duration and converts it to milliseconds [* 60000] before sending it to the three banks of oscillators [pd
The purpose of the three banks is to allow the chords to develop, change, and overlap through time. The duration is divided by two \([\frac{1}{2}]\) for the first bank (since the oscillators will be working in pairs to form the total duration). The trigger bang float object \([t\ b\ f]\) ensures the “float” (floating point number) enters the right hand side inlet of \([pd\ \text{fm\_two\_chord\_pair\_odd\_harm}]\) before the \([\text{bang}]\) enters the left hand side inlet.

![Figure 2.5 [pd oscillators]](image)

The second bank further subdivides the duration by three \([\frac{1}{3}]\), and the third bank by two \([\frac{1}{2}]\). For the second and third banks, the duration is sent to a float object \([f]\) (which stores the float entering via the right hand side inlet) and to a trigger bang float object \([t\ b\ f]\). The \([t\ b\ f]\) seeds the \([\text{delay}]\) via the right inlet, and follows with a bang to the left. A bang will be produced at the outlet of the \([\text{delay}]\) after the elapse

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77 The number of oscillators in each bank is related to the processing power of the computer. The number in Fig.2.5, 2+4+6, is the maximum number that my Compaq Evo N1000c can comfortably handle with 512MB of RAM.

78 \([t\ b\ f]\) is an abbreviation for \([\text{trigger bang float}]\).
of the seeded time, banging out the stored float in [f] to the right inlet of [pd fm_two_chord_pair_odd_harm] before banging the left inlet.

The function of [pd fm_two_chord_pair_odd_harm] (Figure 2.6) is to control two banks of six oscillators [pd mixout_x6] at the bottom of the canvas. The one at the right plays a six-part chord first and the one on the left follows with a complementary six-part chord.

Figure 2.6 [pd fm_two_chord_pair_odd_harm]
[pd fm_two_chord_pair_odd_harm] receives the number of harmonics via [r range].\textsuperscript{79} [t f f] firstly sends the number to seed the six subtraction [-] objects, then sends it to the right inlet of [pd random_x6].

The right [inlet] of [pd fm_two_chord_pair_odd_harm] receives the numerical value of a “duration” and sends it to seed [random] before the left [inlet] receives a [bang] to start. The “start” [inlet] bangs, in order, [random], [random 100], and [pd random_x6].

[random] will output a random value less than the “duration” that seeded it (0 to n-1). [random 100] will output a value less than 100 (that is, between 0 and 99 inclusive), which will serve as the “amplitude” for the oscillators. These values are sent straight to seed one of the [pd mixout_x6]s and to two [f ]s ready to seed the other [pd mixout_x6].

Within the object [pd random_x6] there are six [random]s (see Figure 2.7), each producing six different random numbers when [random_x6] receives a bang. Each random value produced by [pd random_x6] will therefore be less than half the received range (see Figure 2.6). Each of the outputs is then multiplied by 2 and incremented by 1 [× 2] [+ 1] in order to produce only odd harmonics. This procedure ensures there will be no “octave” relationships between the harmonics: they will all be odd. Each odd harmonic is sent to one of the [pd mixout_x6]s for immediate performance. It is also sent to [- ] [abs]\textsuperscript{80} (seeded by the total number of harmonics) to produce a complementary value as a positive integer. This is stored in [f ] for delayed performance from the other [pd mixout_x6].

\textsuperscript{79} [r range] is an abbreviation for [receive range].

\textsuperscript{80} [abs] for absolute.
Each [pd mixout_x6] (Figure 2.8) is a bank of six oscillators, each one containing three [pd fund_fm_osc_on_off_L] objects and three [pd fund_fm_osc_on_off_R] objects.
Each individual oscillator receives the fundamental pitch via [r fundamental] and a unique harmonic via the first six [inlet]s of [pd random_x6], which have been aligned on the [pd mixout_x6] canvas left-to-right. The seventh and eighth [inlet]s of [pd random_x6] receive the amplitude and duration respectively and send them to the oscillators in [pd fund_fm_osc_on_off_L] or [pd fund_fm_osc_on_off_R]. The maximum amplitude for the system is 1, so the amplitude for each oscillator is divided by 1000 [/ 1000], which, in principle, allows for ten oscillators to be running at maximum volume without distortion due to clipping.

The two harmonic oscillators used in *The paradox of Pythagoras*, [pd fund_fm_osc_on_off_L] (Figure 2.9) and [pd fund_fm_osc_on_off_R] (Figure 2.10), are identical except that one oscillator is routed to the left audio output while the other is routed to the right. The left hand side of the canvas is the patch for frequency modulation and refers to the technique developed by John Chowning to generate complex timbres. The right hand side of the canvas controls the amplitude envelope of the sound.

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81 See Chowning 1973 for the original paper and Chowning 1989 for subsequent research. The frequency modulation section of the canvas is an adaptation of Pd’s help file (Help, Pure Documentation…pd\doc\3.audio.examples\A07.freqency.mod.pd.), explained in Puckette (2003, 126-129).
Figure 2.9 [pd fund_fm_osc_on_off_L]
In Figures 2.9 and 2.10 the uppermost objects are the four inlets. In the following section, these will be referred to as the first, second, third and fourth inlets.
and are numbered respectively in ascending order as they appear from left to right; the first of these is the left-most inlet while the fourth is the right-most.

The frequency of each oscillator is calculated harmonically by multiplying the fundamental frequency by the selected harmonic. Figure 2.9 shows how this is achieved in the left oscillator. The first [inlet] puts the value of the of the fundamental in the left inlet of the multiplication object [* ]; the second [inlet] sends the harmonic number to the right inlet of the same [* ] object. Multiplication of these values is performed when the first inlet of the [* ] object is triggered by the middle outlet of the [t b b f] object, which happens after the right inlet of the [* ] has read the right-most outlet of the [t b b f] object; this ensures that the selected harmonic is loaded into the [* ] object before multiplication is performed.

The third inlet temporarily stores the peak amplitude value of the oscillator in [f ]. This value is loaded into the amplitude envelope generator (the lower-most [line~] object) and triggered when the left-most output of [t b b f] sends a bang; that is, after the frequency of the oscillator has been selected. This ensures that any change in harmonic number initiates the envelope.

Finally, the right-most [inlet] sends the duration to the [line~] object that affects the frequency modulation, as well as to the [t f f f] object that affects the amplitude.

The patch shown in Figure 2.9 also calculates the values for durations of attack, sustain and decay, the sum of which equals the total duration of the envelope. The process begins by generating a random value less than the total duration to produce attack; it then generates a random value less than the remaining duration to

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82 [line] changes the current value to a new value incrementally over the seeded time. [line~] does the same operation for signals.
produce sustain; finally, by subtracting both from the total duration, it produces decay.

**Attack:** when the total duration is received via the fourth [inlet] it seeds the [random] object. This in turn produces a random duration less than the total duration when it is triggered by a bang received via the second [inlet]; this is the attack time. The attack time seeds the ramp generator [line~], which is subsequently given its target amplitude value, previously received via the third [inlet] and stored in the [f ] object. As a result the [line~] object generates a ramp envelope from 0 to the target (amplitude) over the seeded duration; the outlet of the [line~] object is then sent to control the right input of the signal multiplication object [*~].

**Sustain is calculated in two steps:** firstly, the difference between the total duration and the attack is calculated; the attack value produced by the [random] object is sent to the [t f f] object; this is initially sent to the right inlet of the [+ ] object where it is stored as an offset for calculating the sum of attack and sustain times; it is subsequently used to calculate the time remaining by subtracting attack time from total duration (previously seeded by the fourth [inlet]); the [abs] object is used to eliminate the possibility of calculating negative duration values. Secondly, a random number less than this difference is calculated and added to the original attack duration; when the [random] object is triggered by a bang from the middle outlet of [t b b f] object its outlet sends random values to the inlet of the [t b f] object; initially this seeds the [random] object by sending a value to its right inlet and subsequently performs a calculation that sums the attack and sustain times; this is done by sending a trigger to the left inlet of the [random] object which generates a random number which subsequently performs addition when a value is sent to the left inlet of the [+ ] object.
Decay: the difference between attack-plus-sustain and the total duration is then calculated via \([-\)] (seeded by total duration) and [abs], and the result sent to seed [f], in preparation for decay. Simultaneously, the sum of attack and sustain is sent to a [delay] via [t b f] in order to seed the [delay] and then perform the calculation. The result is that the [delay] bangs out after the sum of attack and sustain, which in turn reads the duration stored in [f], which passes through a [t b f] object.

The float seeds the duration [line~] and the bang triggers a message box that sends the value “0” to the right inlet of the [line~] object; this ensures that a new envelope starting from zero is triggered for every pitch.

The total duration from the fourth [inlet] also sees the duration of the [line~] in the FM section of the canvas. To establish a kind of structural relationship, and because a moderate effect was aesthetically desired, the frequency of the pitch is used as the modulation frequency. It passes through [t f b], which bangs a random number less than 1000 as the modulation index, which is passed to the signal multiplier object [\(*\)] via [line~]. The oscillator [osc~] converts the modulation frequency into a signal which is modified by the changing modulation index [\(*\)] and sent to seed [\(+\)] and add to the original frequency of the harmonic.

The whole effect, from the three banks of oscillators, is of two sets of two six-part chords, overlapping with four sets of two six-part chords, overlapping with six sets of two six-part chords, resulting in slow changes of pitch, texture and timbre.
2.3 Music of the spheres

Music of the spheres is a particular variant of The paradox of Pythagoras. Exploring higher harmonics, and therefore “lower” fundamentals (already far below the range of hearing), I arranged the patch using the duration of planets’ orbits around the sun as the range of fundamentals from which to choose. Figure 2.11 shows the top canvas.

