

University of Wollongong Thesis Collections

University of Wollongong Thesis Collection

University of Wollongong

Year 2007

Algorithms, microtonality, performance:
eleven musical compositions

Warren Burt
University of Wollongong

Burt, Warren, Algorithms, microtonality, performance: eleven musical compositions, PhD thesis, Faculty of Creative Arts, University of Wollongong, 2007.
<http://ro.uow.edu.au/theses/754>

This paper is posted at Research Online.

NOTE

This online version of the thesis may have different page formatting and pagination from the paper copy held in the University of Wollongong Library.

UNIVERSITY OF WOLLONGONG

COPYRIGHT WARNING

You may print or download ONE copy of this document for the purpose of your own research or study. The University does not authorise you to copy, communicate or otherwise make available electronically to any other person any copyright material contained on this site. You are reminded of the following:

Copyright owners are entitled to take legal action against persons who infringe their copyright. A reproduction of material that is protected by copyright may be a copyright infringement. A court may impose penalties and award damages in relation to offences and infringements relating to copyright material. Higher penalties may apply, and higher damages may be awarded, for offences and infringements involving the conversion of material into digital or electronic form.

**Algorithms, Microtonality, Performance: Eleven Musical
Compositions**

A thesis submitted in partial fulfillment of the
requirements for the award of the degree

DOCTOR OF PHILOSOPHY

from

UNIVERSITY OF WOLLONGONG

by

Warren Burt, B.A., M.A.

Faculty of Creative Arts

2007

Thesis Certification

CERTIFICATION

I, Warren Burt, declare that this thesis, submitted in partial fulfillment of the requirements for the award of Doctor of Philosophy, 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.

A handwritten signature in black ink, appearing to read 'Warren Burt', written in a cursive style.

Warren Burt

09 February 2007

Table of Contents

Table of Contents	1
List of Tables	6
List of Figures	9
Abstract	11
Acknowledgments	13
Introduction	16
PART ONE – THEORETICAL CONCEPTS	19
1.1 Algorithms	19
1.1.1 History	20
1.1.2 Motivations	21
1.1.3 Kinds of processes	24
1.2 Microtonality	26
1.3. Why combine algorithmic composition with microtonality?	31
1.4 Extreme duration	34
1.5 Ervin Wilson	37
1.6 Moments of Symmetry (MOS)	40
1.6.1 Basic Definition	40
1.6.2 Some Initial Examples	43
1.6.3 Other Characteristics of MOS Scales	45
1.6.4 Not all scales with only two step sizes are MOS	54
1.6.5 MOS and world music scales	56
1.6.6 Other mathematical properties related to MOS	57
1.6.7 Just-Intonation and Quasi-MOS	58
1.6.8 MOS and equal-beating intervals	62
1.6.9 Perception and MOS	63
1.6.10 Ways I've used MOS	64
1.7 Euler-Fokker Genera	66
1.8 The Scale Tree	72
1.9 Additive Sequences, Limits and Number Triangles	78
1.9.1 Additive Sequences	78
1.9.2 Limits	79
1.9.3 Number Triangles	81
1.9.4 Scale Realisation	84
1.10 Tetrachords and the Greek modal system	88
1.11. ArtWonk Probability Distributions and Additive Sequence Generators	93
1.12. Some notes on the technologies used in these pieces.	99
PART TWO- DISCUSSION OF WORKS	101
2.1 For JSB and JT: Non-Directional Journey Out from the Enharmonic	101
2.1.1 Introduction	101
2.1.2 Tuning System	104
2.1.2 Algorithm	106
2.1.3 Process – Real Time Usage	110
2.2 The Malleable Urn	112
2.2.1 Introduction	112
2.2.2 Tuning System	114
2.2.3 Algorithm	117

