Abstract

In their 2005 paper *A Framework for Comparison of Processes in Algorithmic Music Systems*, Rene Wooller et al suggest four categories of generative systems within musical composition; linguistic/structural, interactive/behavioural, creative/procedural and biological/emergent.[1] In this paper I aim to explore each of these generative frameworks by creating an autonomous device that can play the piano to a set of guidelines that I instil within it, adhering to each of the categories suggested above. An autonomous machine will be used so my compositions can be performed in a well made acoustic space on a good quality instrument all whilst removing the human element from each system; this will be done in order to distinguish between 'direct control of a physical instrument and indirect control via program code'.[2]

I will also be exploring the history of generative techniques, finding examples for each category, presenting my own systems for each of the four defined structures and reflecting upon the process taken to achieve these tasks.

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[1] Rene Wooller, Andrew R. Brown, Eduardo Miranda, Rodney Berry, and Joachim Diederich, *A Framework for Comparison of Process in Algorithmic Music Systems* (Sydney: Creativity and Studio Press, 2005), pp. 1.

[2] Nick Collins , and Andrew R. Brown, 'Generative Music Editorial', *Contemporary Music Review*, 28 (2009), pp. 1-4, (p. 2).

Notes

All compositions were created in the open source visual programming language Pure Data, communicating with an Arduino Mega 2560 via Hans-Christoph Steiner's PDuino.

For a detailed account of the construction of my autonomous machine please view thegenerativepiano.tumblr.com.

All compositions are documented as their original Pure Data patches and as a video of one instance of each composition in real-time. Please consult the accompanying CD for both.

All Pure Data notation will appear as suggested by puredata.info as [object], [message(and [float\.

Each Pure Data patch is presented on the accompanying CD in its own folder; this is to include any objects from external libraries created by myself or others (of which I will credit the authors; if their real names are not obtainable I will use their name as it appears in the Pure Data forum). This is to enable each patch to run on any incarnation of Pure Data.

Any illustrations offered are to help with explanations and may have been doctored to ease understanding and not as structured within the patches.

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Introduction

As a genre, generative music can be a broad term, encompassing aspects of algorithmic music, chance music, process music and interactive music. This led to Rene Wooller, Andrew R. Brown, Eduardo Miranda, Rodney Berry and Joachim Diederich to define the genre as its four basic elements: linguistic/structural, interactive/behavioural, creative/procedural and biological/emergent. These frameworks were, according to Wooller et al, defined to 'initialise development of a more integrated and hopefully less confusing framework'.[3]

I intend to explore the use of generative systems in composition by using these suggested frameworks as themes for compositions of my own. Each composition will be written for the piano and will be played by a machine created by myself playing music that the system dictates.

In an article for *Music Therapy Today*, Paul Brown notes that 'the intention of generative music production is to produce a unique piece of music each time the process or system producing it is reset'.[4] Because of this, Brown continues to explain, 'generative music in its purest form is not recorded'.[5] Due to the ephemeral nature of generative music I will be offering one instance of each composition as a recording and will also be offering the Pure Data patch so other instances can be observed too. The outcome of these compositions should help, as Wooller et al suggest, in the 'understanding of the processes and potential

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[3] Rene Wooller, Andrew R. Brown, Eduardo Miranda, Rodney Berry, and Joachim Diederich, *A Framework for Comparison of Process in Algorithmic Music Systems* (Sydney: Creativity and Studio Press, 2005), p. 1.

[4] Paul Brown, 'Is the Future of Music Generative?', *Music Therapy Today*, vol. 6, 2 (2005), pp. 215-274, (p. 216).

[5] *Ibid.*, p. 216.

of algorithmic systems by assisting the composer in designing or selecting algorithms that meet creative needs'.[6]

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[6] Rene Wooller, Andrew R. Brown, Eduardo Miranda, Rodney Berry, and Joachim Diederich, *A Framework for Comparison of Process in Algorithmic Music Systems* (Sydney: Creativity and Studio Press, 2005), p. 14.

The History of Generative Techniques in Composition

In the Editorial for issue 28 of the journal *Contemporary Music Review*, Nick Collins claimed that generative music is so widely used today that it is mainstream.[7] With both computer game developers and 'on-hold music' composers looking toward generative techniques to help in keeping customers 'engaged via adaptability and variation',[8] and online generative radio stations such as Patch Werk Radio and Radio Web Macba broadcasting around the clock, there could be some truth to Collins' statement. Brian Eno brought the term generative music to the public's attention with his 1996 album *Generative Music 1* but how far back can we trace the use of generative techniques in composing?

To start we must first understand what is meant by generative music. Owain Rich offers this as a definition:

> Generative music is commonly agreed to describe music in which a system or process is composed to generate music rather than the composition of the direct musical event which will result from that system. The generative composer has only indirect control of the final musical result, and the creativity of the compositional process is found in the decisions about how the system will operate and the rules inside the system.[9]

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[7] Nick Collins , and Andrew R. Brown, 'Generative Music Editorial', *Contemporary Music Review*, 28 (2009), pp. 1-4, p. 1.

[8] Paul Brown, 'Is the Future of Music Generative?', *Music Therapy Today*, vol. 6, 2 (2005), pp. 215-274, p. 256.

[9] Owain Rich, *The Evolution of the Score and Generative Music: To What Extent Can Computer Code Ever Be Considered a Musical Language?* (Cambridge: Cambridge Press, 2003), p. 2.

An often used analogy for generative music is the image of a wind chime moving in the wind, creating pitches and rhythms determined by the size of the chimes, the positioning of the object itself and the surrounding environment (wind, shade, etc.). The simplicity of this analogy captures the essence of generative music and allows one to imagine how such a system might work at larger scales. Although this could be seen as a simplistic overview, the output could be a complex and diverse soundscape, or as Alan Dorin notes: ‘the wind-chime's structure dictates the timbres and pitches that it is capable of creating. Although it is capable of producing an infinite variety of sound-events, it may not produce any timbre or sound-event,.[10]

The term generative music, according to Paul Brown in his 2005 paper *Is the Future of Music Generative?,* was coined by Brian Eno to describe the music he created using SSEYO's computer software, Koan;[11] however the liner notes of Eno’s 1975 album *Discreet Music* tell the reader that Eno’s compositional technique for the album was to ‘explore multiple ways to create music with limited planning or intervention’*,*[12] so evidently generative techniques have been around much longer. As Boden and Edmonds suggest, ‘generative music may encompass any rule-based system, no matter how subjective the rules’.[13] With this definition in mind, how far back can we trace generative techniques in composition?

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[10] Alan Dorin, 'Generative Processes and the Electronic Arts', *Organised Sound*, vol. 6, 1 (2001), pp. 47-53, p. 50.

[11] Paul Brown, ‘Is the Future of Music Generative?’, *Music Therapy Today*, vol. 6, 2 (2005), pp. 215-274, p. 215.

[12] Brian Eno, sleeve notes to Brian Eno, *Discreet Music* (Virgin, ASIN: B0002PZVGQ, 1975), p. 3.

[13] Margaret A. Boden, and Ernest A. Edmonds, ‘What is Generative Art?’, *Digital Creativity,* vol. 20, 1 (2009), pp. 21-46, p. 34.

Brown argues that the ancient Greeks had the first example of generative music in the form of their Aeolian harp.[14] This comprised of a set of strings of different thicknesses that were tuned to resonate in unison with each other, producing rising and falling harmonies depending on the strength of the wind. This primitive generative example would be quite limited in its output and it wasn't until the introduction of the concept of algorithms a millennium later that the history of generative techniques grew.

Antony Stafford Beer describes an algorithm as 'a comprehensive set of instructions for reaching a known goal'[15] and although not all algorithmic music could be termed generative, Karlheinz Essl claims that algorithmic thinking could be traced back to Pythagoras;[16] however David Cope claims the first example of an algorithm was by Abu Ja'far Mohammed ibn Musa al-Khowarizmi in the ninth century.[17] The first use of an algorithm used as a compositional technique has been credited to Guido of Arezzo after he developed a system pairing pitches with vowel sounds from a religious text.[18] Philippe de Vitry, Guillaume de Machaut and Guillaume Dufay have all been said to have used algorithmic techniques in various ways, combining the rhythmic, pitched, and textual material of motets utilising, according to Colin Sullivan, 'placement of a fixed pattern of pitches decided by a repeating rhythmic pattern'.[19]

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[14] Paul Brown, 'Is the Future of Music Generative?', *Music Therapy Today*, vol. 6, 2 (2005), pp. 215-274, p. 222.

[15] Anthony Stafford-Beer, *Brain of the Firm, 2nd Edition* (New York: Wiley Publishing, 1994), p. 305.

[16] Karlheinz Essl, 'Algorithmic Composition', in *The Cambridge Companion to Electronic Music*, ed. by Nick Collins and Julio d'Escrivan Rincon (Cambridge: Cambridge Press, 2009), pp. 107-125, p. 107.