Choose a fundamental: Earth default

![Checkbox options]

Choose the no of harmonics above fundamental: 3.95097e+011 default

![Checkbox options]

Click on the desired maximum duration (minutes)

![Checkbox options]

Figure 2.11 Music of the spheres top canvas

As for The paradox of Pythagoras, the names of the first two objects are truncated for the purposes of discussion. The full names are [pd fundamental_of_mercury_venus_earth_mars_jupiter_saturn_uranus_neptune_pluto] and [pd number_of_harmonics_9.53307e+010_2.43507e+011_3.95097e+011_7.44542e+011_4.69577e+012_1.16606e+013_3.32804e+013_6.52428e+013_9.80559e+013]. Note that Pd’s method of notating the exponential is to use “e+”. 
Earth’s fundamental was taken to be 365.26 days; Mercury’s fundamental, 87.96 Earth days; Venus’s, 224.68 Earth days; Mars’s, 686.98 Earth days; Jupiter’s, 11.862 Earth years; Saturn’s, 29.456 Earth years; Uranus’s, 84.07 Earth years; Neptune’s, 164.81 Earth years; and Pluto’s, 247.7 Earth years.

[Figure 2.12] calculates the fundamental frequencies. Mercury is $1.31583 \times 10^{-7}$ Hz; Venus, $5.15136 \times 10^{-8}$ Hz; Earth, $3.16872 \times 10^{-8}$ Hz; Mars, $1.68478 \times 10^{-8}$ Hz; Jupiter, $2.67132 \times 10^{-9}$ Hz; Saturn, $1.07575 \times 10^{-9}$ Hz; Uranus, $3.76915 \times 10^{-10}$ Hz; Neptune, $1.922165 \times 10^{-10}$ Hz; and Pluto, $1.27926 \times 10^{-10}$ Hz.

[Figure 2.12]

[Figure 2.13] gives the choice of number of harmonics. As listed in the Pd object’s name, these are $9.53307 \times 10^{10}$, $2.43507 \times 10^{11}$, $3.95897 \times 10^{11}$, $7.44542 \times 10^{11}$, $4.69577 \times 10^{12}$, $1.16606 \times 10^{13}$, $3.32804 \times 10^{13}$, $6.52428 \times 10^{13}$, and $9.80559 \times 10^{13}$.

[pd number_of_harmonics_9.53307e+010…] (Figure 2.13) gives the choice of number of harmonics. [pd duration_1_2_5_10_15_20_30_40_50_60] and [pd oscillators] are the same as in *The paradox of Pythagoras*.

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84 As listed in the Pd object’s name, these are $9.53307 \times 10^{10}$, $2.43507 \times 10^{11}$, $3.95897 \times 10^{11}$, $7.44542 \times 10^{11}$, $4.69577 \times 10^{12}$, $1.16606 \times 10^{13}$, $3.32804 \times 10^{13}$, $6.52428 \times 10^{13}$, and $9.80559 \times 10^{13}$.
The nine “movements” of *Music of the spheres* are included on the companion CD to this volume.\(^8^5\) The general effect of *Music of the spheres* is sometimes quite different from *The paradox of Pythagoras*. At these extreme low frequencies, the effects of frequency modulation may cease to be heard as changing timbres, instead allowing changing frequencies to be heard as gliding tones.

Having developed patches to “sculpt” sound into complementary panels, the next phase of the project was to extend aspects of *The paradox of Pythagoras*, especially the notion of higher harmonics based on a sub-audio fundamental and oscillators with variable amplitude envelopes, to compose pieces of some length and scale. Chapter 3 describes the compositions that comprise this next phase: the series of three works entitled *Music of Grace*.

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\(^{8^5}\) As with the recordings of *The paradox of Pythagoras*, these nine recordings match the nine fundamentals to the “equivalent” nine options for harmonics.
Chapter 3

Music of Grace

Chapter 3 describes the three extended electronic works that comprise the series Music of Grace. MP3 recordings of the pieces are included on the companion CD in the sleeve of this volume. Also included on the companion CD are the related appendices in soft copy. 86

3.1 The cat dances and the moon shines brightly

The cat dances and the moon shines brightly 87 extends and develops an extract from Bach’s Befiehl du deine Wege, transposed down one tone. The extract is given below in Figure 3.1 (cf. the original in Figure 1.1). The MIDI note numbers, which are used in the piece to determine the harmonic numbers, are shown for each pitch.

A table showing the actual pitches of the harmonics, together with the number of cents deviation from equal temperament, is given in Appendix G. A version of Figure 3.1, written at actual pitch, is given in Appendix H.

The number 62, the first and last numbers of the extract, is of structural importance in this piece. 88

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86 All appendices are provided in soft copy on the companion CD to this volume to allow for maximum flexibility when accessing the often lengthy materials.
87 This is the full text (without line breaks) of a poem by John Gracen Brown, entitled The Cat and the Moon (Brown 2005, 5).
88 62 is also taken as being the lowest number for the right hand; number 60, first note second bar, is altered in the piece to facilitate this convention.
Figure 3.1 Extract from Befiehl used for *The cat dances*

The top canvas of *The cat dances and the moon shines brightly* (Figure 3.2) shows that the piece progresses through five “panels”. The (bang) between them signals to the observer the initiation of the next panel.

```
start

pd_panel_1

pd_panel_2

pd_panel_3

pd_panel_4

pd_panel_5

end
```

Figure 3.2 *The cat dances and the moon shines brightly* top canvas
There are in total 50 different individual patches in *The cat dances and moon shines brightly*, too many for each one to be discussed individually here in the main body of the thesis. These patches can be found in Appendix H. Additionally, the complete composition structure of *The cat dances*, showing the placement of all embedded sub-patches in relation to each other, is given in Appendix I. The intention is that the two appended documents allow the description, detail and structure of the work discussed here to be cross referenced and compared if the reader requires.

The piece has five sections, which I have termed “panels”.

The piece as a whole loosely reflects the “visions” of movement and lunar light suggested by the title. Panel 1 presents chords based on the Bach extract, beginning tentatively, each note of the chord with the same overall duration, but with a different dynamic envelope which helps to change the balance and differentiate the component pitches. The upper note of each chord is based on the right hand of the Bach extract, and the chord itself is derived from the calculation symmetrical axes between the number assigned to the top note, and the number 62 (the first and last notes of the extract).

Panel 2 continues with chords, inserting melodic components derived from the axes of each chord. The melodic inserts are based on axes between the notes in the chord and the number 62.

Panel 3 interpolates melodic descending passages between chords. The series of chords is put out of synchronisation and is periodically interrupted by descending runs, sometimes ending in a slow trill.

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89 After Donatoni (see chapter 1).
90 John Gracen Brown refers to these short poems as “visions”. See chapter 1.
91 The detail of these calculations, which convert symmetrical pairs of MIDI numbers into asymmetrical pairs of frequencies, is given in Appendix H.
Panel 4 transforms the chords into “arpeggios” that trigger other events (according to whether arpeggiation is ascending and descending). A “melody” based on the Bach extract is played, accompanied by arpeggios derived from the chords.

Panel 5 reads the Bach extract again and applies procedures that control the duration of the melodic lines, add trills, and direct the two parts into contrary motion before a final chord to finish.

3.2 The heavy dark trees line the streets of summer

The heavy dark trees line the streets of summer\textsuperscript{92} is the second in the collection of pieces entitled \textit{Music of Grace}. Like the first, discussed in the previous section, it too extends and develops an extract from Bach’s \textit{Befehl du deine Wege}. The extract is given below in Figure 3.3 (\textit{cf.} the original in Figure 1.1). Like the previous piece, this extract is transposed down one tone from the original to begin on D.\textsuperscript{93} The MIDI note numbers, which are used for later calculations, are shown for each pitch. (A version of Figure 3.3, written at actual pitch, is given in Appendix J.)

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{fig33.png}
\caption{Figure 3.3 Extract/arrangement from \textit{Befiehl} used for \textit{The heavy dark trees}}
\end{figure}

\textsuperscript{92}This is the full text (without line breaks) of a poem by John Gracen Brown, entitled \textit{Streets on a Summer Night} (Brown 2005, 5).

\textsuperscript{93}See Chapter 2 for the significance of the pitch D.
As a kind of homage to Franco Donatoni, the extract has been laid out in the approximate rhythm and voicing of the first three beats of the eighth bar of the second movement of Schönberg’s *Fünf Klavierstücke*, op.23 (1923), a musical fragment used by Donatoni as the genesis of his seminal work *Etwas ruhiger im Ausdruck* (1967) for clarinet, violin, cello and piano. My interest in, and appreciation for, Donatoni was rekindled in 2003 when Cornell University doctoral student Yotam Haber contacted me a number of times over a period of a year to discuss Donatoni’s composition technique and this piece in particular.\(^9^4\) I therefore decided to apply processes not unlike Donatoni’s to the second piece of the *Music of Grace* series.

The left hand of the extract above is the first seven pitches of *Befiehl*, transposed down a tone (as noted above) plus two octaves for the first three notes, and one octave for the last four notes. The right hand uses chords taken from the original right hand part, with minor rhythmic adjustments.

*The heavy dark trees line the streets of summer* has five sections, again labelled “panels” after Donatoni. It loosely reflects visions of repetitive periodicity that move in and out of phase, as suggested by the title. The top canvas of *The heavy dark trees line the streets of summer* (Figure 3.4) shows the five panels through which the piece progresses.

\(^9^4\) A significant part of Haber’s research (Haber 2004) was to compare and critically evaluate analyses by myself (Barkl 1985) and Robert Piencikowski (1990).
A detailed discussion of the 257 different patches that comprise the piece is given in Appendix J where every individual object in the piece is reproduced. It also includes some more detailed discussion of differences between the various sub-patches. Most significantly, however, this appendix may be reproduced as a collection of screen prints that represent the entire piece. In order to assist the understanding of how the patches are organised in the piece, the complete composition structure of *The heavy dark trees line the streets of summer* is given in Appendix K.\(^{95}\)

\(^{95}\) Again, these appendices are intended to facilitate the reader’s cross referencing.
Panel 1 breaks up the original material, transposing and dissipating it. It is transposed and altered rhythmically, and is accompanied by sustained chords. The resultant musical material is stored in a series of arrays.

Panel 2 collates material to be played by taking it from the Panel 1 arrays and writing it to a new array where it can be subsequently reread and played by Panels 3 and 4.

Panels 3 and 4 play concurrently: they read the arrays, perform transformations on the material, and “coagulate” it by playing it in an overlapping accelerando. At the same time, the material is modified and rewritten to the original arrays, in effect, “recycling” it in a constant flux. There are eight tempos (or “clocks”) ranging from 1-55 to 15-55 notes per bar. Panel 3 and Panel 4 are accompanied by soft chords taken from the Befiehl extract.