2.2.4 Process – Real Time Usage	118
2.3 <i>The Animation of Lists And the Archytan Transpositions</i>	123
2.3.1 Introduction	123
2.3.2 Tuning System	127
2.3.3 Algorithm	132
2.3.4 Process – Real Time Usage	138
2.4 <i>Homage to Wyschnegradsky</i>	143
2.4.1 Introduction	143
2.4.1.1 The Logos Foundation	144
2.4.1.2 The Working Method	145
2.4.2 Tuning System	148
2.4.3 Algorithm	151
2.4.3.1 Distributions	151
2.4.3.2 Choice of distributions	152
2.4.3.3 Effects of distribution choice on musical texture	153
2.4.4 Process – Real Time Usage	154
2.5 <i>Lehmer’s Kookaburra</i>	157
2.5.1 Introduction	157
2.5.2 Tuning System	159
2.5.3 Algorithm	160
2.5.4 Process – Real Time Usage	166
2.6 <i>The MOSsy Slopes of Mt Meru – The Meru Expansion</i>	167
2.6.1 Introduction	167
2.6.2 Tuning System	168
2.6.3 Algorithm	176
2.6.4 Process – Real Time Usage	180
2.7 <i>Pythagoras’ Babylonian Bathtub</i>	183
2.7.1 Introduction	183
2.7.2 Tuning System	187
2.7.3 Algorithm	192
2.7.3.1 Chord selection	192
2.7.3.2 Chord variability	197
2.7.3.3 Composite timbres and beats from chord combinations	199
2.7.4 Process – Real Time Usage	201
2.8 <i>Saturday in the Triakontahedron with Leonhard</i>	204
2.8.1 Introduction	204
2.8.2 Tuning System	206
2.8.3 Algorithm	215
2.8.4 Process – Real Time Usage	221
2.9 <i>18 New Fuguing Tunes for Henry Cowell</i>	225
2.9.1 Introduction	225
2.9.2 Tuning System	226
2.9.3 Algorithm	230
2.9.4 Process – Real Time Usage	238
2.9.4.1 Questions	238
2.9.4.2 The Timbres	244
2.9.4.3 The Overall Form	245
2.10 <i>Someone Moved in a Room</i>	248
2.10.1 Introduction	248

2.10.2 Tuning System	248
2.10.3 Algorithm	253
2.10.3.1 Sonification	253
2.10.3.2 The Data	257
2.10.4 Process – Real Time Usage	261
2.11 <i>Proliferating Infinities</i>	267
2.11.1 Introduction	267
2.11.2 Tuning System	271
2.11.3 Algorithm	278
2.11.4 Process – Real Time Usage	282
2.11.5 Thoughts after listening	284
2.12 Conclusions and Future Directions	288
2.12.1 Conclusions	288
2.12.2 Future Directions	289
REFERENCES	291

The Animation of Lists and the Archytan Transpositions CD XI130 – in pocket in back cover

Appendix on DVD-ROM - in pocket on back cover - contents listed by filename

3.1 After JSB and JT
3.1.1 After JSB and JT - MP3 file
3.1.2 After JSB and JT - Score in PDF
3.2 The Malleable Urn
3.2.1 The Malleable Urn MP3 file
3.2.2 Malleable Urn Score
3.2.3 Malleable Urn Ukulele Scale Catalog
3.2.4 Malleable Urn Scales scl and tun formats
3.2.5 Malleable Urn CD cover
3.3 The Animation of Lists
3.3.1 Animation Of Lists MP3 file
3.3.1.2 And The Archytan Transpositions MP3 file
3.3.2 Animation of Lists Score
3.3.3 Animation of Lists Scale Catalog
3.3.4 Scala files Animation of Lists Scales
3.3.5 Animation of Lists reviews Complete
3.3.6 Commercial CD cover and liner notes
3.3.7 Copy of commercial CD
3.4 Homage to Wyschnegradsky
3.4.1 Homage To Wyschnegradsky MP3 file
3.4.2 Homage to Wyschnegradsky Scale catalog
3.4.3 Homage to Wyschnegradsky Scales
3.4.4 Logos And Electronic Pieces CD cover
3.5 Lehmer's Kookaburra
3.5.1 Lehmers Kookaburra MP3 file
3.5.2 Logos And Electronic Pieces CD cover
3.6 MOSSy Slopes of Mt Meru
3.6.1.1 MOSSy Slopes Meru Expansion MP3 file