[17] David Cope, *The Algorithmic Composer* (Wisconsin: A-R Editions, Inc., 2000), p. 1.

[18] Curtis Roads, *The Computer Music Tutorial* (Massachusetts: MIT Press, 1996), p. 822.

[19] Colin Sullivan, 'An Exploration of Algorithmic Composition via the Fibonacci Sequence' (unpublished paper, 2010) <http://colin-sullivan.net/media/uploads/2010/12/Colin-Sullivan_Algorithmic-Composition-Fibonacci_Theory.pdf> [last accessed 5 April 2013], p. 2.

In 1660 Giovanni Andrea Bontempi wrote his *New Method of Composing Four Voices, By Means of Which One Thoroughly Ignorant of the Art of Music can Begin to Compose*. In this text, Bontempi proposed various systematic means of composition; one such system was a wheel comprising of a tier for each of the four vocalists that the user could turn to create a unique four-part harmony. This is, as Cope claims it to be, 'one of the many forerunners of contemporary algorithmic composition'.[20] It has been argued that Bach's *The Art of Fugue* is an early example of generative music as Bach instilled a set of guidelines utilised for the composition of the nineteen fugues that, according to Joshua Epstein, 'explore the generative power of a single fugue theme'.[21] However, Bach was still accountable for the outcome of the music so perhaps it is not strictly generative as, by a definition offered by Brown, 'the generative music composer, besides defining the musical parameters within the piece, essentially separates himself from the creation of the final piece of music'.[22]

John Cage's 1951 *Music of Changes* is claimed by Don Michael Randel to be the first piece of music to be conceived largely through random procedures,[23] a piece composed through tossing coins, reading the Chinese text *I Ching* and the matching result determining every musical decision. Although not strictly random, as Nick Collins notes: 'this view is essentially naive, showing an ignorance of probability theory',[24] it is also worth noting that Cage's seminal 4'33" has been argued to be a generative piece, as Brown states: 'the content of the

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[20] David Cope, *The Algorithmic Composer* (Wisconsin: A-R Editions, Inc., 2000), p. 6.

[21] Joshua M. Epstein, *Generative Social Science: Studies in Agent-Based Computational Modelling* (Princeton: Princeton University Press, 2007), P. 47.

[22] Paul Brown, 'Is the Future of Music Generative?', *Music Therapy Today*, vol. 6, 2 (2005), pp. 215-274, p. 215.

[23] Don Michael Randel, *The Harvard Concise Dictionary of Music and Musicians* (Cambridge: Harvard University Press, 2002), P. 17.

[24] Nick Collins , and Andrew R. Brown, 'Generative Music Editorial', *Contemporary Music Review*, 28 (2009), pp. 1-4, p. 3.

piece was formed from the random background ambience throughout the duration of its performance'.[25] However, other aleatoric techniques can be traced back much further, Sullivan suggests an aleatoric technique of composition was evident through the works of Athanasius Kircher in the mid-1600s, where he 'created a system for musical composition via algorithms that required table lookups for pitch and rhythmic values in order to create melody'.[26] Kircher also provided methods for developing melodies for hymns in terms of modes and counterpoint, using his own creation: the Organum Mathematicum. This counting machine has been described by Jim Bumgardner as 'the 17th century equivalent of a laptop computer'.[27]

Techniques of chance music became increasingly popular in the eighteenth and nineteenth centuries with the use of *Musikalisches Würfelspiele; a musical parlour-game that* used a system involving dice to choose pieces of music from previously composed phrases. With composers such as Kirnberger, C.P.E. Bach and Mozart involved in composing these chance-based musical parlour games, the output has been claimed to be more of a direct result of the composer's skill of knowing how to end musical phrases so another could be placed next to it to sound like a coherent piece of music, or as Lawrence Zbikowski observes:

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[25] Paul Brown, 'Is the Future of Music Generative?', *Music Therapy Today*, vol. 6, 2 (2005), pp. 215-274, p. 222.

[26] Colin Sullivan, 'An Exploration of Algorithmic Composition via the Fibonacci Sequence' (unpublished paper, 2010) <http://colin-sullivan.net/media/uploads/2010/12/Colin-Sullivan_Algorithmic-Composition-Fibonacci_Theory.pdf> [last accessed 5 April 2013], p. 2.

[27] Jim Bumgardner,'Kircher's Mechanical Composer: A Software Implementation' (unpublished paper 2009) <http://krazydad.com/pubs/kircher_paper.pdf> [last accessed 5 April 2013], p. 2.

> In truth, chance played little part in the success of the music produced by such games. Instead, what was required of the compilers... [was] a little knowledge about how to put the game together and an understanding of the formal design of waltzes.[28]

Although Zbikowski continues to note that the possible outcome from one of these games could produce '45,949,729,863,572,161 different yet similar waltzes',[29] and if the intention of generative music is to produce a unique piece of music each time the generative process or system producing it is reset then a quadrillion possible compositions means the outcome would be fairly unique.

French born artist Marcel Duchamp also experimented with aleatoric compositional techniques in the early twentieth century; his first musical offering *Erratum Musical* was composed by picking notes from a hat that were used to dictate each melody line for a three-part harmony. This composition predates Cage's chance music by nearly forty years and although Cage is quoted as saying the techniques used for this piece were 'rather bland and uninteresting',[30] it was their similar aesthetics that led to biographer Kenneth Silverman to suggest they had a 'spiritual empathy'.[31] Duchamp's experimental compositional processes interested Cage, and under the pretence of learning chess, Cage was reported to have 'spent many hours in Duchamp's apartment, learning, asking him little and reverently

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[28] Lawrence M. Zbikowski, *Conceptualizing Music: Cognitive Structure, Theory, and Analysis* (Oxford: Oxford University Press, 2002), p. 142.

[29] Lawrence M. Zbikowski, *Conceptualizing Music: Cognitive Structure, Theory, and Analysis* (Oxford: Oxford University Press, 2002), p. 148.

[30] Kenneth Silverman, *Begin Again: A Biography of John Cage* (Illinois: Northwestern University Press, 2012), p. 228.

[31] *Ibid*., p. 228.

observing',[32] to which Cage is quoted as asking Duchamp 'how is it that you used chance operations when I was just being born?'[33]

In the 1930s Henry Cowell was experimenting with allowing performers to determine primary elements of a score's realization; in his 1934 piece *Mosaic Quartet,* Cowell allowed the players to arrange the fragments of music in a number of different possible sequences. He also used specially devised notations to introduce variability into the performance of a work, sometimes instructing the performers to improvise a short passage. Although this technique took the final result out of the composer's hands perhaps it blurs the line between generative music and a musician's interpretation, Paul Griffiths regards this resultant blur as 'hardly aleatory, since exact pitches are carefully controlled and any two performances will be substantially the same'.[34]

As has been observed, not all aleatoric systems are generative; however, Brown suggests that serialism is, by its nature of instilling strict rules into the compositional process, a generative system, with composers such as Anton Webern, serialism uses 'extreme mathematical precision to create compositions'.[35] Essl mirrors this thought suggesting that although Webern's outlines were defined, 'infinite variants are obtained by utilizing random procedures and aleatoric methods for constructing the rhythmic structure'.[36] Essl continues

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[32] Roy Kotynek, and John Cohassey, *American Cultural Rebels: Avant-garde and Bohemian Artists, Writers and Musicians from the 1850s through the* [sic] *1960s* (North Carolina: McFarland Publishing, 2008), p. 191.
[33] John Cage, and Joan Retallack, *Musicage: Cage Muses on Words, Art, Music* (Connecticut: Wesleyan University Press, 1997), p. 110.
[34] Paul Griffiths, *The New Grove Dictionary of Music and Musicians, second edition*, ed. by Stanley Sadie and John Tyrrell (London: Macmillan Publishers, 2001), p. 215.
[35] Paul Brown, 'Is the Future of Music Generative?', *Music Therapy Today*, vol. 6, 2 (2005), pp. 215-274, p. 222.
[36] Karlheinz Essl, *ebern Uhr Werk* (liner notes for his software, 2011) <http://www.essl.at/works

to explain that as a generative structure, serialism becomes ‘a unifying principle which can control every detail of a composition – it affects all aspects of a musical structure, comparable with the DNA of a biological cell’.[37] This is an interesting analogy as five years after Webern’s untimely death Stanislaw Ulam and John von Neumann introduced cellular automata as a computational theory. While studied throughout the 1950s and 1960s, it was not until the 1970s and Conway's *Game of Life*, a two-dimensional cellular automaton, that interest in the subject expanded beyond academia. The scope of these self-reproducing algorithms was important to the field of generative music, as Edvardo Miranda notes:

> If we assume that music composition can be thought of as being based on pattern propagation and the formal manipulation of its parameters, it comes as no surprise that researchers started to suspect that cellular automata could be associated to some sort of musical representation in order to generate compositional material.[38]

Xenakis criticised the ‘incomprehensible auditory chaos of serialism’,[39] claiming it was ‘self-destructive in its current complexity’.[40] This resulted in him suggesting a more statistical approach to composition. In his paper The Crisis of Serial Music, Xenakis introduces the idea of replacing the deterministic causality of serialism with the more general concept of probability;[41] in this paper he also coined the term stochastic music. Xenakis initially composed with stochastic formulas by hand, notably *Metastasis* in 1955 although he later

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/webernuhrwerk/download.html> [last accessed 6 April 2013].