Panel 5, like the final panel of Etwas ruhiger, reads the results and selects material from the arrays. Its purpose is to take the “chaotic” values written to the arrays and reconstitute something approaching the original extract.

The nine “mixout” objects are banks of oscillators. Each object has eight oscillators, making 72 oscillators altogether.

3.3 The crystals in the cave absorb the light as if they have not seen it in a million years

The third piece of the Music of Grace series is The crystals in the cave absorb the light as if they have not seen it in a million years.6 Like the first and second pieces, the third extends and develops an extract from Bach’s Befiehl du deine Wege. The extract is given below in Figure 3.5 (cf. the original in Figure 1.1). In this case, the

6 This is the full text (without line breaks) of a poem by John Gracen Brown, entitled Cavern Crystals (Brown 2005, 5).
extract is a simplification of the 40 chords that Bach wrote, transposed to the key of D
minor. The MIDI note numbers, which are used in the piece’s calculations, are
shown for each pitch. (A version of Figure 3.5, written at actual pitch, is given in
Appendix L.)

![Please see print copy for Figure 3.5]

Figure 3.5 Chords from *Befiehl* used for *The crystals in the cave*

The top canvas of *The crystals in the cave* (Figure 3.6) shows the panels
through which the piece progresses.

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97 See Chapter 2 for the significance of the pitch D.
A discussion of all 718 individual patches in detail can be found in Appendix L, where every different object in the piece is reproduced. Additionally, the complete patch structure of *The crystals in the cave absorb the light as if they have not seen it in a million years*, showing the placement of all embedded sub-patches in relation to each other, is given in Appendix M.

The nine “mixout” objects are banks of oscillators that operate in a similar manner as those used in the previous piece.

*The crystals in the cave absorb the light as if they have not seen it in a million years* loosely reflects visions of absorption, then reflection through multiple prisms, as suggested by the title. Panel 1 plays the 40 chords of the *Befiehl* extract, some decorated by slow trills. The durations of the chords are based on the intervals between the top notes.

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98 As for the previous two pieces in the *Music of Grace* series, it is acknowledged that many of the patches are identical except for small details (such as assigning to which oscillator the frequency information is to be sent). However, as previously noted, the intention is to include full documentation in addition to explanation. It will also be noticed that, because many of the patches are similar, much less textual annotation is required.

99 See Appendix J for an explanation of the internal workings of these objects.
Panel 2 plays the 40 chords of the *Befiehl* extract, in order, each one “answered” by the chord axes in a descending arpeggio.

Panel 3 lightens the texture of the previous two panels. Two notes from each of the 40 chords are sustained, decorated by pitches taken from the chords’ axes. Every time a sustained note changes, it is reinforced by the accompanying chord.

Panel 4 is built from ten sets of ascending arpeggios. In each set, four overlapping arpeggios, from four successive chords, rise fairly rapidly over a period of 3840 ms, answered by slower and softer arpeggios based on their axes.

### 3.4 Reflections on the compositional process

In composing *Music of Grace* I was conscious of the influence of “instrumental” thinking, especially in the initial phases. Most obviously, the primary or source material, being a Bach chorale, tended to maintain my thinking in terms of “notes”, “chords” and “bars”, rather than, perhaps, a more “abstract” notion of “frequencies”, “densities” and “durations”.

*The cat dances* (the first piece) is linear in its approach and unfolds in a manner not unlike a traditional instrumental work. *The heavy dark trees*, by contrast, has an entirely different structure, evident in the way it writes data to arrays for later use. Moreover, in its later sections (Panel 3 and Panel 4) it reads-writes-reads in quick succession, using the computer more recursively.

These two pieces scaled the use of Pd up to a large number of patches: 50 different patches (or the equivalent of 1,032 pages of text code) for *The cat dances* and 257 different patches (or 595 pages of code) for *The heavy dark trees*. This aspect, or capability, was further extended in the third piece, *The crystals in the cave*, to 718 different patches (equivalent to 7,644 pages of text code), which would seem to indicate Pd’s capacity to “scale up” to a remarkable degree. Instead of using arrays,
in this case banks of similar objects were lined up to process or modify the musical material concurrently in real time. As such, it differs significantly, not only from the previous two works in *Music of Grace*, but also from a linear instrumental approach.
Chapter 4

Discussion and Conclusion

4.1 Discussion

The primary purpose of discussion so far in this thesis has been to understand the processes involved in composing the electronic pieces in this folio\textsuperscript{100} where the process of composition is discernable graphically in the form of Pure Data patches.\textsuperscript{101}

While this may be of value to the interested listener, musicologist or even composition student, the principal motivation for doing this has been to clarify my own understanding of the compositional processes taking place in my work by finding a suitable way in which to document them. There are many cases in my own previous work where I simply cannot recall the composition process or method. Although this may not be particularly significant in itself, the importance of this enquiry lies in the potential or capacity for artistic development, improvement and refinement. That is, I, a composer, am much more likely to develop consistently if I am not struggling to remember the last thing I did. For me, therefore, the value of the documentation of composition process is one of memory and recall, irrespective of the genre in which I happen to work.

The question that arises at this point is whether Pd and the application of Agus’s conventions have facilitated this outcome. The answer would appear to be a qualified “yes”, though the project has not been entirely trouble-free. On its own, visually examining a Pd patch, without testing it, will not always accurately predict its

\textsuperscript{100} See Appendix Q for details of performances of the works while this thesis was being prepared.
\textsuperscript{101} The “process of composition” refers here to the “entire” production process of composition, typical of much electroacoustic music, as distinct from the production of a score which describes the process of composition for the benefit of the next person in the production chain.
operation. In particular, the order in which connections are drawn from a single source will be, all other things being equal, the order in which the messages are sent. This situation is easily clarified by the use of the [trigger] object, such as [tb b], where the right outlet bangs before the left. A consistent use of [trigger] may also confirm its corollary—that where feeds are sent to multiple objects from a single source, the precise order of data flow is immaterial.

Nonetheless, visually examining a complex dynamic patch some time after its construction can be challenging, not only to imagine all its events dynamically changing, but to imagine how the outcome of the patch interacts with other patches operating concurrently. Additionally, when describing the patches, it became clear that even being able to follow the functional operation of a patch or group of patches is not the same thing as discerning the musical effect or musical meaning of the composition or even parts of the composition. For this, additional commentary at the “interpretive” level (as distinct from the “descriptive” level) will always be necessary.

One of the comments from the “Pd discussion group” was that Agus’s proposed conventions were “common sense”. To some degree this must be true, yet it does disregard the specific purpose of these conventions. As Agus clarifies in his email, the aim was to maintain a consistent and similar style when a number of people were working semi-independently on different aspects of a large, complex patch. More particularly, Agus and his group were working with (or at the very least incorporating) the text code of Pd. For this reason, Agus recommended that only functional objects should be “in-line”: non-functional objects should be offset and

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102 Such as [pd clock_accel_15-55]. See Figure J.243.
103 See Appendix D.
104 See Appendix O “Email Re: Pd conventions”.
105 See Appendix P “Pd code” for an example.
labelled “DEBUGGING” (see Figure 4.1). The label facilitates the identification of the non-functional object in the code, and having the object offset allows its deletion at any time (for example, after testing) without compromising signal flow.

Because I was not working with the code, this aspect of the conventions was not important. Indeed, the number of monitoring, or “debugging”, objects in the project made the use of the label itself oppressive, cluttering the patch when it was obvious why, for example, a [bang] was there. Similarly, in-line objects such as bangs and number boxes can be very useful when laying out a patch; and there are numerous instances of their use in this regard in this project.

A further recommendation by Agus was not well supported by the Pd discussion group: the use of camelCase. The convention of camelCase is useful in

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106 In this context, “non functional” refers to objects used for monitoring purposes (such as using a [bang] to blink when a process has occurred, or a number box to show a value) whereas “functional” refers to objects essential to the operation of the patch (such as using a [bang] to initiate another object).

107 “DEBUGGING” labels were therefore deleted from the patches.

108 See again, for example, [pd clock_accel_15-55]. However, one proviso should be acknowledged here. Music requiring a rhythmic exactitude (with an accuracy down to the millisecond) needs to minimise the number of objects through which the signal passes. Needless to say, such accuracy was not required for this project.

109 See Appendix O. The term camelCase refers to a typographic convention used by computer programmers for creating labels using multiple words with white space removed; the first letter of the
that it keeps text together and minimises space. Unfortunately it is not useful for numbers; in this project I chose to use underscores to keep text and numbers consistently together.

Another recommendation by Agus was to avoid using the [send] object where possible. Specifically, from Agus’s point of view, tracking the use of [send]s by multiple developers in code is particularly difficult. However, even in graphic patches one can easily lose track of what is sent where. In *The cat dances and the moon shines brightly* I avoided [send]s altogether. The result was more “organic”, but also possibly wasteful, with oscillators being used briefly and then left dormant.

Using [send]s in *The paradox of Pythagoras* facilitated a convenient GUI; and using them in *The heavy dark trees line the streets of summer* and *The crystals in the cave absorb the light as if they have not seen it in a million years* allowed the efficiency of a bank of oscillators that could be called into service any time they were required. The use of [send]s in these cases was limited and defined and did not lead to any confusion on my part; indeed, their use seemed not only to suit these more structured process-style compositions, but be consistent with Agus’s recommendation for “global” sends and receives.

In summary, while Agus’s conventions were useful to acknowledge as a benchmark and a viable starting point (particularly with regard to “common sense” procedures such as signal flow) it became evident that differences between his project and this project led to certain inevitable adjustments to respond to different purposes and methods. As such, it seems unlikely that the wide diversity of users in the Pd community would ever commit to a “definitive” set of programming conventions.

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first word is spelt using lower case while subsequent words are spelt using an initial capital without spaces.