- 3.6.1.2 MOSsy Slopes 2002 CD MP3 files
- 3.6.2 MOSsy Slopes Meru Scale Catalog
- 3.6.3 Scala files MOSsy Slopes Meru Scales
- 3.6.4 Burt 2002b Recurrent Sequences Paper
- 3.6.5 Burt 2002b Recurrent Sequences Sound Examples
- 3.6.6 MOSsy Slopes Meru Expansion CD cover
- 3.6.7 MOSsy Slopes Mt Meru 2002 CD cover
- 3.7 Pythagoras Babylonian Bathtub
 - 3.7.1.1 Pythagoras Bath Part 01 MP3 file
 - 3.7.1.2 Pythagoras Bath Part 02 MP3 file
 - 3.7.2 Pythagoras Babylonian Bathtub Scale catalog
 - 3.7.3 Scala files Pythagoras Babylonian Bathtub scales
 - 3.7.4 Pythagoras Bath CD cover
 - 3.7.5 Pythagoras Bath CD liner notes
- 3.8 Saturday in the Triakontahedron
 - 3.8.1 Saturday Triakontahedron Leonhard MP3 file
 - 3.8.2 Euler Genus (3 5 7 9 11 13) Scale Catalog
 - 3.8.3 Scala files Euler Genus(3 5 7 9 11 13)
 - 3.8.4 Saturday Triakontahedron CD cover
- 3.9 18 New Fuguing Tunes for Henry Cowell
 - 3.9.1 18 New Fuguing Tunes for Henry Cowell MP3 files
 - 3.9.2 3.9.2 18 New Fuguing Tunes Scale Catalog
 - 3.9.3 Scala scl and tun files 12 Note EFGs based on 3 5 & 7
 - 3.9.4 18 New Fuguing Tunes For Henry Cowell CD cover
 - 3.9.5 Calculator Sequences for 18 New Fuguing Tunes
 - 3.9.6 Parameter settings for each movement
 - 3.9.7 VSampler3 Tuning for non-12
- 3.10 Someone Moved in a Room
 - 3.10.1 Someone Moved in a Room MP3 files
 - 3.10.2 Someone Moved in a Room Scale catalog
 - 3.10.3 Scala files for scales used in Someone Moved in a Room
 - 3.10.4 Someone Moved In A Room CD cover
 - 3.10.5 Data used in Someone Moved in a Room
 - 3.10.6 Power Point Presentation with sound examples and unpublished paper
- 3.11 Proliferating Infinities
 - 3.11.1 Proliferating Infinities MP3 files
 - 3.11.2 Proliferating Infinities Scale catalog
 - 3.11.3 Scala files for scales used in Proliferating Infinities
- 3.12 Articles by Warren Burt
 - 3.12.1 Burt 1975 Aardvarks IV Masters Thesis UCSD
 - 3.12.2 Burt 1987a Tuning Forks EMI Vol 2 No 5
 - 3.12.3 Burt 1987b Tuning Forks ArtLink
 - 3.12.4 Burt 1988 SamplesIII NMA6
 - 3.12.5 Burt 1995 CombinationProductDissonances 1-1
 - 3.12.6 Burt 1996a Parentheses Algo Comp Org Snd
 - 3.12.7 Burt 1996b MicrotonalPitchSystems ACMC96
 - 3.12.8 Burt 1996c Wilsonian Path Part One 1-1
 - 3.12.9 Burt 1997a Harmonic Colour Fields ACMC 97
 - 3.12.10 Burt 1997b Microtonal Structural My Monodies LMJ7

- 3.12.11 Burt 1998 Wilsonian Path Part Two 1-1**
- 3.12.12 Burt 1999 Fast Random Fingerboard wb website**
- 3.12.13 Burt Dempster 1999 70sIn90s WOD 18-19**
- 3.12.14 Burt 2002a Structure and Necessity Chroma 33**
- 3.12.15 Burt 2002b Recurrent Sequences ACMC02**
- 3.12.16 Burt 2005a Thoughts on Volume Chroma 36**
- 3.12.17 Burt 2005b Exp Music 2005 WLT**
- 3.12.18 Burt 2005c From Sonification to Sound Art**
- 3.12.19 Burt 2005d Long Distance Composing ACMC05**
- 3.12.20 Burt 2005e Probability Distributions ArtWonk**
- 3.12.21 Burt 2007 Wilson Installation Forthcoming PNM**
- 3.13 References with broken links in pdf format and other material**
 - 3.13.1 Carey, Norman - Thesis formerly online at theory.rochester.edu**
 - 3.13.2 Chalmers John Personal Communication re MOS 2 Sept 2006**
 - 3.13.3 Graeme Breed MOS Proofs Website**
 - 3.13.4 Scheirer, Watson, Vercoe Complexity Short Musical Segments**