[37] Karlheinz Essl, ‘Algorithmic Composition’, in *The Cambridge Companion to Electronic Music*, ed. by Nick Collins and Julio d’Escrivan Rincon (Cambridge: Cambridge Press, 2009), pp. 107-125, p. 113.

[38] Eduardo Miranda, *Composing Music with Computers* (Oxford: Focal Press, 2004), p. 124.

[39] Iannis Xenakis, ‘The Crisis of Serial Music’, in ‘The Writings of Iannis Xenakis’, *Perspectives of New Music,* vol 41*,* 1 (2003), pp. 154-166, p. 160.

[40] *Ibid*., p. 160.

[41] *Ibid*., p. 160.

programmed a computer to aid the compositional process leading to a set of compositions with the prefix *ST.*

Essl claims that the 1950s started an algorithmic revolution and that this period ‘has drastically changed not only the way in which art is produced, but also the function and self-creation of its creators’.[42] This revolution could have been spurned by the development of computer technologies, as Collins notes, ‘live computer music is the perfect medium for generative music systems’.[43] History has proven this idea to be true due to the influx of generative music since the advent of computing. The first example of computer generated music is a matter of some contention, programmer and composer Christopher Ariza claims that David Caplin and Dietrich Prinz’s 1955 program written to generate and synthesize the *Musikalisches Würfelspielen* of the eighteenth century was the first computer generated music[44] whereas Essl offers Lejaren A. Hiller and Leonard M. Isaacson’s *Illiac Suite* as the first example.[45] Whichever example is believed to be the first, this paved the way for a lot of computer based generative systems to be created, a direct lineage of which can be found in albums such as Eno’s own *Generative Music 1* to Autechre’s 2001 *Confield.*

The 1950s and 1960s saw an increase of aleatoric techniques with process experimentalists such as Stockhausen, Reich and Cage. Terry Riley’s *In C,* like Cowell’s earlier works has been

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[42] Karlheinz Essl, ‘Algorithmic Composition’, in *The Cambridge Companion to Electronic Music*, ed. by Nick Collins and Julio d’Escrivan Rincon (Cambridge: Cambridge Press, 2009), pp. 107-125, p. 108.

[43] Nick Collins, ‘Generative Music and Laptop Performance’, *Contemporary Music Review*, vol. 22, 4 (2003), pp. 67-79, p. 67.

[44] Christopher Ariza, ‘Music and Technology: Algorithmic and Generative Music Systems’ (unpublished lecture, Massachusetts Institute of Technology, Spring 2010) <http://ocw.mit.edu/courses/music-and-theater-arts/21m-380-music-and-technology-algorithmic-and-generative-music-spring-2010/lecture-notes/MIT21M_380S10_notes.pdf> [last accessed 4 April 2013], p. 4.

[45] Karlheinz Essl, ‘Algorithmic Composition’, in *The Cambridge Companion to Electronic Music*, ed. by Nick Collins and Julio d’Escrivan Rincon (Cambridge: Cambridge Press, 2009), pp. 107-125, p. 112.

claimed to be generative as more of the output was removed from the composer. The piece is notated, but was conceived with an improvisatory spirit that demands careful listening by all involved in the performance. Players are asked to perform each of the 53 phrases in order, but may advance at their own pace, to a set pulse, repeating a phrase or a resting between phrases as they see fit resulting in isorhythms comparable to the motets of de Vitry, de Machaut and Dufay mentioned earlier. Similarly Steve Reich's *It's Gonna Rain,* a piece created using six tape loops of varying lengths that were played to form a complex set of overlap points where combinations of the same ambient textures are rarely heard. Each of these examples would be different every time they are performed, adhering to the aesthetic nature of generative music; Jamie Sexton notes Reich and Riley's work as 'playing key roles within the development of generative music'.[46]

Reich's tape works led Brian Eno to establish the compositional features and principles of ambient music. This subsequently led to Eno creating musical systems that could produce music of infinite length that never repeated rather than linear works that had a fixed structure and time frame. Eno regards *It's Gonna Rain* as a big inspiration for such systems, claiming it was 'probably the most important piece that I heard, in that it gave me an idea I've never ceased being fascinated with – how variety can be generated by very, very simple systems'*.*[47]

At the same time that *Discreet Music* was being created composer Christain Wolff was also exploring with aleatoric techniques in his composition *Burdocks,* a piece written for 'one or

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[46] Jamie Sexton, and K.J. Donnelly (ed), *Music, Sound and Multimedia: From the Live to the Virtual* (Edinburgh: Edinburgh University Press, 2007), p. 97.

[47] Brian Eno, *Generative Music*, talk delivered in San Francisco, June 8, 1996 transcribed at <http://www.inmotionmagazine.com/eno1.html> [last accessed 5 April 2013]

more orchestras, any number of players, any instruments or sound sources'.[48] *Burdocks* lets the performers dictate the sounds made whilst, as Amy C. Beal notes, 'actively engaging with the music'.[49] The 1970s also saw the first film score to utilise aleatoric techniques in John Williams' score for the film *Images.* According to Rayburn and Wright this started the use of chance techniques being used for passages of film scores by such composers as Mark Snow (*X-Files: Fight the Future*) and John Corigliano (*Altered States*).[50]

As Essl claims, the introduction of computer languages such as Max/MSP, Pure Data and Lisp meant icompositional algorithms can now be implemented as generators [exist] which are capable of creating musical structures in real time*'.*[51] These languages and the advances in computer power meant that computer music was no longer confined to the domain of MIDI, as Essl notes, 'as computers became faster and faster, it was possible to generate audio in realtime directly in the computer'*.*[52]

The advances in computing also meant that music for computer games could utilise more powerful audio requirements. Edo Paulus claims 'computer games have always been the most technologically innovative branch in the interactive computer media in respect to interactive music'*,* [53]and the 1980s saw the first example of generative music as a concept

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[48] Christian Wolff, *Burdocks,* (C.F.Peters Corp.,1972), p. 1.

[49] Amy C. Beal, 'Christian Wolff in Darmstadt, 1972 and 1974', in *Changing the System: the Music of Christian Wolff,* ed. by Thomas, Phillip, and Stephen Timothy Chase (Surrey: Ashgate Publishing, 2010), pp. 23-47, p. 27.

[50] Fred Karlin, and Rayburn Wright, *On the Track: a Guide to Contemporary Film Scoring, second edition* (London: Routledge, 2004), p. 436.

[51] Karlheinz Essl, 'Algorithmic Composition', in *The Cambridge Companion to Electronic Music*, ed. by Nick Collins and Julio d'Escrivan Rincon (Cambridge: Cambridge Press, 2009), pp. 107-125, p. 118

[52] Karlheinz Essl, *Generative Music: Answers to a Questionnaire by Håkon Normann* <http://www.essl.at/bibliogr/generative-music.html> [last accessed 6 April 2013]

[53] Edo Paulus, 'The use of Generative Music Systems for Interactive Media' (unpublished masters thesis, School of Art, Utrecht, 2001), p. 4.

starting to be used in many video games. The first use was in Tengen's *RBI Baseball* for the Nintendo Entertainment System, where having a runner on base changed the music. The use of such techniques is still being used to 'enhance the game player's gaming experience',[54] with a notable case being Peter Chilvers' generative score for the decade-long game franchise *Creatures.*

Chilvers has also been instrumental in the popularity of generative mobile phone apps, having aided Eno's ideas, by creating together with him iPhone and iPod Touch applications, blurring the distinction between game and instrument. Their latest offering, *Scape*, described on the App Store as an app that 'makes music that thinks for itself'*,* the app comes with 10 pieces precomposed by Eno and Chilvers, questioning Brown's definition of pure generative music.

The distinction that Brown suggests between fixed and pure generative music has also been blurred recently with advances such as London music duo Icarus' *Fake Fish Distribution*, a self-described 'album in 1000 variations',[55] where the downloaded album generates a one-of-a-kind album for each purchaser, and MadPlayer, a generative personal music player that gives the user 'the ability to easily create, play, interact with, listen to, modify and transport professional-sounding music in a digital format'.[56]

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[54] Paul Brown, 'Is the Future of Music Generative?', *Music Therapy Today*, vol. 6, 2 (2005), pp. 215-274, p. 256.