One further comment by Agus may deserve attention: he makes the point in his email that “hearing scientists prefer to use something like Matlab\(^{111}\) which can be pretty much guaranteed click-free”\(^{112}\). Indeed, despite attention to the control of the onset of pitches (the “attack” of the envelope), at certain times the program can be heard operating in the background. While Agus’s current research into hearing science may demand an artefact-free environment, to my ears these minor noises do not affect the integrity of the project. Indeed, because I regard the computer and its program as a “machine” or “instrument”, evidence of the workings of that machine, while it is clearly desirable that it be kept to a minimum, is no more or less undesirable than any inherent machine noise.\(^{113}\)

The electronic pieces in this folio display four different approaches. *The paradox of Pythagoras* is virtually a single-patch piece, generating a sound environment. *The cat dances and the moon shines brightly*, by contrast, is far more “organic”, where patches and oscillators are used in a more linear conception as the piece “develops” in time. *The heavy dark trees line the streets of summer* takes a contrary approach, where banks of oscillators are set up for use as and when required and the material is treated in a far more recursive manner, unlike the linearity of *The cat dances*. *The crystals in the cave absorb the light as if they have not seen it in a million years* combines and extends aspects of the two, using banks of like objects to take a fresh look at the original material in a process oriented way.

\(^{111}\) MATLAB (matrix laboratory), created by *The MathWorks*, is a numerical computing environment that allows matrix manipulation, numerical analysis, implementation of algorithms, and the plotting of data. It does not imitate the modalities of a patchable analogue synthesiser like Pd does.

\(^{112}\) See Appendix O.

\(^{113}\) Analogies in the world of acoustic music may be guitar fret noise and breathing for singers and wind players.
4.2 Conclusion

The aim of the project was to compose a folio of electronic pieces that used Pd as a “meta-compositional instrument”: that is, a vehicle for documenting the creative process in a graphical way, as a kind of analytical notation.

The pieces extended and explored creative aspects of my previous research into binary processes, symmetry, and complementary pairs, using sine tone frequencies based on the higher partials of sub-audio fundamentals.

Pd programming conventions, proposed by Trevor Agus, provided a standard benchmark with regard to “common sense” signal flow conventions, and were only adjusted when significant differences between working in code (Agus) and working graphically (in this project) were encountered.

Despite the “composition of the composition” being evident in the graphical layout of the patches, it became clear that further “interpretive” commentary was necessary to explain the artistic or musical purposes of different patches. Nonetheless, it was shown that a composition in Pd can explicitly show its own construction and interrelation of compositional elements, providing a kind of descriptive analysis of the work. Moreover, Pd was shown to be suitable for relatively large scale, multi-sectional projects. Perhaps of most importance, however, was that Pd allowed me to realise the music of my imagination, leaving me free to approach the process of composition, including the composition of instrumental music, from a broader perspective and with a heightened appreciation.
Chapter 5

Epilogue: Here…

Mid-way through composing *The crystals in the cave*, which was discussed in chapter 3 and Appendix L, the opportunity presented itself to compose an instrumental chamber piece. Thus, as the electronic music composition project was drawing to a close, it overlapped with the process of composing instrumental music. In order to link the two together and highlight similarities and differences in the process of composition between the two media, I decided to use the same source material used in *The crystals in the cave* for the instrumental piece. Chapter 5 describes the process of composing the chamber work entitled *Here…* It revisits instrumental composition in the light of the electronic works composed using Pure Data and reviews some of the special characteristics of instrumental writing. The composition of this piece acts as an epilogue to the project since, after an intense period of composing purely electronic music, it allowed a return to the issues identified at the beginning of the project.

5.1 Origins

*Here…* (for clarinet, piano and cello) is the result of an invitation to submit a short piece for the 2008 Aurora Festival. The Festival included composer workshops with academic staff from the Universities of Western Sydney,114 Wollongong115 and California, San Diego,116 and with the contemporary chamber group *Charisma*117 at the Joan Sutherland Performing Arts Centre in Penrith, NSW. (The MP3 recording

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114 Professor Michael Atherton, Dr Diana Blom, Dr Bruce Crossman, Professor Roger Dean and Dr Garth Paine.
115 Dr Houston Dunleavy.
116 Professor Chinary Ung.
117 Roslyn Dunlop (clarinet), David Miller (piano) and Julia Ryder (cello).
provided on the companion CD is the live recording from the Festival concert.\textsuperscript{118)}

Although initially reluctant to set aside time for this project (considering my other commitments), I recognised that it was an excellent opportunity to investigate the transfer or projection of some of the organisational thinking I had applied to Pd back to instrumental (acoustic) music.

\textit{Here...} is the title of a rather bleak poem by John Gracen Brown.\textsuperscript{119} My use of the title is not so much to illustrate the poem as to highlight the “humanness” and immediacy of the ensemble and its creation of the music in real time. The source material for the piece is exactly the same as for \textit{The crystals in the cave}; that is, 40 chords taken from Bach’s \textit{Befiehl du deine Wege}. These chords were transposed to the key of D minor and laid out on a single clef (Figure 5.1).

\textsuperscript{118} 18 April 2008.

\textsuperscript{119} Brown (2005: 6). Using just the title of the poem as the title of the piece, as distinct from the whole poem (as I did with the electronic works) was not fortuitous. My intention was to reflect the complementary nature of the instrumental piece to the electronic pieces. The complete poem is: “Here there is the cold wind, / The darkness of the night / And these lonely hills – without end.”
5.2  *Here*…

*Here*… for clarinet, piano and cello comprises 11 panels.

Panel 1: bars 1-14;
Panel 2: bars 15-32;
Panel 3: bars 33-41;
Panel 4: bars 42-48;
Panel 5: bars 49-54;
Panel 6: bars 55-62;
Panel 7: bars 63-74;
Panel 8: bars 75-80;
Panel 9: bars 81-87;
Panel 10: bars 87-92;
Panel 11: bars 92-98.

The full score is reproduced in Appendix R.

5.2.1 Panel 1

The first panel of Here… (bars 1-14) contrasts the complementary textures of the piano chords with the clarinet and cello. The piano chords (always mf) are derived from inversions of chords from the Befiehl extract. Instead of reading “up” the original chord (d’-f’’-a’’-d’’ as it appears in Figure 5.1), the piano reads “down” to form the chord d-a-f’-d’’. The left- and right-hand dyads are then “filled in” with notes that form the axes of symmetry for the dyad: f-gb for the left-hand and a’-bb’ for the right-hand. The first phrase of the piano comprises the first five chords of the Befiehl extract. The process comes to a halt upon the repetition of the first d, and the first chord of the piece is repeated (Figure 5.2).
The descending clarinet staccato semiquaver line reads the axes of the piano chords, beginning with the first chord right-hand (piano $bb'-a'$ becoming clarinet $bb''-a''$) and ending with the fourth chord left-hand (piano $ab-g$ becoming $ab-g$ at the same pitch in the clarinet). The cello reads the fifth chord axes. The clarinet also includes two ($mf$) semiquavers that reinforce the cello’s entry: these two notes are the last two from the cello, forming a kind of harmonic reinforcement.

The piano continues with five chords. The first of the five is the same as the first chord of the piece, but with its position inverted so $f$ is on the bottom and $f'-'$ is on the top. Chords 6-7-8 of the Befiehl extract follow before the initial chord of the second phrase is repeated (Figure 5.3).
Figure 5.3 *Here...* bars 3-4

Again the clarinet reads the axes of the piano chords as a descending figure (chords 6-7 of the *Befiehl* extract) and the cello reads the axes of the last new chord (chord 8 of the *Befiehl* extract), while the clarinet reinforces the cello’s entry by doubling the last two pitches. This time the articulation is different, contrasting the semitones with the other intervals through the use of slurs.
The number of new chords used in the second piano phrase (three in this case) is determined by the inversion of the first chord in the phrase. The top note of the first (and last) chord of the first piano phrase was d'♬; the top note of the first (and last) chord of the second piano phrase is f'♬: an interval of three semitones.

Similarly, the next inversion of the first Befiehl chord has gb'♬ as its top note: an interval of one semitone triggering just one new chord from the Befiehl extract for the third piano phrase. The single axis pitch of c'♬ (right-hand) and c (left-hand) generate a decorated response in the clarinet and cello.

The rest of the panel, to midway through bar 12, continues in the same manner, the first and last chords of each piano phrase repeating the first chord of the piece in higher and higher inversions, adding new chords from the Befiehl extract according to the intervallic change, with the clarinet and cello playing the chord axes with different contrasting articulations.

Midway through bar 12 the texture changes, preparing for a more “dramatic” conclusion to the first panel. The piano has, so far, used 33 chords from the Befiehl extract and now plays chords 34-40 as cascading arpeggios, without including dyad axes. These are played by the clarinet (piano top stave axes) and the cello (piano bottom stave axes), holding the last note as a trill until the piano completes its last arpeggio in bar 14 (Figure 5.4). The trill repeats as an “upbeat” to panel 2.
5.2.2 Panel 2

Panel 2 re-reads the initial piano chords in an arpeggiated form while contrasting clarinet and piano inserts with accented reinforcement.

The range of the piano has been restricted. The right hand’s top note is $d'$, and its range is within one octave; for the left hand, the lowest note is D and its range is also restricted to one octave. These range restrictions are also assigned to the clarinet and cello. The rationale for the restriction is the range of the first chord itself: in effect the first chord has been transposed down one octave and provides the boundary for all chords that follow. All piano notes from panel 1 are thus repositioned in panel 2 (Figure 5.5).
The piano right-hand reads notes from bar 1 until the first pitch-class repetition, in this case f, as does the left-hand, which stops before the repetition of D. (This follows the rationale for the interruption of the first piano phrase in panel 1.) Each hand resumes the process after waiting for exactly one beat (four semiquavers). Because the right-hand’s phrase was seven semiquavers and the left-hand’s phrase was four semiquavers, the “open space” before the resumption of the process is just

Figure 5.5 Here... bars 15-16
one semiquaver. The clarinet and cello, having reinforced the piano entry at unison, insert a *forte* semiquaver into the space. The pitches are taken from the clarinet insert in bars 1-2: the first note $bb$ for the clarinet, and the last note of the insert $G$ for the cello.

Again, cello and clarinet reinforce the piano entries at unison and fill the space between piano entries, two semiquavers this time, with pitches taken from each end of the clarinet insert from bars 1-2 (the clarinet reading forwards and the cello reading backwards).