List of Tables

Table 1: Comparison of interval sizes and steps in diatonic MOS scales in 12-tone Equal-Temperament and Pythagorean Just-Intonation	42
Table 2: Pitches and step sizes of MOS pentatonic scale in 12-tone Equal-Temperament with step sizes of 300 and 200 cents, and a generating interval of 700 cents. (This is the pentatonic scale discussed above – (C D E G A)).....	43
Table 3: Pitches and step sizes of MOS scale of 9 steps in 25-tone Equal-Temperament with step sizes of 144 and 96 cents, and a generating interval of 528 cents.....	43
Table 4: Pitches and step sizes of non-MOS scale of 8 steps in 25-tone Equal-Temperament with step sizes of 96, 144, and 240 cents, and a generating interval of 528 cents	44
Table 5: Pitches and step sizes of non-MOS scale of 10 steps in 25-tone Equal-Temperament with step sizes of 48, 96 and 144 cents, and a generating interval of 528 cents	44
Table 6: Pitches and step sizes of MOS scale of 10 steps with step sizes of 99.27 and 168.37 cents, and a generating interval of Phi, 833.09 cents.....	45
Table 7: Listing of Step Intervals of the Pythagorean 3-limit Just- diatonic scale.....	46
Table 8: Listing of Step intervals from Table 6, the 10-tone scale with Phi as a generator.....	47
Table 9: Pitches and step sizes of a nine-tone MOS scale with step sizes of 144 and 96 cents, and a generating interval of 528 cents, which is a subset of 25-tone Equal-Temperament	49
Table 10: Pitches and step sizes of the other MOS scale of 9 steps in 25-tone Equal-Temperament, with step sizes of 96 and 144 cents, and a generating interval of 672 cents	49
Table 11: 18-note MOS scale made by stacking a generator interval of 328.32 cents ..	50
Table 12: Number of scale steps contained in each occurrence of the generator in the scale shown in Table 11	51
Table 13: Number of steps contained in each generator interval, in a scale made with 8 elements of the Fibonacci Series from 3 to 89.....	51
Table 14: Number of steps contained in each generator interval, in a scale made with 10 elements of the Fibonacci Series from 3 to 233.....	52
Table 15: MOS scale sizes from various generators. Additive sequences are in bold	53
Table 16: Vaziri’s Persian tuning – a 17-tone, 2 step scale using quarter-tones.....	55
Table 17: Step intervals in a 10-note scale made with Phi as a generator.....	58
Table 18: Step intervals in a 10-note Just- scale made by treating the Fibonacci Series from 8 to 610 as harmonics.....	59
Table 19: Step intervals in a 10-note Just- scale made by treating the Fibonacci Series from 3 to 233 as harmonics.....	60
Table 20: Euler Genus 333 – a chain of three perfect 3/2 fifths.....	67
Table 21: All possible factors in Euler-Fokker Genus 3 5 7	69
Table 22: Listing of Euler Genus 3 5 7, factors, ratios, and cents values	70
Table 23: Farey Series of order 6	72
Table 24: Farey Series of order 4	73
Table 25: Farey Series of order 4, carried out fully from 0/1 to 1/0	73
Table 26: Convergence of Scale Tree intervals when treated as Just-Intonation ratios.	76

Table 27: Ratio of each successive two elements of the Fibonacci series, as it tends to Phi	79
Table 28: Ratios of Additive Sequence (Fibonacci rule) with seeds of 1, 3, approaching Phi	80
Table 29: Ratios of Additive Sequence (Fibonacci rule) with seeds of 6, 5, approaching Phi	80
Table 30: Rules and limits of additive sequences used in this thesis	84
Table 31: 12-note scale made by treating elements of the Fibonacci series as harmonics	85
Table 32: 12-note scale resulting from taking the limit of the Fibonacci series as a generator (first method).....	86
Table 33: 12-note scale resulting from taking the limit of the Fibonacci series as a generator (second method).....	86
Table 34: Principal tetrachords listed in ancient Greek tuning theory	90
Table 35: Ancient Greek mode names compared with contemporary Church mode names	91
Table 36: Pitches available on C, F and G strings of harp in special tuning of <i>For JSB and JT</i>	104
Table 37: Pitches available on D and A strings of harp in special tuning of <i>For JSB and JT</i>	104
Table 38: Pitches available on E and B strings of harp in special tuning of <i>For JSB and JT</i>	105
Table 39: Complete set of pitches available on all strings of the harp in special tuning of <i>For JSB and JT</i>	105
Table 40: Available pitches in the special harp tuning of <i>For JSB and JT</i> compared with pitches of 24-tone Equal-Temperament.....	105
Table 41: Pedal settings for Aristoxenus' Enharmonic Dorian on harp strings in special tuning of <i>For JSB and JT</i>	106
Table 42: Possible modes made by rotating order of intervals of Aristoxenus' Enharmonic Dorian mode	115
Table 43: The three possible orders of two quarter-tones and a major 3 rd	116
Table 44: Seven-note scales made from tetrachords 2 and 3 in Table 43	116
Table 45: Complete listing of quarter-tone modal scales used in <i>The Malleable Urn</i>	116
Table 46: Method of displaying random number sequences in the score of <i>The Malleable Urn</i>	118
Table 47: Tuning forks scale – Just-Intonation ratios, cents, interval names	128
Table 48: Tuning fork scale transposed up 28/27	129
Table 49: Tuning fork scale transposed down 28/27	129
Table 50: 49-note scale made by combining original scale with its transpositions	130
Table 51: Assignment of pitches to measures for frame mounted forks.....	137
Table 52: Assignment of pitches to measures for hand held forks.....	138
Table 53: Spatial setup of tuning forks for recording session.....	140
Table 54: Basic 7-note quarter-tone mode used in <i>Homage to Wyschnegradsky</i>	148
Table 55: All 7 modes formed by rotating the basic quarter-tone mode used in <i>Homage to Wyschnegradsky</i>	149
Table 56: 13-note scale made by summing the seven 7-note modes listed in Table 55	150
Table 57: The seven quarter-tone modes used in <i>Homage to Wyschnegradsky</i> , covering three octaves, and showing changes from one mode to another with underlining	151