[55] *Fake Fish Distribution* <http://www.icarus.nu/FFD/> [last accessed 5 April 2013]

[56] MadPlayer <http://www.studiofifield.com/madplayer-madwaves.php> [last accessed 5 April 2013]

The internet has also proven to be fertile ground for generative music; in 1997 Andrew Garton created an internet based installation lasting for six weeks that was said to have been ‘an ever-changing generative sound space that combined the medium of radio and that of the Internet into an exploration of non-repetitive creative possibilities’.[57]Garton’s follow up internet installation *Tat Fat Size Temple* lasted for nine days and was so popular it was released internationally by ORF/KunstRadio as a CD and Booklet. Essl has also had numerous web-based generative installations too, his *Lexicon-Sonate* was realised as an interactive version for the internet with Florian Cramer creating ‘infinite realtime composition for computer-controlled piano’.[58] The internet has also been an inspiration to artists Mark Hansen and Ben Rubin, their *Listening Post* on display at London’s Science Museum is said to be a ‘dynamic portrait of online communication’.[59]

With the advances of computer technology and generative techniques being used in such wide ranging multimedia as film scores, computer games and mobile phone apps, the popularity of the genre has led Eno to expand upon the idea of fixed and pure generative music by suggesting:

> From now on there are three alternatives: live music, recorded music and generative music. Generative music enjoys some of the benefits of both its ancestors. Like live music, it is always different. Like recorded music, it is free of time-and-place limitations - you can hear it when you want and where you want.[60]

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[57] *Sensorium Connect* <http://www.abc.net.au/arts/lroom/sensorium/> [last accessed 5 April 2013]

[58] Karlheinz Essl, Lexicon-Sonate Online <http://www.essl.at/works/lexson-online.html> [last accessed 5 April 2013]

[59] *ListeningPost*,<http://www.sciencemuseum.org.uk/visitmuseum/galleries/~/link.aspx?_id=822C31BCD5734CDE94E701ED170F4909&_z=z> [last accessed 6 April 2013]

[60] Brian Eno, *A Year With Swollen Appendices: the Diary of Brian Eno* (London: Faber and Faber, 1996), p. 69.

My Compositions

For a number of years I have been interested in generative systems used to compose music, the idea of creating a set of rules and watching them transform into a body of music is inspiring. The nature of generative music means it is possible to create a piece of music that could be just as surprising to the composer as the listener, or to quote Brian Eno:

> Now the wonderful thing about [generative music] is that it starts to create music that you've never heard before. This is an important point I think. If you move away from the idea of the composer as someone who creates a complete image and then steps back from it, there's a different way of composing. It's putting in motion something and letting it make the thing for you.[61]

My interest has led me to create my own generative compositions such as *Generative Piece in A Flat Minor, No. 5*[62] and has inspired me to develop an entirely generative sound engine in an internet based game I've been creating.[63] In this section I will be introducing my systems based on each of the four categories theorised by Wooller et al.

An important aspect of generative music, as Brown notes, is 'when a generative music process or system is reset whilst the overall characteristics of the music are similar to the

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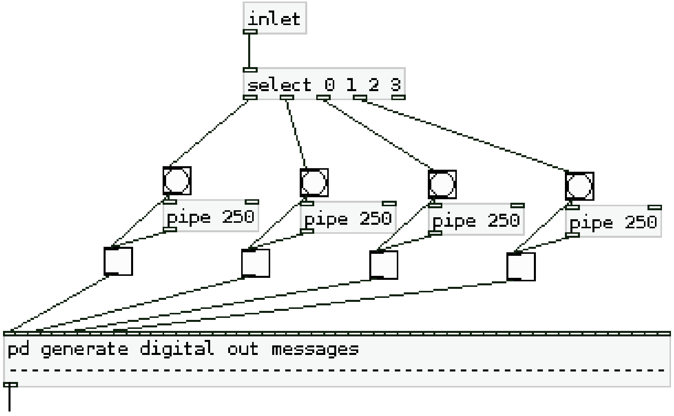
[61] Brian Eno, *Generative Music*, talk delivered in San Francisco, June 8, 1996 transcribed at <http://www.inmotionmagazine.com/eno1.html> [last accessed 5 April 2013]

[62] Toby Butchart, *Generative Piece in A Minor, No. 5*<http://www.youtube.com/watch?v=hbRI8c_1Uwl> [last accessed 12 April 2013]

[63] Toby Butchart, *The Fight for Castle Quilldore* <www.castle-quilldore.co.uk> [last accessed 12 April 2013]

previous piece of music produced by the system or process the actual music itself is different'.[64] In keeping with this generative aesthetic I wanted each composition to have its own unique characteristics so that when reset it would achieve similar musical qualities.

Each composition is of a finite length and is triggered after a 10,000 millisecond delay; both of these rules were set so that each performance would have an unobstructed beginning and a definite end. Each patch also communicates with the Arduino Mega 2560 in the same way, using a patch created by myself using the object [arduino]. When the patch receives a number it will create two on-messages, one triggered 250 milliseconds after the other, this information is used to activate and de-activate the magnet in each solenoid, and in turn strike a piano key. Figure 1.1 below demonstrates a scaled down version of this patch, for the full version see the patch arduinomega-all-outs.pd on the accompanying CD.



1.1 – How Pure Data communicates with the Aduino board

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[64] Paul Brown, 'Is the Future of Music Generative?', *Music Therapy Today*, vol. 6, 2 (2005), pp. 215-274, p. 219.

Creative/Procedural (see appendix 1 or patch1.pd on the accompanying CD)

As a definition of procedural music Andy Farnell offers this: ‘procedural audio is non-linear, created in real time according to a set of programmatic rules’.[65] For my piece exploring the idea of creative/procedural generative music I decided to utilise first-order Markov chains as this would mean the composition adheres to the criteria and follows a set of programmatic rules.

Invented by Russian mathematician Andrei Andreevich Markov, Markov chains, in a musical context, can work by analysing the chance of any given pitch going directly to any other pitch. The first computer program that used Markov chains to compose was developed in 1957 by Hiller and Isaacson, composing the piece *Illiac Suite.*

Whilst researching Markov chains I discovered a piece of software written by David Cope called *Experiments in Musical Intelligence,* or *EMI. EMI* has been used to autonomously compose music that evokes styles of classical composers and has been used, according to *The New Grove Dictionary of Music and Musicians* to ‘record commercially available music ranging from short pieces to full length operas’.[66]

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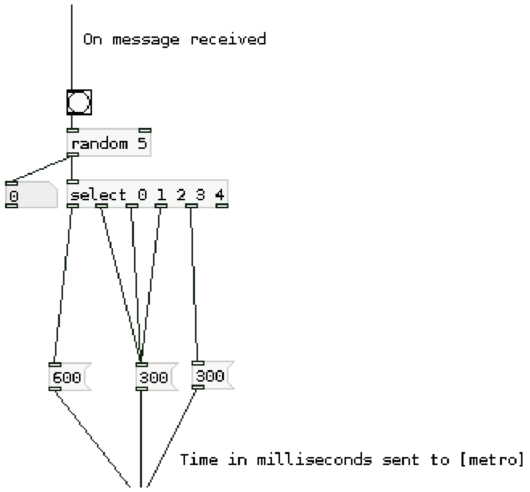
[65] Andy Farnnell,‘An Introduction to procedural audio and its application in computer games’ (unpublished paper, 2007) <http://obiwannabe.co.uk/html/papers/proc-audio/> [last accessed 4 April 2013]

[66] Dale Cockrell, *The New Grove Dictionary of Music and Musicians, second edition*, ed. by Stanley Sadie and John Tyrrell (London: Macmillan Publishers, 2001), p. 453.

Inspired by Cope's software I decided to create a composition that, using Markov chains, would compose music similar to that of Bach. At the time of creating this system, due to an initial design error (please refer to thegenerativepiano.tumblr.com), I thought my autonomous machine would be limited to the white notes on a piano, because of this I knew my piece would have to be centred around the key of C Major (or its relative minor or any related mode). Because of this the Bach piece I analysed for the data to create my Markov chain was Bach's *Fugue in D Major* knowing I could just transpose the collective data down by a whole-tone. My first step was to extract the data from the composition. I entered each note used in the piece of music into an x and y column in a spreadsheet and recorded each time a note moved from one set position to another, I then used this information to work out the probability of each note's movement within the composition (for the complete spreadsheet see appendix 2).

The probability of each note's movement range in value from 0 (which indicates that the corresponding event will never occur) to 1 (which indicates that the event will occur with absolute certainty) so, for example, a value of 0.25 would equate to a 25% chance of occurrence. From the data I can say that within Bach's *Fugue in D Major*, the likelihood of the movement of the melody from note G5 to the F#5 is 60% and from G5 to both the A5 and B5 it is 20%. Once I had collected the data I split the information into two parts, one for the bass melody and one for the upper melody, I did this by studying the score to see which of the 32 notes used were the highest and lowest for each voice. With the data turned into two probability lookup tables I then started work on the Pure Data patch to turn this information into music. Using the Pure Data library *Cyclone* I loaded my two probability tables into the [prob] object. Each note was numbered chronologically i.e. the note D2 became 0, E2 became 1, etc. This resulted in two distinct melody lines that could be assigned to any given frequencies (for the complete data see appendices 3 and 4) these numbers were then assigned their corresponding midi note value as I prototyped each patch with the internal general midi sound module.