The third piano phrase (bar 16) is extended to two sub-phrases; that is, the repeated note is accented and the new sub-phrase continues immediately. This time, the two sub-phrases trigger a rest of two beats between this and the next piano phrase—a break that is again filled by *forte* clarinet and cello inserts taken from the clarinet in bars 1-2.

The fourth piano phrase (bar 17) extends to three sub-phrases. The clarinet and cello match this by using three repeated notes (rather than two) to reinforce each accent. The rests at the end of the piano phrase are also extended to three beats duration for each hand (filled by the clarinet insert from bar 3) (Figure 5.6).
The process continues through bars 18-22, the piano extending to five sub-phrases (generating equivalent repeated notes for reinforcement and longer rests between the piano phrases). The end of the process is triggered by the simultaneous completion of the reading of the fourth piano phrase from bars 4-5, and its consequent clarinet insert from bar 5 for the clarinet and cello.

At bar 23 the texture changes. The piano dynamic changes to *forte* and plays the complete fifth piano phrase from bars 5-6. The clarinet reinforces the right-hand
accents (still generated by repeated notes) and the cello uses the left-hand accents to create a sustained counter melody (Figure 5.7). Repeated notes in the cello are decorated with a mordent.

![Musical notation](image)

Figure 5.7 *Here...* bars 23-24

The clarinet and cello respond with material taken from the fifth clarinet insert from bars 6-7 (the clarinet reading forwards and the cello retrograde), this time played in doubled semiquavers, mimicking the initial clarinet and cello reinforcement in bar 15. The reading of the sixth piano phrase and clarinet insert from panel 1 follow in
the same manner. From the reading of the seventh piano phrase, however, the range begins to expand, the process continuing until the end of bar 32 and the completion of the reading of the tenth piano phrase from bar 12.

5.2.3 Panel 3

Panel 3, beginning at bar 33, features crescendo chords followed by decorated ascending clarinet figures (Figure 5.8).

![Figure 5.8 Here... bars 33-34]
Each long crescendo chord is taken from the second last chord of each piano phrase in panel 1. The fortissimo chord is the last chord of each piano phrase. That is, the first chord in bar 33 is taken from the fifth chord of bar 1, and the second chord of bar 33 is taken from the sixth chord of bar 1. For each crescendo chord the clarinet and cello double the highest and lowest piano notes; they then arpeggiate the chord as an upbeat to the reinforcement of the fortissimo chord. The cello follows the changes in the piano, but the clarinet uses d’’’ as its constant upper limit.

The ascending clarinet figure plays the axes of the fortissimo piano chord: d-f gives d’’-e’; gb-a gives g’-ab’; a-f’ gives db’’; f’-a’ gives g’’; and bb’-d’’ gives c’’’. Double axes are given as staccato semiquavers and single axes are given as quavers decorated with mordents alternating normal and inverted.

The process continues until the completion of the reading of the fifth piano phrase from panel 1. The final clarinet flourish reads the axes of the fortissimo chords (1 descending, 2 ascending, 4 descending, 5 ascending), holding its upper fortissimo chord limit, d’’’ (Figure 5.9).
At bar 42 the demisemiquavers of the clarinet flourish are transferred to the piano \((pp)\) while the clarinet and cello play \textit{pianissimo} descending phrases (Figure 5.10).
The piano reads from the first piano phrase of panel 1 (all six chords), right-hand followed by left-hand (marked by the slurs) in an overlapping descending manner. The direction changes (to ascending) when the piano begins reading the second phrase from panel 1 in bar 43 and this process continues until the completion of the reading of the fifth phrase in bar 48.
The clarinet and cello read the right- and left-hand chords of the piano (from panel 1) respectively to form descending legato arpeggios. The beginning of each new piano phrase (from panel 1) is marked by a decorative mordent, and preceded by a rest that completes the crotchet beat.\(^{120}\) The duration of each arpeggio note is determined by the interval to the next note: thus, for example, d’’’ -b♭’ in the clarinet is 4 semitones and generates a duration of 4 semiquavers for d’’’; b♭’ to a’ is 1 semitone, generating a duration of 1 semiquaver for b♭’ . The duration last note of each original panel 1 phrase is always a semiquaver.

The process continues until the fifth phrase from panel 1 has been read by the piano, and stops at bar 48, triggered by a rhythmic unison between clarinet and cello upon their completion of the reading of the second piano phrase from panel 1 (bar 3). The final piano chord in bar 48 is the last chord from the fifth piano phrase (bar 6).

5.2.5 Panel 5

At bar 49 the piano takes over the role of the clarinet and cello in the previous panel, continuing with a reading of the third piano phrase from bars 3-4. Again, the change from one original phrase to another is marked by alternating mordents preceded by a rest that completes the beat (Figure 5.11).

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\(^{120}\) A semiquaver rest is also inserted before each clarinet arpeggio as a notional breathing point.
The clarinet and cello, instead of duplicating or imitating the piano’s texture from panel 4, play two-octave demisemiquaver staccato arpeggios. The arpeggios are read from the third piano phrase of panel 1 (bars 3-4), the clarinet taking the right-hand and the cello taking the left-hand. The arpeggios coincide with every second piano pitch (right-hand relative to the clarinet and left-hand relative to the cello) and alternate their direction.
The process ends at bar 54 with the completion of the reading of the fifth piano phrase from bars 5-6 in the piano (the clarinet has completed the fifth chord and the cello the sixth chord). The final piano chord of the fifth phrase is repeated to initiate panel 6.

5.2.6 Panel 6

In panel 6 the lead is taken by the cello, which imitates the descending figures of the previous two panels while punctuations are provided by clarinet and piano. The cello line reads the six chords of the first piano phrase in bar 1. The clarinet and piano punctuations are taken from both the first and second piano phrases (Figure 5.12).
The durations for the cello are derived from the intervals. Intervals of one semitone are given one semiquaver. All other intervals are doubled to augment the line: that is, the interval from the initial a’ to gb’ is three semitones, giving a duration of six semiquavers.

5.2.7 Panel 7

At bar 63, panel 7 begins reading from panel 1 again (but omitting the repetitions and inversions of the initial chord). The final d’ in the cello from panel 6 initiates a feature of this pitch. All Ds from panel 1 are assigned to the clarinet and cello, and sustained until the end of the crotchet beat. When clarinet and cello’s Ds coincide, they are both trilled; if not, every second sustained D is decorated with a trill. The piano reads the remaining chord notes (Figure 5.13).
At bar 69, once the tenth piano phrase from panel 1 has been read, the music re-reads from bar 63, restricting the range and changing the texture. Rhythmically, each instrument cycles through triplets, quadruplets and quintuplets. The piano restricts its pitch to two notes per hand, and plays on every second subdivision of the...
The process is interrupted at the end of the reading of the sixth piano phrase in bar 67. From bar 72, the piano re-reads from bar 69, transposing the material up a further octave and performing it in a melodic or linear fashion, rather than as two-note
dyads in each hand. The clarinet and cello also re-read from bar 69, this time omitting any pitches that are not preceded by a D (Figure 5.15).

Figure 5.15 Here... bars 72-73

5.2.8 Panel 8

At bar 75 the texture changes completely, with an ascending arpeggio flourish followed by a pianissimo clarinet line edging its way to its top register (Figure 5.16).
The arpeggios are read from the first piano chord in bar 1. Each arpeggio is a different length so each instrument reaches its “target” at a different time. The clarinet line reads the chord notes, adding axes between them. Chord notes ascend and axes descend.
The process continues with the second and third chords from the first piano phrase, cello and then piano joining the clarinet in the ascending lines. In the final example, the piano doubles the clarinet with trills (Figure 5.17).
5.2.9 Panel 9

Panel 9 continues to contrast the piano material with clarinet and cello inserts. At bar 81 the piano reads the first piano phrase again, this time at original pitch. Axes are omitted from the first and last chords and only the inside parts are played from the remaining chords (Figure 5.18).
Clarinet and cello reinforce the first and last chords of each piano phrase by playing the second and third voice of the chord (the cello plays the second and third voice from the bottom). Each clarinet and cello reinforcement is preceded by a D grace note (d'''' for the clarinet and d for the cello).

Figure 5.18 Here... bars 81-82
The piano phrase is “answered” by clarinet and cello *ppp* arpeggios that read the last chord of the piano phrase (that is, the complete “original” piano chord, including axes). The arpeggios alternate descending with ascending, and alternate trilled with normal. The duration of each note of the arpeggio is determined by the number of chords in the preceding piano phrase, minus the first and last chord. That is, in the first piano phrase there are six chords (or four, not counting the first and last), giving a duration of four semitones (one crotchet) for each arpeggiated note. A total of four piano phrases from panel 1 are read in this manner.

### 5.2.10 Panel 10

Panel 10 begins on the third beat of bar 87 with the first chord of the fifth piano phrase played *fortissimo*. The upbeat to the chord is given by the clarinet, playing d′′′ (the top note of the chord) preceded by a′′ (the second voice of the chord) (Figure 5.19).
Figure 5.19 *Here...* bars 87-88

The cello softly sustains the bottom note of the chord. The clarinet and piano answer the chord with arpeggiation of each subsequent new chord in the fifth piano phrase (omitting the last chord which repeats the first). The clarinet plays a different inversion of the piano’s right-hand, decorated with flutter-tongue. The process continues until the reading of the eighth phrase. In each case the *fortissimo* piano chord is preceded by the clarinet “upbeat”, fixed at the pitch of d’’’, and preceded by a grace note that successively reads “down” the first piano chord of the piece.

5.2.11 Panel 11

Panel 11, the final panel of the piece, begins on the second beat of bar 92 and reads the first nine piano phrases from panel 1 in rhythmic unison (omitting the inversions of the first chord) (Figure 5.20).
The clarinet and cello read the fourth voice of the right- and left-hand of the piano respectively, with sustained notes alternating trilled and normal. For the piano, left- and right-hands alternate between two and one note per hand, chosen from the remaining chord notes. Durations are determined by the intervals of the clarinet: a second generates a semiquaver’s duration; a fourth generates four semiquavers’ (a
crotchet) duration. At the end of every phrase an extra semiquaver rest is inserted into the clarinet part as a notional breathing place.