Table 58: Additive sequence rules and MOS divisions used in <i>The MOSsy Slopes of Mt Meru: The Meru Expansion</i>	175
Table 59: 23-note MOS Just-Intonation scale made by treating the elements of the Fibonacci series as harmonics.....	176
Table 60: Division of Just Fibonacci scale from Table 59 divided into 13 + 10-note interlocking groups. Numbers in boxes refer to scale degrees.....	176
Table 61: Input to Accumulator module in <i>SoftStep</i> and output of Modulo module with range of Accumulator from 0 to 127 and range of Modulo set to 30.....	178
Table 62: Generator sizes and 11- to 19-note MOS scales available on Scale Tree	191
Table 63: Chord vocabulary made for <i>Pythagoras' Babylonian Bathtub</i>	196
Table 64: Pitches of 11-tone MOS scale with generator of 3 steps out of 16 ET	198
Table 65: Pitches of 14-tone MOS scale with generator of 6 steps out of 17 ET	198
Table 66: "I Ching chord 2" mapped to scales of Tables 64 & 65.....	199\\
Table 67: Pitches of 14-tone MOS scale with generator of 425.23 cents	201
Table 68: "I Ching chord 2" mapped to scales of Tables 67 and 65, beat frequencies between different versions shown in Hz	201\\
Table 69: The 10 ways of combining sets of 3 out of 6 factors	210
Table 70: Euler Genus 3 5 7 9 11 13 as 8 parallel 8-note scales with scale degrees 0-63 for <i>Vaz Modular</i> and <i>Scala</i> *.tun format. Combination 1: 3-5-7 x 9-11-13	213
Table 71: Euler Genus 3 5 7 9 11 13 as 8 parallel 8-note scales with scale degrees 0-63 for <i>Vaz Modular</i> and <i>Scala</i> *.tun format. Combination 2: 3-5-9 x 7-11-13	214
Table 72: Probability Distributions for <i>Saturday in the Triakontahedron with Leonhard</i>	216
Table 73: Euler-Fokker Genera used in <i>18 New Fuguing Tunes for Henry Cowell</i>	228
Table 74a: 18 Diatonic type 7-note MOS scales found between 21- and 31-tone ET. Part 1	252
Table 74b: 18 Diatonic type 7-note MOS scales found between 21- and 31-tone ET. Part 2	253
Table 75: Data Types from Wollongong Room Calorimeter Project.....	258
Table 76: Wilson's first 11 additive sequence rules and limits.....	273
Table 77: Number seeds for 12 number triangles used to generate scales.....	274
Table 78: Generalized rules for deriving right wing additive sequences from any number triangle	276