I used another Markov chain for the rhythm of the composition, but used a different technique; I created a second spreadsheet to collate the data from the amount of times each note is played in relation to the duration of each note, I worked out the probability of each notes rhythmic value (see appendix 5). To make this data function as a Markov chain within Pure Data I created a set of [random] objects for each note, the value of which corresponded to the lowest division of the probability data, for example the note G2 appears five times in *Fugue in D Major,* once as a quaver, three times as a semi-quaver and once as a dotted quaver, so the chance of a G2 being a semi-quaver is three in five. The [random] object would pick from 5 values every time the corresponding note-on message is received, feeding the note length in milliseconds to a [metro] object. So with three out of the five outlets from the [random] object being assigned to the [300(message, the note has a three in five chance of being held for 300 milliseconds, which in this instance is the length of a semi-quaver (please see picture 2.1 below).



2.1 – Determining the possibility of a note’s rhythmic value

This process will function as a Markov chain as it achieves the desired goal of producing, as Alpine, Miranda and Hoggar suggest, ‘output note values based on the transition matrix weightings, which could be MIDI note values, frequency, or any other desirable metric’.[67]

The length of the performance will always be the same and this was set to the same amount of bars as Bach’s composition, similarly the dynamics are always static as the original was composed for an organ and according to Joseph P. Swain the organs available at the time of composing would have featured a simple on/off system meaning no dynamic control.[68]

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[67] Kenneth McAlpine, Eduardo Miranda, and Stuart Hoggar ‘Making Music with Algorithms: A Case-Study System’, *Computer Music Journal*, vol. 23, 2 (1999), pp. 19-30, p. 21.
[68] Joseph P. Swain, *The A to Z of Sacred Music* (Maryland: Scarecrow Press, 2010), p. 172.

Biological/Emergent (see appendix 6 or patch2.pd on the accompanying CD)

Composers have been influenced and inspired by nature for centuries, from Vivaldi's *The Four Seasons*, with nature inspiring the macrostructure of a set of four violin concertos, Debussy's *La Mer*, with movements titled evocatively, such as *Dialogue of the Wind and the Sea* to pieces based on more abstract natural phenomena such as Xenakis' *Pithoprakta*, a piece based on the statistical mechanics of gases. The inspirational traits of nature led to Debussy asking:

> Who can know the secret of musical composition? The sound of the sea, the outline of a horizon, the wind in the leaves, the cry of a bird - these set off complex impressions in us. And suddenly, without consent of anyone on this earth, one of these memories bursts forth, expressing itself in the language of music.[69]

These Proustian qualities can be seen in the field of generative music too, in 1961 Iannis Xenakis theorized that some of the key principles of stochastic music can be found in nature, offering such examples as 'the collision of hail or rain with hard surfaces, or the song of cicadas in a summer field',[70] with this in mind I decided to base my piece exploring biological/emergent themes on a wealth of musical elements found in nature; the birdsong.

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[69] Simon Trezise, *Debussy: La Mer* (Cambridge: Cambridge University Press, 1994), p. 2.
[70] Iannis Xenakis, *Formalized Music: Thought and Mathematics in Composition Pendragon Edition* (Maesteg: Pendragon Press, 1992), p. 9.

I wanted to explore how individual bird-calls could layer not only musically but also rhythmically by looping calls of different lengths, producing a complex set of overlapping points where combinations of the same textures would rarely be heard, reminiscent of Eno's tape looping experiments on *Discreet Music*. I also wanted to recreate motifs found in a bird's song on the piano, with the original calls on top.

To achieve this I acquired eight samples of English found species of bird and put each into a processing chain using a fast Fourier algorithm for pitch detection so each bird-call could be replicated on a piano. Using the [fiddle~] object for this, I needed a way to reduce the data stream so I used the attack from each sample to determine when the pitch data should be read. The collective samples had a range of just over two octaves of which I transposed by two octaves so the resulting sounds would fit comfortably on a piano, so unlike the creative/procedural patch the range used for this composition is chromatic. With the samples looping and the pitches being mirrored via midi data I had the basis for my patch, I just needed to add movement and structure.

I decided to let the emergence of each sample be dictated by the migratory pattern for each specific bird and with the data taken from the RSPB[71] I introduced a system which uses the individual migratory pattern to automate each sample's volume. I did this by letting Pure Data choose an integer at random from between 0 and 30000 to dictate in milliseconds the length of the cycle for each sample, this figure was then divided by 12 so I had the length of a month relative to each cycle and a counter was created to count through the months in the timescale suggested by the initial integer. The month each bird migrated in to Britain

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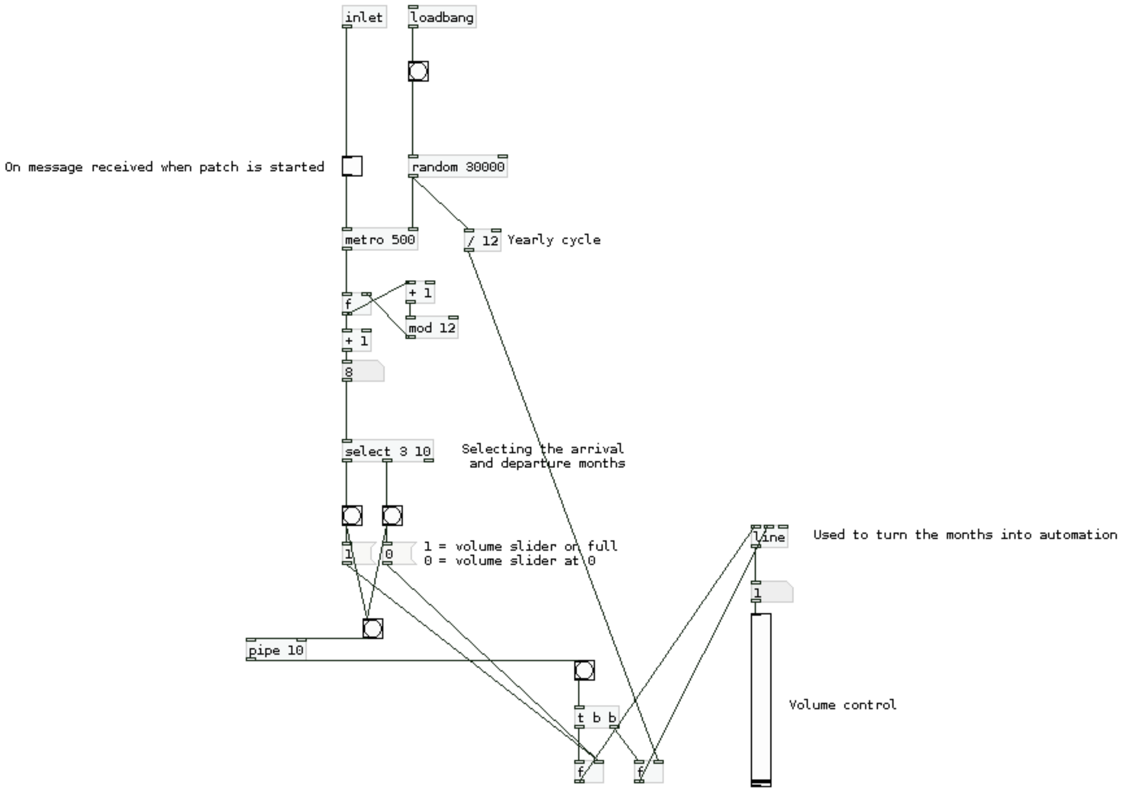
[71] RSPB *Bird Migrations* <http://www.rspb.org.uk/wildlife/birdguide/name/> [last accessed 28 March 2013]

would trigger a [1(message and the month each bird migrated out would trigger a [0(, these messages were fed into a volume slider using the [line] object to turn the values into a ramp. For example, the Sand Martin arrives in Britain in March and departs in October so the messages would trigger when the counter reached 3 and 10 respectively (see figure 3.1 below).

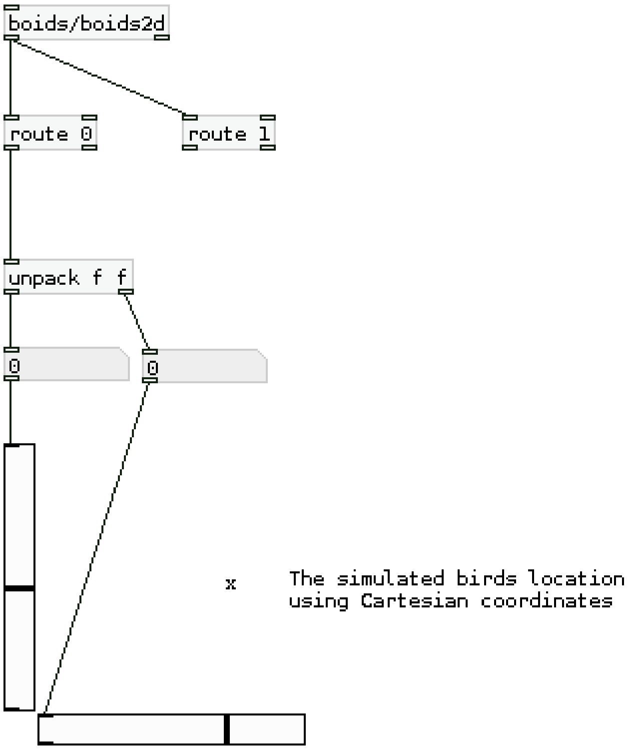


3.1 – Turning migratory patterns into volume automation

To determine when each melody was played on the piano I again looked to the movement of birds to dictate this. Inspired by Kathy Hinde's installations *Piano Migrations* and *Bird Step-Sequencer,* in which Hinde uses the movement of birds to trigger real-time events, I used Craig Reynolds' Pure Data library boids to trigger a gate in the note-on data flow.