The process concludes with the reading of the chord from the tenth phrase and a well-earned rest (Figure 5.21).

![Figure 5.21 Here... bars 97-98](image)

5.3 Discussion

Composing, and subsequently writing about, the acoustic instrumental work *Here*..., after an intense period of focusing solely on electronic music, served to highlight two features of this project.

Firstly, since I did not keep notes with regard to compositional procedures employed during the “white heat” of actually composing *Here*..., recalling them afterwards through looking at the score proved difficult. Indeed, certain specific triggering devices eluded me for two or three days before I was able to work them out, thus reinforcing the “meta-compositional” value of the Pd patches used in *The*
paradox of Pythagoras and Music of Grace, the two electronic works discussed in chapters 2 and 3.

The second feature was to revisit the differences in my personal approach to the two media (acoustic and electronic) and to discover that the responses I had to my initial MIDI studies were reinforced (see Chapter 1.4 MIDI Studies). Whilst, in a formal sense, Here… is not dissimilar to the Music of Grace series, the involvement of human performers and acoustic instruments have once again significantly influenced the parameters and general shape of the work. As a primary example of this, throughout the piece the tempo is more-or-less as fast as possible; as such, the tempo is effectively set by how fast the performers can play, rather than how fast the listener can hear (that is, the perceptions of the listener).121

In Panel 1, the articulations applied to the clarinet and cello at different times highlight with slurs the semitones or non-semitones, a “proximity”, or lack of it, that has a particular physical reality when orientated to the cellist’s fingerboard, and at the end of Panel 1 the piano articulates its entire keyboard range. By comparison, for computers and oscillators, such precise notions would be less meaningful: there is no difference in “effort” between close and wide intervals and, with a range that extends beyond the limits of human hearing, articulating the range of oscillators would become an impractical exercise.122

Panel 2 features coordinated accents between instruments—an exciting event for human performers, but not necessarily so for computers.

121 For example, two distinct notes are generally able to be heard (under experimental conditions) if their onsets are at least 3 milliseconds apart: closer than this and the two notes “smear” together. Frequency difference, timbre and general acoustic conditions may raise the time difference required to up to 50 milliseconds (Schubert 1979).
122 This is not to say that compositions are not written that do the equivalent for computers, pushing the processing power or other parameters of the technology to their limits, and using this concept as a creative tool for composition. The distinction is that this acoustic work deals with human parameters rather than overtly technological ones (to the extent that it does not even contain “extended” instrumental techniques). Indeed, equivalent “human” parameters have regularly been explored in a similar way in real-time human interaction (performance) with computers (Nelson 1989, Roads 1986).
Panel 3 features dynamic change, fast arpeggiation and definition of the extremes of register, in particular the pitch-class D, which lies close to the top of the conventional range of the clarinet and close to the bottom of the range of the cello. D becomes more significant as a featured pitch because of this relative placement. Panel 4 contains a virtuosic piano line, while Panel 5 revisits coordination between the instrumentalists, every piano note triggering arpeggiations in either the cello or clarinet.

Panel 6 is the cellist’s solo, and an opportunity for expressive playing; Panel 7 advances ensemble coordination to rhythmic unison, trills adding not only colour, but “life” to the sound, before featuring the contrast between tessitura, dynamic, synchronicity and non-synchronicity through Panels 8 to 11.

The aspects of composition summarised above are inherent to my approach to the process of composing instrumental music. They apply not only to the “sound” of the work, but to the “here-and-now” of the work’s realisation by human performers in real time. In the light of the “freedoms” experienced in the process of composing the electronic pieces for this folio, these are qualities I may now regard as “special”, even precious, as a complementary part of my future compositional processes.
Bibliography

The following bibliography contains only those items that were consulted in the preparation of this thesis.\textsuperscript{123} For reasons of clarity the bibliography is grouped into sections: Books and Dissertations, Chapters and Articles, Conference Proceedings, Music Recordings, Music Scores, WWW Discussion List Messages, and WWW Documents and Pages. All documents sourced from the web are held in either hard or soft copy.

Books and Dissertations


\textsuperscript{123} Attempts at a comprehensive bibliography, even just for Pd, would be counter productive. Even by 1964 the bibliography for electronic music extended to over 120 pages (see Cross 1967).


**Chapters and Articles**


**Conference Proceedings**


Music Recordings


Cologne—WDR: Early Electronic Music, CD. BVHAAST 9016 [n.d.].


**Music Scores**


**WWW Discussion List Messages**


WWW Documents and Pages


Attachments (CD data)

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Figure H.7  [pd high_1-22]  H7
Figure H.8  [pd low_1-22]  H8
Figure H.9  [pd axis_50]  H9
Figure H.10  [pd mixout_x6_d]  H11
Figure H.11  [pd osc_on_off_pair_H_L_d]  H12
Figure H.12  [pd osc_on_off_L]  H14
Figure H.13  [pd osc_on_off/_R]  H15
Figure H.14  [pd osc_on_off_pair_L_H_d]  H16
Figure H.15  [pd osc_on_off_R]  H17
Figure H.16  [pd osc_on_off/_L]  H18
Figure H.17  [pd no_of_voices_playing]  H19
Figure H.18  [pd p_1b]  H20
Figure H.19  [pd beat_accent]  H21
Panel 2:
Figure H.20  [pd panel_2]  H22
Figure H.21  [pd p_2a]  H23
Figure H.22  [pd axis_melody]  H24
Figure H.23  [pd p_2b]  H25
Figure H.24  [pd axis_melody_p2b]  H26
Figure H.25  [pd beat_accent_2b]  H27
Panel 3:
Figure H.26  [pd panel_3]  H27
Figure H.27  [pd p_3a]  H29
Figure H.28  [pd high_3_1-7]  H30
Figure H.29  [pd low_3_1-7]  H31
Figure H.30  [pd descending_axes]  H32
Figure H.31  [pd delay_semiquaver_bank]  H33
Figure H.32  [pd delay_semiquaver_1]  H34
Figure H.33  [pd delay_semiquaver]  H35
Figure H.34  [pd repeat_down_12]  H37
Figure H.35  [pd 38_26_trilled]  H38
Figure H.36  [pd mixout_x2_d]  H39
Figure H.37  [pd p_3b]  H40
Figure H.38  [pd high_3_8-14]  H41
Figure H.39  [pd low_3_8-14]  
Figure H.40  [pd descending axes_3b]  
Figure H.41  [pd p_3c]  
Figure H.42  [pd high_3_15-22]  
Figure H.43  [pd low_3_15-22]  

Panel 4:
Figure H.44  [pd panel_4]  
Figure H.45  [pd high_melody]  
Figure H.46  [pd 0_1_out]  
Figure H.47  [pd ascending_descending_arpeggio_axes]  
Figure H.48  [pd low_high_62_trigger]  
Figure H.49  [pd high_melody_fast]  

Panel 5:
Figure H.50  [pd panel_5]  
Figure H.51  [pd trills]  

Appendix I:
Figure I.1  “Tree” diagram scheme  

Appendix J:
Figure J.1  Extract/arrangement from Befiehl used for The heavy dark trees—actual pitch  
Figure J.2  The heavy dark trees line the streets of summer top canvas  
Figure J.3  [pd high_array]  
Figure J.4  [pd high_1_2_3_4_5_6_7_8_9_10_11_12]  
Figure J.5  [pd low_array]  

Panel 1:
Figure J.6  [pd panel_1]  
Figure J.7  [pd p_1_chords_low]  
Figure J.8  [pd p_1_chords_high]  
Figure J.9  [pd low_0]  
Figure J.10  [pd low_0_0]  
Figure J.11  [pd delay_number]  
Figure J.12  [pd low_0_1]  
Figure J.13  Low rhythm at tempo=10000 ms  
Figure J.14  [pd low_0_2]  
Figure J.15  [pd low_0_3]  
Figure J.16  [pd low_0_4]  
Figure J.17  [pd low_0_5]  
Figure J.18  [pd low_0_6]  
Figure J.19  [pd low_1]  
Figure J.20  Low rhythm at tempo=6000 ms  
Figure J.21  [pd low_1_0]  
Figure J.22  [pd low_1_1]  
Figure J.23  [pd low_1_2]  
Figure J.24  [pd low_1_3]  
Figure J.25  [pd low_1_4]  
Figure J.26  [pd low_1_5]  
Figure J.27  [pd low_1_6]  
Figure J.28  [pd low_2]
Figure J.29  Low rhythm at tempo=4285 ms
Figure J.30  [pd low_2_0]
Figure J.31  [pd low_2_1]
Figure J.32  [pd low_2_2]
Figure J.33  [pd low_2_3]
Figure J.34  [pd low_2_4]
Figure J.35  [pd low_2_5]
Figure J.36  [pd low_2_6]
Figure J.37  [pd low_3]
Figure J.38  [pd low_3_0]
Figure J.39  [pd low_3_1]
Figure J.40  [pd low_3_2]
Figure J.41  [pd low_3_3]
Figure J.42  [pd low_3_4]
Figure J.43  [pd low_3_5]
Figure J.44  [pd low_3_6]
Figure J.45  [pd low_4]
Figure J.46  [pd low_4_0]
Figure J.47  [pd low_4_1]
Figure J.48  [pd low_4_2]
Figure J.49  [pd low_4_3]
Figure J.50  [pd low_4_4]
Figure J.51  [pd low_4_5]
Figure J.52  [pd low_4_6]
Figure J.53  [pd low_5]
Figure J.54  [pd low_5_0]
Figure J.55  [pd low_5_1]
Figure J.56  [pd low_5_2]
Figure J.57  [pd low_5_3]
Figure J.58  [pd low_5_4]
Figure J.59  [pd low_5_5]
Figure J.60  [pd low_5_6]
Figure J.61  [pd low_6]
Figure J.62  [pd low_6_0]
Figure J.63  [pd low_6_1]
Figure J.64  [pd low_6_2]
Figure J.65  [pd low_6_3]
Figure J.66  [pd low_6_4]
Figure J.67  [pd low_6_5]
Figure J.68  [pd low_6_6]
Figure J.69  [pd high_0]
Figure J.70  High rhythm at tempo=10000 ms
Figure J.71  [pd high_0_0]
Figure J.72  [pd pairs]
Figure J.73  [pd high_0_1]
Figure J.74  [pd threes]
Figure J.75  [pd high_0_2]
Figure J.76  [pd high_0_3]
Figure J.77  [pd high_0_4]
Figure J.78  [pd high_1]
Figure J.79  High rhythm at tempo=6000 ms  J64
Figure J.80  [pd high_1_0]  J65
Figure J.81  [pd high_1_1]  J65
Figure J.82  [pd high_1_2]  J66
Figure J.83  [pd high_1_3]  J66
Figure J.84  [pd high_1_4]  J67
Figure J.85  [pd high_2]  J68
Figure J.86  High rhythm at tempo=4285 ms  J68
Figure J.87  [pd high_2_0]  J69
Figure J.88  [pd high_2_1]  J70
Figure J.89  [pd high_2_2]  J70
Figure J.90  [pd high_2_3]  J71
Figure J.91  [pd high_2_4]  J71
Figure J.92  [pd high_3]  J72
Figure J.93  [pd high_3_0]  J73
Figure J.94  [pd high_3_1]  J73
Figure J.95  [pd high_3_2]  J74
Figure J.96  [pd high_3_3]  J74
Figure J.97  [pd high_3_4]  J75
Figure J.98  [pd high_4]  J76
Figure J.99  [pd high_4_0]  J77
Figure J.100 [pd high_4_1]  J77
Figure J.101 [pd high_4_2]  J78
Figure J.102 [pd high_4_3]  J78
Figure J.103 [pd high_4_4]  J79