List of Figures

Figure 1: Euler-Fokker Genera 3 3 3 3 3 5 as displayed as a 2 dimensional matrix performance keyboard in <i>Scala</i> tuning software.....	68
Figure 2: Euler-Fokker Genus 3 5 7 graphically represented as a cube.....	69
Figure 3: Basic Lambdoma of order 4	74
Figure 4: Lambdoma of order 4 filled in with ratios octave-reduced	74
Figure 5: David Finnemore's diagram of the Scale Tree (used by permission)	75
Figure 6: Graph of ratios of successive elements in the Fibonacci series.....	81
Figure 7: Pascal's, or Pingala's, or 1-1 Triangle (beginning)	82
Figure 8: 3-5 Triangle (beginning).....	82
Figure 9: Adding the numbers along the diagonals of the 1-1 triangle produces the Fibonacci series (diagram from Kak 2004).....	83
Figure 10: Harp pedal notation for Aristoxenus' Enharmonic Dorian tuning	106
Figure 11: Basic motive of <i>For JSB and JT</i> , for retuned chromatic pedal harp	107
Figure 12: Notation for <i>For JSB and JT</i> , for retuned chromatic pedal harp	109
Figure 13: Tablature notation for Section 1 of <i>The Malleable Urn</i> -One of 21 pages. 120	
Figure 14: Warren Burt performing <i>The Malleable Urn</i> - Gallery East, Clovelly, November 14, 2004.....	121
Figure 15: Cover to XI 130: <i>The Animation of Lists and the Archytan Transpositions</i> 124	
Figure 16: Back cover, XI 130: <i>The Animation of Lists and the Archytan Transpositions</i>	124
Figure 17: Typical dimensions for one of the set of tuning forks.....	125
Figure 18: Tuning forks frame with treble forks, and bass forks with resonators	126
Figure 19: Warren Burt with hand held tuning forks in studio, 1988	127
Figure 20: Numbering of forks in tuning fork frame	136
Figure 21: Tubi, the computer controlled quarter-tone tubulon at Logos Foundation. 147	
Figure 22: Puff, the computer-controlled quarter-tone organ rank at Logos Foundation	159
Figure 23: Output of the Lehmer equation mapped to pitch where $A+B = 1.0$	161
Figure 24: Output of the Lehmer equation mapped to pitch where $A + B = 2.0$	162
Figure 25: Output of the Lehmer equation mapped to pitch where $A+B = 2.87$	163
Figure 26: Output of the Lehmer equation mapped to pitch where $A+B = 3.62$	164
Figure 27: Diagram from Wilson 1993 (used by permission) showing derivation of Fibonacci series from diagonals of Pascal's triangle	169
Figure 28: Diagram from Wilson 1993 (used by permission) showing derivation of number series with rule $B_n = B_{n-3} + B_{n-1}$ from a different series of diagonals of Pascal's triangle	170
Figure 29: Diagram from Wilson 1993 (used by permission) showing derivation of number series with rule $C_n = C_{n-3} + C_{n-2}$ from yet another series of diagonals of Pascal's triangle	171
Figure 30: List from Wilson 1997 of the first 31, of 192 additive sequence rules, with their limits, formed by summing different diagonals of Pascal's triangle	172
Figure 31: Rhythm modules in <i>SoftStep</i> patch for <i>The MOSsy Slopes of Mt. Meru</i>	179
Figure 32: Warren Burt performing <i>Pythagoras' Babylonian Bathtub</i> at Cecil St Studios, Melbourne,	186
Figure 33: Warren Burt performing <i>Pythagoras' Babylonian Bathtub</i> at Cecil St Studios, Melbourne,	186

Figure 34: Horagram made by <i>Scala</i> showing MOS scales sizes for scale generator of 355.556 cents	188
Figure 35: On-screen 19-tone Equal-Temperament keyboard made by <i>Scala</i>	193
Figure 36: <i>Scala</i> 19-note keyboard with Yasser’s Hexad selected as mode. Green keys are non-modal tones and do not play. Red dots indicate sustained notes	194
Figure 37: Wilson’s triakontahedron mapping of Euler Genus (3 5 7 9 11 13).....	207
Figure 38: Euler-Fokker Genus 3 5 7 graphically represented as a cube.....	208
Figure 39: Wilson’s diagram of the Euler Genus as a “cube of cubes”	209\
Figure 40: <i>ArtWonk</i> performance interface for <i>Saturday in the Triakontahedron</i> with <i>Leonhard</i>	221
Figure 41: Scale 2, Euler Fokker Genera 3(5) 5(1) made in <i>Scala</i> 2D Play matrix.....	229
Figure 42: Scale 9, Euler Fokker Genera 5(2) 7(3) made in <i>Scala</i> 2D Play matrix.....	229
Figure 43: Graph 1 – output of pocket calculator process 1 level deep	236
Figure 44: Graph 2 – output of pocket calculator process 2 levels deep	236
Figure 45: Graph 3 – output of pocket calculator process 3 levels deep	236
Figure 46: Graph 4 – output of pocket calculator process 4 levels deep	236
Figure 47: Graph 5 – output of pocket calculator process 5 levels deep	237
Figure 48: Graph 6 – output of pocket calculator process 6 levels deep	237
Figure 49: Graph 7 – output of pocket calculator process 7 levels deep	237
Figure 50: Graph 8 – output of pocket calculator process 8 levels deep	237
Figure 51: Graph 9 – output of pocket calculator process 9 levels deep	237
Figure 52: <i>SoftStep</i> patch used for <i>18 New Fuguing Tunes for Henry Cowell</i> with parameter values for Movement 18 shown	240
Figure 53: Sit – raw data from Calorimeter Project	260
Figure 54: Drink – raw data from Calorimeter Project	260
Figure 55: Sit – normalized data from Calorimeter Project	260
Figure 56: Drink – normalized data from Calorimeter Project	260
Figure 57: Performance interface for <i>Someone Moved in a Room</i> made with <i>ArtWonk</i>	263
Figure 58: 2-1, or Lucas Triangle, showing different additive sequences on different sides of the diagram	272
Figure 59: 2-5 Triangle, showing different additive sequences on different sides of the diagram, which follow same rule as additive sequences in Figure 58	272
Figure 60: Place-numbers for positions of digits in a number triangle.....	275
Figure 61: Additive sequence generators for <i>ArtWonk</i>	278