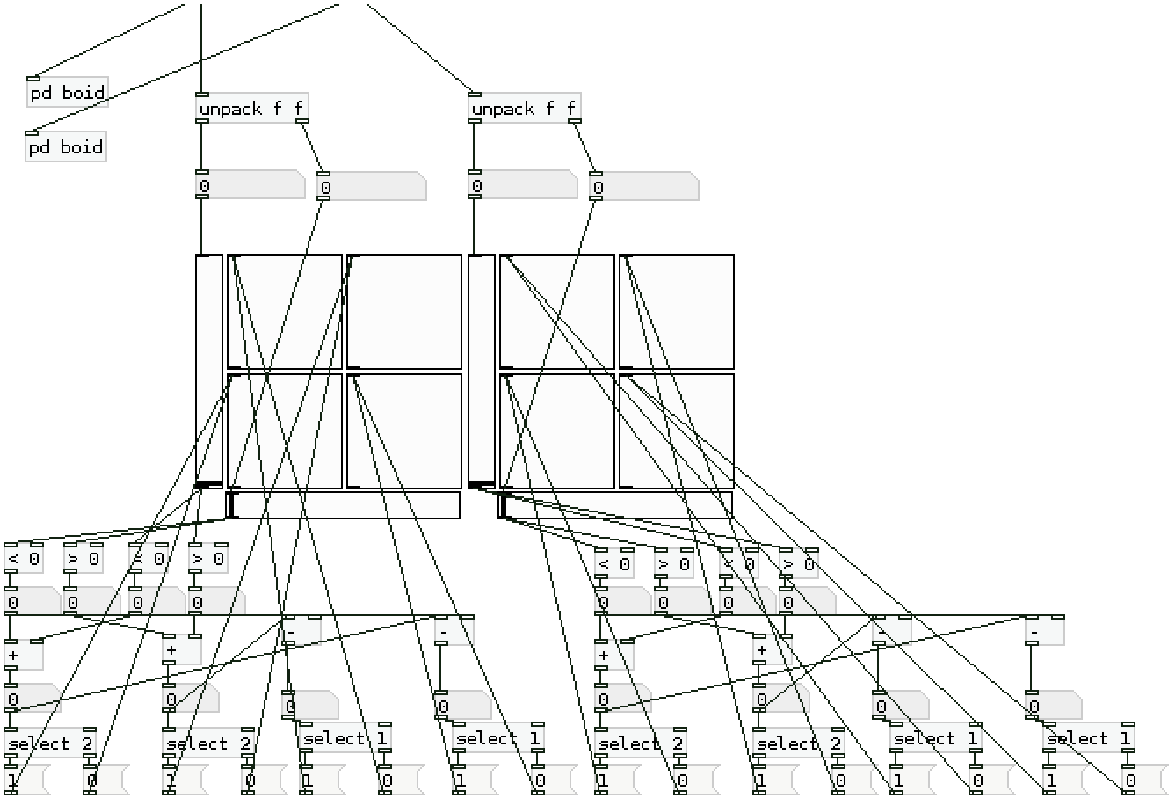
Boids is a Pure Data replica of a piece of computer software developed by Reynolds in 1986. The software is a computer model of coordinated animal motion, simulating flocking behaviour using artificial intelligence. I initially created a simulated bird to control each gate but soon realised that to be impractical due to the grouping nature of the simulated flock.

As the output of the simulation is a video rendering of the flocking I had to find a way to turn this simulation into data. The coordinates of each simulated bird are given as an x and y value and using these values to control a horizontal and vertical slider respectively meant that I could map the path taken without the need for Pure Data’s visual environment GEM (see figure 3.2 below).



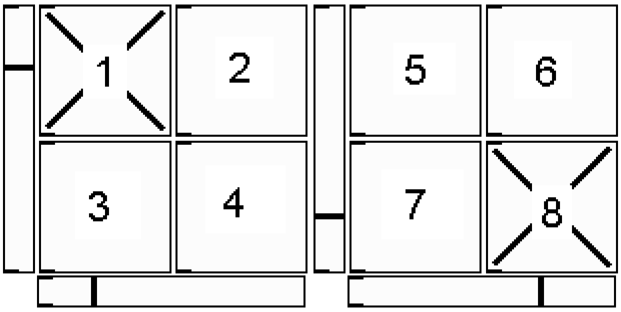
3.2 – Using sliders to define Cartesian coordinates

As the flight of each bird was represented by its Cartesian coordinates I created a grid from the imaginary plain and split it into quarters. The coordinates were then filtered through a set of greater than or smaller than equations so that the position of the bird was defined by its space in each of the four quarters (see figure 3.3 below).



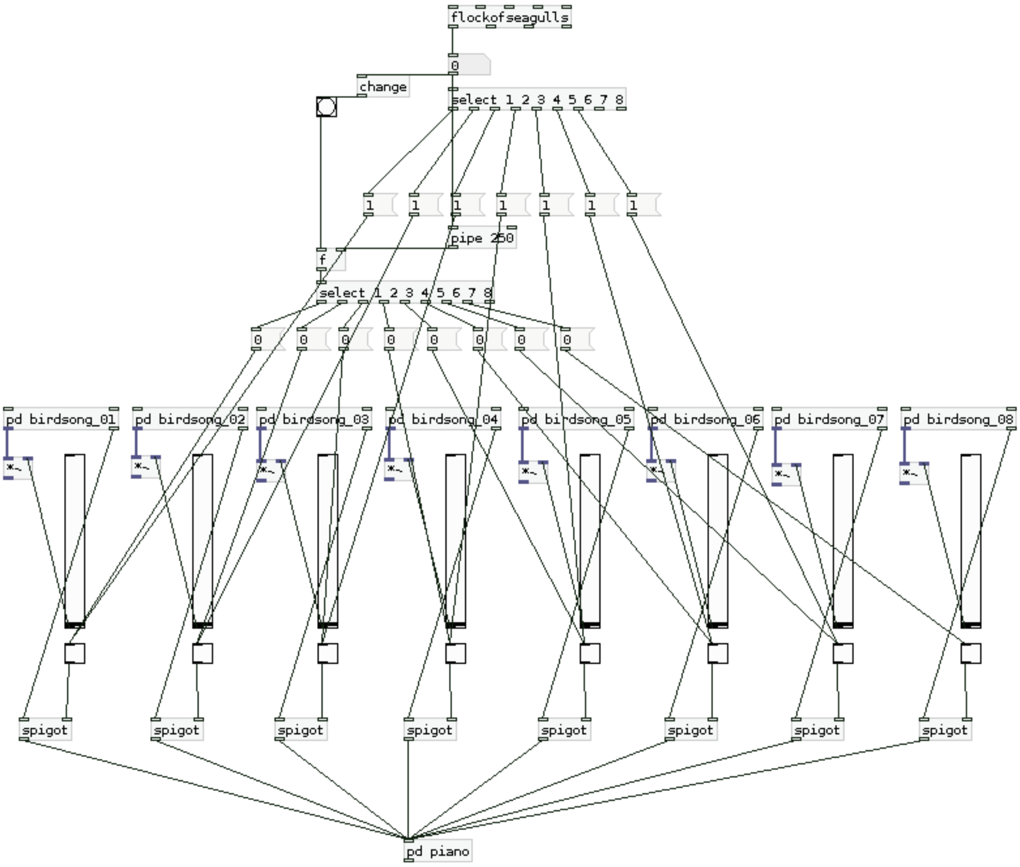
3.3 – Broadening location into quarters

The system I ended up devising had a simulation of two birds in the same imaginary plain. Each bird would trigger an integer depending on which quarter it was in (see figure 3.4 below), then a second simulation would determine which of the two bird’s paths to choose.



3.4 – Using location to determine events

The resulting integer would be used to trigger a gate for its relative melody, turning it off when the number changed (see figure 3.5 below).



3.5 – Using a bird's flight-path to trigger gates

This system is repeated four times so the highest possible outcome is four of the bird's melodies layered on top of each other and the lowest possible outcome is none (for the complete sub-patch see appendix 7 or flockofseagulls.pd on the accompanying CD).