Panel 2:
Figure J.104  [pd panel_2]  J80
Figure J.105  [pd low_to_low_p_1]  J81
Figure J.106  [pd low_0_to_low_p_1]  J81
Figure J.107  [pd low_0_0_to_low_p_1]  J82
Figure J.108  [pd low_0_1_to_low_p_1]  J83
Figure J.109  [pd low_0_2_to_low_p_1]  J83
Figure J.110  [pd low_0_3_to_low_p_1]  J84
Figure J.111  [pd low_0_4_to_low_p_1]  J84
Figure J.112  [pd low_0_5_to_low_p_1]  J84
Figure J.113  [pd low_0_6_to_low_p_1]  J85
Figure J.114  [pd low_1_to_low_p_1]  J85
Figure J.115  [pd low_1_0_to_low_p_1]  J86
Figure J.116  [pd low_1_1_to_low_p_1]  J86
Figure J.117  [pd low_1_2_to_low_p_1]  J87
Figure J.118  [pd low_1_3_to_low_p_1]  J87
Figure J.119  [pd low_1_4_to_low_p_1]  J87
Figure J.120  [pd low_1_5_to_low_p_1]  J88
Figure J.121  [pd low_1_6_to_low_p_1]  J88
Figure J.122  [pd low_2_to_low_p_1]  J89
Figure J.123  [pd low_2_0_to_low_p_1]  J90
Figure J.124  [pd low_2_1_to_low_p_1]  J90
Figure J.125  [pd low_2_2_to_low_p_1]  J90
Figure J.126  [pd low_2_3_to_low_p_1]  J91
Figure J.127  [pd low_2_4_to_low_p_1]  J91
Figure J.226  [pd_accel_5-55]  J152
Figure J.227  [pd_clock_tabread_high_5-55]  J152
Figure J.228  [pd_clock_accel_5-55]  J153
Figure J.229  [pd_accel_7-55]  J154
Figure J.230  [pd_clock_tabread_high_7-55]  J154
Figure J.231  [pd_clock_accel_7-55]  J155
Figure J.232  [pd_accel_9-55]  J156
Figure J.233  [pd_clock_tabread_high_9-55]  J156
Figure J.234  [pd_clock_accel_9-55]  J157
Figure J.235  [pd_accel_11-55]  J158
Figure J.236  [pd_clock_tabread_high_11-55]  J158
Figure J.237  [pd_clock_accel_11-55]  J159
Figure J.238  [pd_accel_13-55]  J160
Figure J.239  [pd_clock_tabread_high_13-55]  J160
Figure J.240  [pd_clock_accel_13-55]  J161
Figure J.241  [pd_accel_15-55]  J162
Figure J.242  [pd_clock_tabread_high_15-55]  J162
Figure J.243  [pd_clock_accel_15-55]  J163

Panel 5:
Figure J.244  [pd_panel_5]  J164
Figure J.245  [pd_p_5_low]  J165
Figure J.246  [pd_p_5_high]  J166

Mixout objects:
Figure J.247  [pd_mixout_0]  J167
Figure J.248  [pd_mixout_x8]  J168
Figure J.249  [pd_osc_on_off_*_L]  J169
Figure J.250  [pd_osc_on_off_*_R]  J170
Figure J.251  [pd_mixout_1]  J171
Figure J.252  [pd_mixout_2]  J171
Figure J.253  [pd_mixout_3]  J171
Figure J.254  [pd_mixout_4]  J172
Figure J.255  [pd_mixout_5]  J172
Figure J.256  [pd_mixout_6]  J172
Figure J.257  [pd_mixout_7]  J173
Figure J.258  [pd_mixout_8]  J173

Appendix K:
Figure K.1  “Tree” diagram scheme  K1

Appendix L:
Figure L.1  Chords from Befiehl used for The crystals in the cave—actual pitch  L2
Figure L.2  The crystals in the cave top canvas  L3