Abstract

Algorithms, Microtonality, Performance: Eleven Musical Compositions,

by Warren Burt

Following a lifetime of creative work and investigation into algorithmic composition and microtonality, I became interested in the speculative mathematical music theory of Ervin Wilson. Encountering his work spurred me on to further investigations in sound and tuning, in a series of compositions using electronic, acoustic, and robotic acoustic instruments. Tuning ideas developed by Wilson and others were extended and expanded into several families of new microtonal musical scales, which were used as the basis for composing a series of algorithmic real-time musical works of extended duration. Some of these works involved collaborative relationships with other musicians, hardware and software instrument designers, and scientists. Wilson's ideas, such as Moments of Symmetry (MOS) scales, Euler-Fokker Genera, limit-ratios, the Scale Tree, and additive sequences and their derivation from number triangles, as well as other tuning ideas, such as permutations of the materials of the ancient Greek modal system were all extended and developed into families of interrelated microtonal scales. The desire to compose works of extended duration was aided by the large size of some of these scale families, which consist of between 60 and 276 new scales each. Acoustic instruments were built or adapted to perform some of these works, including microtonal plucked-string and percussion instruments, and the computer-controlled microtonal instruments of Godfried Willem Raes at the Logos Foundation, in Gent, Belgium. Other works used electronic timbres designed to explore placing of sound in space produced by the interaction of timbre, tuning and room-

acoustics. Software instruments designed to perform the algorithms used were developed in collaboration with John Dunn of Algorithmic Arts, in Fort Worth, Texas. Investigation into the role of timbre and tuning in sonification was carried out with the help of the Wollongong Room Calorimeter project, led by Professor Arthur Jenkins. This thesis discusses how these tunings, algorithms, real-time processes, instruments, and collaborative relationships were used in creating these compositions. Recordings of all compositions discussed are contained in the electronic Appendix, on the attached DVD-Rom. Catalogs of all scales used in the thesis, as well as *Scala* files for all scales, and all data used in composing the pieces is also contained in the Appendix. Additionally, a copy of the commercial CD release of *The Animation of Lists And the Archytan Transpositions*, one of the works discussed in this thesis, is also included.

Acknowledgments

The author would like to thank:

The Faculty of Creative Arts, University of Wollongong for the Fellowship and other funding which made writing this thesis possible.

The Office of Post-Graduate Research, University of Wollongong, for funding in 2006 which partially aided travel to the Sound Symposium, St. John's, Newfoundland in July of that year.

Greg Schiemer, for supervision, and for organizing the *Sonic Connections* events, which provided a forum for presentation of some of this work, and for much conversation about all this.

Houston Dunleavy, for co-supervision.

Ervin Wilson, for sending a constant stream of papers, which continually challenge, and result in new ideas and resources.

Kraig Grady, John Chalmers, David Finnermore, and Brian McLaren, for email conversations about the tuning ideas discussed in this thesis.

John Dunn, of Algorithmic Arts, for developing *ArtWonk*, *SoftStep*, and other software tools used in this work, and who untiringly responded to suggestions for new functions in the software.

Software developers Martin Fay, Matthias Ziegs, Andrew Culver and John Cage, Miller Puckette, Manuel Op de Coul, and S. Christian Collins, whose tools I used in making these pieces.

Godfried-Willem Raes and Kristof Lauwers at the Logos Foundation, Gent, Belgium, for allowing me to work with their marvelous computer-controlled microtonal acoustic instruments, which resulted in the pieces *Homage to Wyschnegradsky* and *Lehmer's Kookaburra*.

The Australia Council's Art and New Technologies program, whose 1985 grant allowed me to build my set of Just-Intonation tuning forks at the CSIRO Department of Applied Physics, Monash University, during that year. Thanks also to all the staff at the CSIRO Department of Applied Physics, whose help enabled the tuning forks to come into being.

Phill Niblock, of XI Records, for commissioning *The Animation of Lists And the Archytan Transpositions*, and Al Margolis, for his patient and meticulous production on the CD.

Mary Jane Leahy and Associate Professor Arthur Jenkins of the Wollongong Room Calorimeter Project, a research project in the Department of Biomedical Sciences,

University of Wollongong, for inviting me to work with data from the project, which resulted in the composition *Someone Moved in a Room*.