I wanted to keep the dynamics of each phrase the same as the original bird-calls so I added a system to the patch aruino-mega-all-outs.pd that would change the pressure used by the solenoids in the performance. Using Thomas Grill's *Max Library* I scaled the amplitude to a relative figure between the values of 0 and 250, these values were used, as milliseconds, within the patch as the time it takes for the solenoid magnet to reset after being activated. The longer the solenoid's magnet is active, the harder it will strike the piano key. With the dynamics, the field recordings and the chromatic nature of this composition it gives the piece its own unique feel.

Linguistic/Structural (see appendix 8 or patch3.pd on the accompanying CD)

In his 1991 book *Computers and musical style*, David Cope explains that linguistically structured music is 'music composed from analytic theories that are so explicit as to be able to generate structurally coherent material',[72] this description could apply to most diatonic music as Salas, Gelbukh and Calvo note: 'music as a language [is] composed of sequences of symbols that form melodies, with lexical symbols being sounds and silences with their duration in time'.[73]

This idea fits into the realm of generative music by introducing a system based on the generative grammar of language by Noam Chomsky. In his book *Syntactic Grammars* Chomsky suggests that humans are able to speak and understand a language mostly because we have the ability to master its grammar. In their 1983 book *A Generative Theory of Tonal Music,* Lerdhal and Jackendoff noted Chomsky's theories could be similarly applied to music.[74] This idea is mirrored by Richard Middleton, who notes, 'Schenkerian analysis of music corresponds to the Chomskyan notion of generative grammar, applying to a two-level generative structure for melody and harmony',[75] because of this I decided to have this composition as a two layered piece with two separate sources for each layer.

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[72] David Cope, *Computers and Musical Style* (Wisconsin: A-R Editions, 1991), p. 72.

[73] Horacio Salas, Alexander Gelbukh, and Hiram Calvo, 'Music Composition Based on Linguistic Approach', *9th Mexican International Conference on Artificial Intelligence* (2010), pp. 117-128, p. 120.

[74] Fred Lerdahl, and Ray Jackendoff, *A Generative Theory of Tonal Music* (Massachusetts: MIT Press, 1996).

[75] Richard Middleton, *Studying Popular Music* (Maidenhead: Open University Press, 1990), p. 146.

For my linguistic/structural composition, I decided that nothing conveys the generative grammar of language better than language itself, for this reason the only material I used for this composition was recorded conversations. I wanted the material used to be flowing conversations and not scripted dialogue so I used the audio from radio panel shows or live discussions for the input.

Inspired by a lecture given by Dr Sebastian Lexer in November 2012, I also wanted to explore the possibilities of using medium other than audio buffers for data storage.[76] I used this idea as the starting block for my composition and looked into using JPEGs as audio buffers. With thanks to Antonio Roberts for working out what data is needed to create a basic header and footer for a JPEG, I developed a Pure Data patch that would take an audio stream and create two JPEGs from the data; one from the amplitude and one from the pitch (for the patch see appendix 9 or speechtopiccy.pd on the accompanying CD). One of the audio streams I chose for the instance of my composition recorded on the accompanying CD is taken from a heated discussion from *Woman's Hour* recorded on the 4th March 2013, the stream is then split via the [peakamp~] and Katja's fast Fourier transformation based [helmholtz~] to receive the amplitude and pitch data respectively (unlike the [fiddle~] object, [helmholtz~] produces the pitch data in Hertz rather than midi numbers). The data had to be scaled on both counts as the information given to write the JPEG is written as RGB values of between 0 and 255, this is a simple operation for the amplitude as the [peakamp~] delivers an output of 0 to 1, however, it was a little more complex to scale the pitch data as the [helmholtz~] object was reading frequencies above that of speech. Milan Sigmund suggests that the range of fundamental frequencies of a human voice is between 50Hz and

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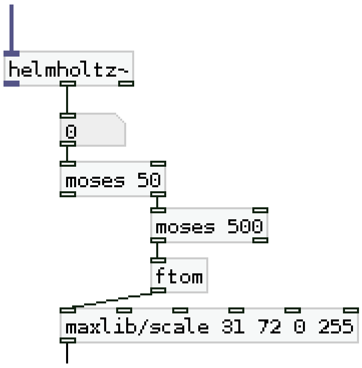
[76] Lexer, Dr Sebastian, 'alternative data storage' (unpublished lecture, University of East Anglia, Norwich, 15 October 2012).

500Hz,[77] with this in mind I could filter the data to remove any frequencies that may not be the fundamental frequencies of speech (such as breath noise), convert the data to a logarithmic scale (using the object [ftom]) and then scale the resulting numbers to between 0 and 255 (see figure 4.1 below).



4.1 – Turning the fundamental frequency of speech into colour values

After each stream of data was put through a chain so a header preceded it and footer followed, it was sent to Mr Peach's [binfile], which converts the numbers into their binary values, this produces a JPEG, storing the data as an image (see figure 4.2 below).

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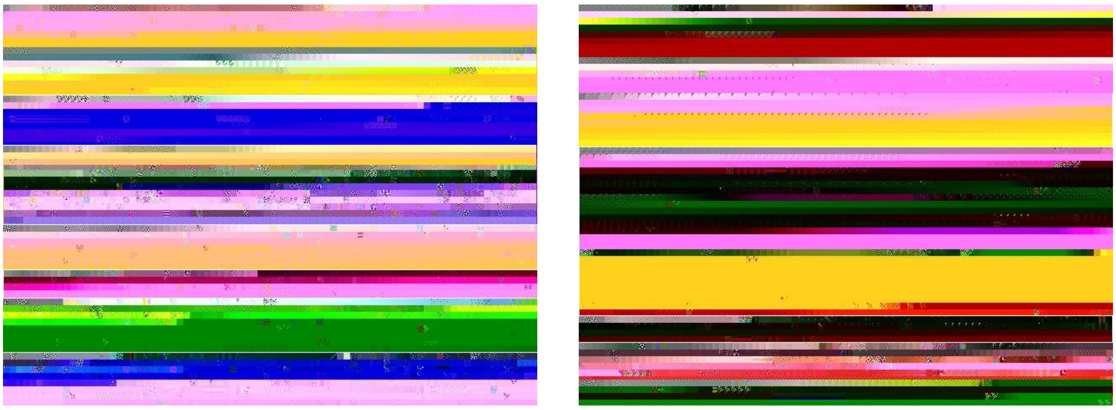
[77] Milan Sigmund, *Voice Recognition by Computer* (Kubitza, Heinz-Werner, Dr Tectum Verlag, 2003), p. 34.



Amplitude

Pitch

4.2 – Numerical data stored as a JPEG

The images were then combined so the resulting JPEG could be read as one continuous stream of data (see appendix 10).

To convert the final JPEG into music I used the [pix_image] object to load the JPEG and the [pix_data] object to read the image as its RGB values. I created a chain where the values were read from left to right, top to bottom using a metronome to count through the image. As the data was collected in groups of three (a value for the red green and blue data respectively), I decided to use these as a chord progressions for the underlying harmony. After scaling the values to fit within two and a half octaves (the range of my autonomous machine) the resulting chords were reminiscent of a twelve-tone composition. This worked well but the result was very metronomic, to resolve this I used the average sum of the RGB figures to add subtle timing discrepancies to the metronome because, according to research carried out by Alison Mattek it is possible to portray emotion in a generative system by adding timing deviations.[78]

Sloboda also notes that ‘the tonal system, as such, offers analogies for the way in which people represent emotions in some semantic space’,[79] because of this I wanted to explore the possibility of melody lines generated from speech patterns. The melody of the piece is realised in real-time based on a source decided by the performer, for the recording on the accompanying CD the material used is episode 3 from series 65 of *Just a Minute.* The audio stream is analysed using a fast Fourier algorithm to generate a pitched representation of the audio. The process used is identical to the previous patch, using the attack to generate the snapshot of data, turning the spoken dialogue into pitch. On top of the melody I decided to superimpose audio samples of the twenty most common verbs, nouns and adjectives (data from englishgenie.com), one sample is chosen at random each time a note is triggered, most of the time the stream is nonsensical but occasionally you can pick out a formed sentence.

Now I had a melody and harmony, this allowed me to examine the macrostructure of the piece. The harmony plays consistently throughout but the melody appears as three different instances; one as the melody of the incoming audio fitting the rhythm of the dialogue, one as the samples of words triggered by the dialogue and one as the pitch of the audio stream but with the rhythm of the harmony, essentially adding a fourth note to each chord. These varieties are triggered when various pitches are hit by the incoming audio. The frequency of these pitches is chosen at random when the patch is loaded.

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[78] Alison Mattek, ‘Computational Methods for Portraying Emotion in Generative Music Composition’ (unpublished undergraduate thesis, University of Miami, 2010), p. 3.
[79] John A. Sloboda, *Generative Processes in Music* (Oxford: Oxford University Press, 2005), p. 62.