Panel 1:
Figure L.3  [pd_panel_1]  L4
Figure L.4  [pd_chords_1-4]  L5
Figure L.5  [pd_chords_1-4_+_axes_+_trills]  L6
Figure L.6  [pd_4_part_chord_1_+_axes]  L7
Figure L.7  [pd_axis]  L8
Figure L.8  [pd_4_part_chord_2_+_axes]  L9
Figure L.237 [pd 4_part_chord_15_+_axes_2] L164
Figure L.238 [pd p3_15bc] L165
Figure L.239 [pd p3_16a] L166
Figure L.240 [pd 4_part_chord_16_+_axes_2] L166
Figure L.241 [pd p3_16bc] L167
Figure L.242 [pd p3_17a] L168
Figure L.243 [pd 4_part_chord_17_+_axes_2] L168
Figure L.244 [pd p3_17bc] L169
Figure L.245 [pd p3_18a] L170
Figure L.246 [pd 4_part_chord_18_+_axes_2] L170
Figure L.247 [pd p3_18bc] L171
Figure L.248 [pd p3_19a] L172
Figure L.249 [pd 4_part_chord_19_+_axes_2] L172
Figure L.250 [pd p3_19bc] L173
Figure L.251 [pd p3_20a] L174
Figure L.252 [pd 4_part_chord_20_+_axes_2] L174
Figure L.253 [pd p3_20bc] L175
Figure L.254 [pd p3_21-20abc] L176
Figure L.255 [pd p3_21a] L177
Figure L.256 [pd 4_part_chord_21_+_axes_2] L177
Figure L.257 [pd p3_21bc] L178
Figure L.258 [pd p3_22a] L179
Figure L.259 [pd 4_part_chord_22_+_axes_2] L179
Figure L.260 [pd p3_22bc] L180
Figure L.261 [pd p3_23a] L181
Figure L.262 [pd 4_part_chord_23_+_axes_2] L181
Figure L.263 [pd p3_23bc] L182
Figure L.264 [pd p3_24a] L183
Figure L.265 [pd 4_part_chord_24_+_axes_2] L183
Figure L.266 [pd p3_24bc] L184
Figure L.267 [pd p3_25a] L185
Figure L.268 [pd 4_part_chord_25_+_axes_2] L185
Figure L.269 [pd p3_25bc] L186
Figure L.270 [pd p3_26a] L187
Figure L.271 [pd 4_part_chord_26_+_axes_2] L187
Figure L.272 [pd p3_26bc] L188
Figure L.273 [pd p3_27a] L189
Figure L.274 [pd 4_part_chord_27_+_axes_2] L189
Figure L.275 [pd p6_27bc] L190
Figure L.276 [pd p3_28a] L191
Figure L.277 [pd 4_part_chord_28_+_axes_2] L191
Figure L.278 [pd p3_28bc] L192
Figure L.279 [pd p3_29a] L193
Figure L.280 [pd 4_part_chord_29_+_axes_2] L193
Figure L.281 [pd p3_29bc] L194
Figure L.282 [pd p3_30a] L195
Figure L.283 [pd 4_part_chord_30_+_axes_2] L195
Figure L.284 [pd p3_30bc] L196
Figure L.285 [pd p3_31-40abc] L197
Figure L.286 [pd p3_31a] L198
Figure L.385  [pd p4_chords_9-12_+24_arp]  L.267
Figure L.386  [pd chord_9_+24_arp]  L.268
Figure L.387  [pd chord_10_+24_arp]  L.268
Figure L.388  [pd chord_11_+24_arp]  L.269
Figure L.389  [pd chord_12_+24_arp]  L.270
Figure L.390  [pd p4_chords_9-12_+36_arp_axes_+48+36]  L.270
Figure L.391  [pd chord_9_+36_arp]  L.271
Figure L.392  [pd chord_10_+36_arp]  L.272
Figure L.393  [pd chord_11_+36_arp]  L.272
Figure L.394  [pd chord_12_+36_arp]  L.273
Figure L.395  [pd axis_9_+48_arp]  L.274
Figure L.396  [pd axis_10_+48_arp]  L.274
Figure L.397  [pd axis_11_+48_arp]  L.275
Figure L.398  [pd axis_12_+48_arp]  L.276
Figure L.399  [pd axes_9_+36_arp]  L.277
Figure L.400  [pd transposition_+36_x6]  L.277
Figure L.401  [pd axes_10_+36_arp]  L.278
Figure L.402  [pd axes_11_+36_arp]  L.279
Figure L.403  [pd axes_12_+36_arp]  L.279
Figure L.404  [pd p4_chords_13-16_+0_arp]  L.280
Figure L.405  [pd chord_13_+0_arp]  L.280
Figure L.406  [pd chord_14_+0_arp]  L.281
Figure L.407  [pd chord_15_+0_arp]  L.282
Figure L.408  [pd chord_16_+0_arp]  L.282
Figure L.409  [pd p4_chords_13-16_+12_arp]  L.283
Figure L.410  [pd chord_13_+12_arp]  L.283
Figure L.411  [pd chord_14_+12_arp]  L.284
Figure L.412  [pd chord_15_+12_arp]  L.284
Figure L.413  [pd chord_16_+12_arp]  L.285
Figure L.414  [pd p4_chords_13-16_+24_arp]  L.285
Figure L.415  [pd chord_13_+24_arp]  L.286
Figure L.416  [pd chord_14_+24_arp]  L.287
Figure L.417  [pd chord_15_+24_arp]  L.287
Figure L.418  [pd chord_16_+24_arp]  L.288
Figure L.419  [pd p4_chords_13-16_+36_arp_axes_+48+36]  L.288
Figure L.420  [pd chord_13_+36_arp]  L.289
Figure L.421  [pd chord_14_+36_arp]  L.290
Figure L.422  [pd chord_15_+36_arp]  L.290
Figure L.423  [pd chord_16_+36_arp]  L.291
Figure L.424  [pd axes_13_+48_arp]  L.292
Figure L.425  [pd axes_14_+48_arp]  L.292
Figure L.426  [pd axes_15_+48_arp]  L.293
Figure L.427  [pd axes_16_+48_arp]  L.293
Figure L.428  [pd axes_13_+36_arp]  L.294
Figure L.429  [pd axes_14_+36_arp]  L.294
Figure L.430  [pd axes_15_+36_arp]  L.295
Figure L.431  [pd axes_16_+36_arp]  L.295
Figure L.432  [pd p4_17-24]  L.296
Figure L.433  [pd p4_chords_17-24_+0_arp]  L.297
Figure L.434  [pd chord_17_+0_arp]  L.297
Figure L.485 [pd chord_24_+36_arp] L324
Figure L.486 [pd axes_21_+48_arp] L325
Figure L.487 [pd axes_22_+48_arp] L325
Figure L.488 [pd axes_23_+48_arp] L326
Figure L.489 [pd axes_24_+48_arp] L326
Figure L.490 [pd axes_21_+36_arp] L327
Figure L.491 [pd axes_22_+36_arp] L327
Figure L.492 [pd axes_23_+36_arp] L328
Figure L.493 [pd axes_24_+36_arp] L328
Figure L.494 [pd axes_21_+24_arp] L329
Figure L.495 [pd axes_22_+24_arp] L329
Figure L.496 [pd axes_23_+24_arp] L330
Figure L.497 [pd axes_24_+24_arp] L330
Figure L.498 [pd p4_25-32] L331
Figure L.499 [pd p4_chords_25-28_+0_arp] L332
Figure L.500 [pd chord_25_+0_arp] L332
Figure L.501 [pd chord_26_+0_arp] L333
Figure L.502 [pd chord_27_+0_arp] L334
Figure L.503 [pd chord_28_+0_arp] L334
Figure L.504 [pd p4_chords_25-28_+12_arp] L335
Figure L.505 [pd chord_25_+12_arp] L335
Figure L.506 [pd chord_26_+12_arp] L336
Figure L.507 [pd chord_27_+12_arp] L336
Figure L.508 [pd chord_28_+12_arp] L337
Figure L.509 [pd p4_chords_25-28_+24_arp] L337
Figure L.510 [pd chord_25_+24_arp] L338
Figure L.511 [pd chord_26_+24_arp] L338
Figure L.512 [pd chord_27_+24_arp] L339
Figure L.513 [pd chord_28_+24_arp] L339
Figure L.514 [pd p4_chords_25-28_+36_arp_axes_+48+36+24+12] L340
Figure L.515 [pd chord_25_+36_arp] L340
Figure L.516 [pd chord_26_+36_arp] L341
Figure L.517 [pd chord_27_+36_arp] L341
Figure L.518 [pd chord_28_+36_arp] L342
Figure L.519 [pd axes_25_+48_arp] L343
Figure L.520 [pd axes_26_+48_arp] L343
Figure L.521 [pd axes_27_+48_arp] L344
Figure L.522 [pd axes_28_+48_arp] L344
Figure L.523 [pd axes_25_+36_arp] L345
Figure L.524 [pd axes_26_+36_arp] L345
Figure L.525 [pd axes_27_+36_arp] L346
Figure L.526 [pd axes_28_+36_arp] L346
Figure L.527 [pd axes_25_+24_arp] L347
Figure L.528 [pd axes_26_+24_arp] L347
Figure L.529 [pd axes_27_+24_arp] L348
Figure L.530 [pd axes_28_+24_arp] L348
Figure L.531 [pd axes_25_+12_arp] L349
Figure L.532 [pd transposition_+12_x6] L350
Figure L.533 [pd axes_26_+12_arp] L350
Figure L.534 [pd axes_27_+12_arp] L351
Figure L.635  [pd axes_39+48_arp]  L405
Figure L.636  [pd axes_40+48_arp]  L405
Figure L.637  [pd axes_37+36_arp]  L406
Figure L.638  [pd axes_38+36_arp]  L406
Figure L.639  [pd axes_39+36_arp]  L407
Figure L.640  [pd axes_40+36_arp]  L407
Figure L.641  [pd axes_37+24_arp]  L408
Figure L.642  [pd axes_38+24_arp]  L408
Figure L.643  [pd axes_39+24_arp]  L409
Figure L.644  [pd axes_40+24_arp]  L409
Figure L.645  [pd axes_37+12_arp]  L410
Figure L.646  [pd axes_38+12_arp]  L410
Figure L.647  [pd axes_39+12_arp]  L411
Figure L.648  [pd axes_40+12_arp]  L411
Figure L.649  [pd axes_37+0_arp]  L412
Figure L.650  [pd axes_38+0_arp]  L412
Figure L.651  [pd axes_39+0_arp]  L413
Figure L.652  [pd axes_40+0_arp]  L413
Figure L.653  [pd p4_1-8a]  L414
Figure L.654  [pd p4_chords1-4+48_arp]  L415
Figure L.655  [pd chord_1+48_arp]  L415
Figure L.656  [pd transposition_+48_x4]  L416
Figure L.657  [pd chord_2+48_arp]  L416
Figure L.658  [pd chord_3+48_arp]  L417
Figure L.659  [pd chord_4+48_arp]  L417
Figure L.660  [pd p4_chords1-4+60_arp]  L418
Figure L.661  [pd chord_1+60_arp]  L418
Figure L.662  [pd transposition_+60_x4]  L419
Figure L.663  [pd chord_2+60_arp]  L419
Figure L.664  [pd chord_3+60_arp]  L420
Figure L.665  [pd chord_4+60_arp]  L420
Figure L.666  [pd p4_chords1-4+72_arp]  L421
Figure L.667  [pd chord_1+72_arp]  L421
Figure L.668  [pd transposition_+72_x4]  L422
Figure L.669  [pd chord_2+72_arp]  L422
Figure L.670  [pd chord_3+72_arp]  L423
Figure L.671  [pd chord_4+72_arp]  L423
Figure L.672  [pd p4_chords1-4+84_arp]  L424
Figure L.673  [pd chord_1+84_arp]  L424
Figure L.674  [pd transposition_+84_x4]  L425
Figure L.675  [pd chord_2+84_arp]  L425
Figure L.676  [pd chord_3+84_arp]  L426
Figure L.677  [pd chord_4+84_arp]  L426
Figure L.678  [pd p4_chords5-8+96_arp]  L427
Figure L.679  [pd chord_5+96_arp]  L427
Figure L.680  [pd transposition_+96_x4]  L428
Figure L.681  [pd chord_6+96_arp]  L428
Figure L.682  [pd chord_7+96_arp]  L429
Figure L.683  [pd chord_8+96_arp]  L429
Figure L.684  [pd p4_chords5-8+108_arp]  L430
Mixout objects:
Figure L.702 [pd mixout_0] L439
Figure L.703 [pd mixout_x8_0] L440
Figure L.704 [pd mixout_1] L440
Figure L.705 [pd mixout_x8_1] L441
Figure L.706 [pd mixout_2] L441
Figure L.707 [pd mixout_x8_2] L442
Figure L.708 [pd mixout_3] L442
Figure L.709 [pd mixout_x8_3] L443
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*The paradox of Pythagoras* movements 1 to 27 (2:28:31)

1. 2 harmonics (0:59)
2. 4 harmonics (1:58)
3. 8 harmonics (3:04)
4. 16 harmonics (4:01)
5. 32 harmonics (4:41)
6. 64 harmonics (5:46)
7. 128 harmonics (7:07)
8. 256 harmonics (7:56)
9. 512 harmonics (7:28)
10. 1,024 harmonics (8:08)
11. 2,048 harmonics (9:12)
12. 4,096 harmonics (10:05)
13. 8,192 harmonics (9:54)
14. 16,384 harmonics (8:20)
15. 32,768 harmonics (8:18)
16. 65,536 harmonics (7:39)
17. 131,072 harmonics (9:31)
18. 262,144 harmonics (8:52)
19. 524,288 harmonics (8:27)
20. 1,048,576 harmonics (9:35)
21. 2,097,152 harmonics (8:39)
22. 4,194,304 harmonics (9:38)
23. 8,388,606 harmonics (10:00)
24. 16,777,216 harmonics (9:56)
25. 33,554,432 harmonics (9:50)
26. 67,108,864 harmonics (9:28)
27. 134,217,728 harmonics (9:59)

*Music of the spheres, movements 1 to 9 (37:06).*

1. Mercury (3:52)
2. Venus (3:56)
3. Earth (3:58)
4. Mars (3:52)
5. Jupiter (3:41)
6. Saturn (4:00)
7. Uranus (4:41)
8. Neptune (4:37)
9. Pluto (4:29)

*Music of Grace, movements 1 to 3 (1:08:22).*

1. *The cat dances and the moon shines brightly* (17:10)
2. *The heavy dark trees line the streets of summer* (20:56)
3. *The crystals in the cave absorb the light as if they have not seen it in a million years* (30:16)

*Here… (6:04).*

1. *Here… ‘Charisma’*: Ros Dunlop (clarinet), David Miller (piano), Julia Ryder (cello) (6:04)