The Music Board of the Australia Council, for funding in 2006 which aided the composition of *Proliferating Infinities*.

To all those who responded promptly to my email inquiries about their work. They know who they are.

And finally, to my life-partner, my collaborator, my first critic and editor, and my unfailing cheerleader, Catherine Schieve, for service above and beyond any and all calls of duty. Even in the darkest times of struggle during this work, she was a source of light, strength, and joy.

Introduction

I love playing with things. Language is a toy, as well as a tool. The eye is a collector of delights. And the ear: timbres, tunings, colours, pitches, rhythms, phrases, found objects, implied patterns, the lot. My musical work, though serious, is all a grand exploration for me. As a composer, I am a musical omnivore. I enjoy composing and making music in an extremely wide variety of forms and genres. And even within the confines of a specific area, I enjoy a diverse approach to my materials. . Unwilling to be hemmed in by any one musical or theoretical approach, I have ranged across a wide span of contemporary ideas, often with a sense of wit and humour. This humour, and this sense of play with materials, frequently expressed in the form of irreverence, is a vital and central part of my work. This might be shown by a quote from my 1996 article “Some parentheses around algorithmic composition” (Burt 1996a).

In our collaborative 1979 super-8 film *Der Yiddisher Cowboy*, composer and cultural historian Ronald Al Robboy, discussing our collaborative and film-making methods, and alluding to the early film-making techniques of such cinema pioneers as Alan Dwan, says that I am the ideal collaborator on such a project because of my ability to make a piece out ‘any thin thread of trashy material’. This scene, in which Robboy is talking directly to the camera in extreme close-up, is immediately followed by a short flickering burst of hand-painted film. On closer examination, or showing in slow motion, the hand-painted film is seen to be a portion of the Fibonacci series, written in my handwriting, one number per frame. (Since the film dealt with many aspects of Eastern European culture and its influence on our lives, this was my loving and irreverent homage to my maternal countryman and teen idol Bartok.)’

This film was a comedy, and Robboy’s remark about “any thin thread of trashy material” was meant humorously – he was going for a laugh. However, underneath the laugh was a serious statement – my use of structural bases for my work has encompassed both serious sources, such as chaos equations and recursive sequences, and silly sources, such as gambling charts and the output of damaged consumer electronics. My approach to both these sources has been the same. I treat both in a playful manner, delighting in the arbitrary; and in a very serious manner, seeing where a rigorous following of these sources leads. For me, working with mathematical systems, different tunings, and algorithmic processes, among many other things – that’s fun, and that’s play. That spirit of playful exploration should be seen as pervading this thesis.

This thesis is a survey of a series of musical works composed between 2002 and 2006. All of the works were made by applying a) an algorithm (or a process, or an information source) to b) a microtonal tuning system with c) some element of real-time generation or real-time performance involved. The pieces were realised with acoustic instruments, acoustic instrument samples, or electronic timbres. Choice of timbre was often a critical part of the composing process, as a number of the works also explore the relationship between tuning and timbre. Many other works were written during this period, but the works under discussion were chosen because they most clearly represent the intersection of the three main interests listed above.

This thesis is in three parts. **Part One** is a series of short essays dealing with some of the main aesthetic, technical and tuning issues used in these works.

Part Two is a description of the particular algorithms, tuning systems, and performance processes used in each work.

Part Three is a digital appendix, found on the accompanying data DVD, which includes MP3 files of recordings of all works discussed in this thesis, articles by the

author referred to in the text; lists of scales (including several extensive catalogs of tunings used in the works), and other data. Each Folder in the Appendix is numbered in agreement with its corresponding chapter. For example, the composition *For JSB and JT* is discussed in Chapter 2.1. The recording of this piece, its score, and all materials related to it are found in Appendix 3.1. The reader is referred to the Table of Contents for further navigational aid through the Appendix.

This thesis assumes familiarity with the concept of musical ratios and cents for expressing tuning. The freeware software *Scala* (Op de Coul 2007) was used extensively, and *Scala* charts and terminology will be extensively used throughout the thesis. For those unfamiliar with *Scala*, it can be downloaded from the site quoted in the References.

A general word on my approach: I am primarily a composer, and only secondarily a theorist. Therefore, my main interest is in using new tunings and interesting algorithms as worked out in the time, space and texture of sonic composition. I am not interested in complete theoretical explications of particular harmonic or algorithmic ideas. This thesis will not attempt complete explorations of any of the concepts discussed herein; rather it will concentrate on the ways that I develop and compose with particular tunings and algorithms.

In the tuning charts in this thesis, cents will be rounded off to a maximum of 3 decimal places, unless the example requires greater precision.