Interactive/Behavioural (see appendix 11 or patch4.pd on the accompanying CD)

As a category of generative music, interactive music is defined by Robert Rowe as 'music generated by a system component that ostensibly has no inputs'.[80] These closed systems as described by Rowe could be as diverse as György Ligeti's *Poeme Symphonique* in which a hundred metronomes are set to different tempos and switched on creating a blanket of ticking, to Steve Reich's *Pendulum Music* using suspended microphones swinging over speakers, creating phasing feedback tones. Both pieces could be seen as generative as each time they are performed they would yield different results, as Rich notes: 'the compositional process is found in the decisions about how the system will operate and the rules inside the system'.[81] In this definition we can see the distinction between interactive generative music and process music can become blurred as one of the main principles of indeterminate music is the process, or the manner in which the elements of a composition are created.

Coined by composer Steve Reich in his 1968 paper titled *Music as a Gradual Process*, process music is defined as '[not] the process of composition but rather pieces of music that are, literally, processes. The distinctive thing about musical processes is that they determine all the note-to-note details and the overall form simultaneously'.[82] In his manifesto Reich

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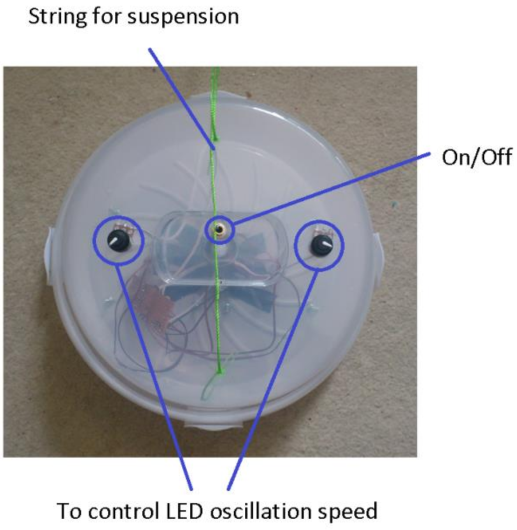
[80] Robert Rowe, 'Machine Learning and Composing: Making Sense of Music with Cooperating Real-Time Agents' (Massachusetts: MIT Press, 1991), p. 6.

[81] Owain Rich, *The Evolution of the Score and Generative Music: To What Extent Can Computer Code Ever Be Considered a Musical Language?* (Cambridge: Cambridge Press, 2003), p. 2.

[82] Steve Reich, 'Music as a Gradual process' <http://ccnmtl.columbia.edu/draft/ben/ feld /mod1/readings/reich.html> [last accessed 5 April 2013]

notes about his own systems that ‘what I'm interested in is a compositional process and a sounding music that are one and the same thing’.[83]

Whilst designing a closed system to produce my interactive/behavioural composition I was instantly inspired by Steve Reich’s *Pendulum Music*. I wanted to replicate the results of turning a pendulum’s motion into sound but I wanted the path taken and speed of the motion to be realised as pitch too. Because of this the system in which my composition is created comprises of a pendulum with two sets of flashing LEDs and a unit with two distance sensors and four photoresistors to capture the movements and light (see figures 5.1 – 5.3 below).



5.1 - The pendulum (top)

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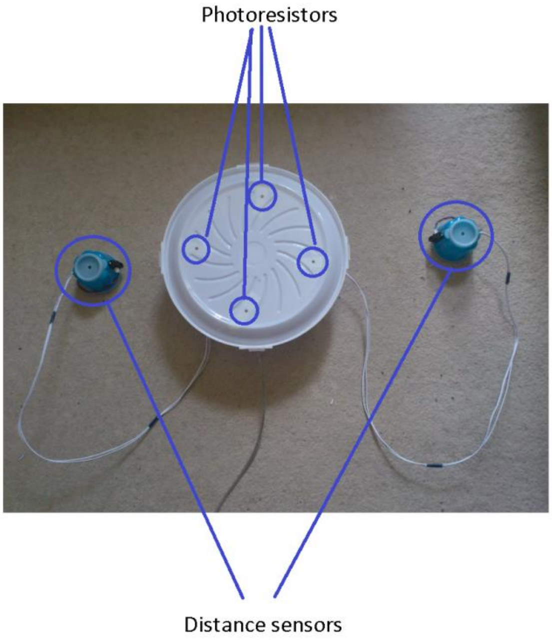
[83] Steve Reich, ‘Music as a Gradual process’ <http://ccnmtl.columbia.edu/draft/ben/ feld /mod1/readings/reich.html> [last accessed 5 April 2013]

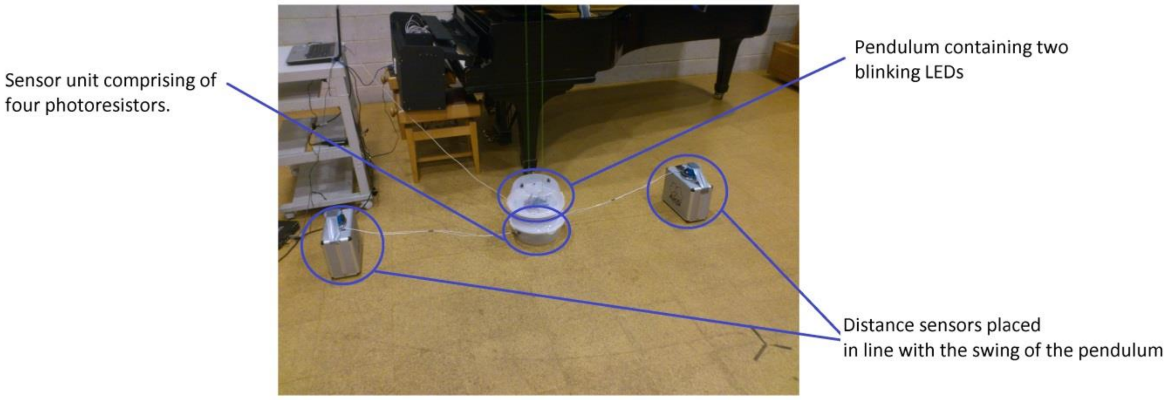
5.2 - The pendulum (bottom)



5.3 – The sensor unit

To create the pendulum I made a simple circuit with a 74C14 Hex Schmitt Trigger IC chip, using two of the outputs as low frequency square wave oscillator controlling LEDs, housed in a round tub that I could suspend from a ceiling to a swing back and forth.

When attached to a higher surface, the motion of my pendulum is picked up by two distance sensors in line with the motion of the pendulum and the flashing LEDs are picked up by four photoresistors on the top of the sensor unit (see figure 5.4 below). When performed the pendulum is held in line with one of the sensors, gently spun to coil the string, and then let go.

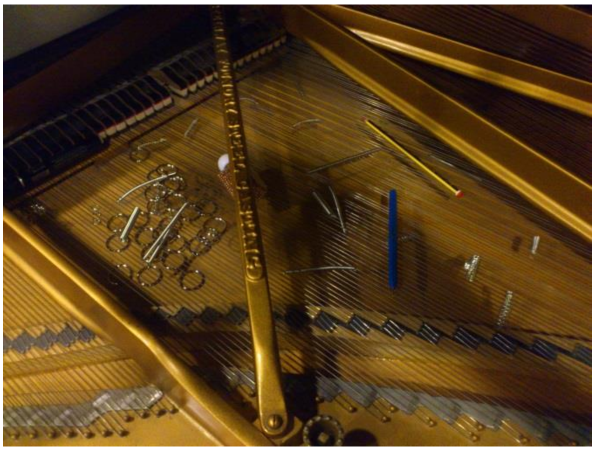

Sensor unit comprising of four photoresistors.

Pendulum containing two blinking LEDs

Distance sensors placed in line with the swing of the pendulum

5.4 – The pendulum's swing being picked up by six sensors

The flashing LEDs were purposefully unsynchronised so that the opposing patterns caused, the gradual speeding up of the pendulum and the spinning of the pendulum could all be translated into rhythms. Because I wanted to exploit these polyrhythms in my composition I turned to the method of preparing the piano to change the timbre of the instrument, giving it a more percussive quality, or as Cage notes, a prepared piano can 'place in the hands of a single pianist the equivalent of an entire percussion orchestra'.[84] I prepared the piano for the performance on the accompanying CD with magnets, ball bearings, key rings, springs and pens until each note had its own unique characteristic (see figure 5.5 below).



5.5 – Prepared piano

With my system defined I had to create an environment that could turn the system into sound, I achieved this by using a second Arduino board so Pure Data could communicate with the sensors. The LEDs were used to trigger piano hits relevant to the motion of the pendulum. I realised fairly early on that a critical flaw in my design was that by the nature of its positioning, every time an LED triggered a note the pendulum would be in the same position. This was because the pendulum and LED circuits were one and the same thing. To combat this I read the data from each distance sensor into an array to create an analog of the described motion. This then meant that every time the photoresistor read a flashing LED it could call data from the array relative to the speed of the pendulum.

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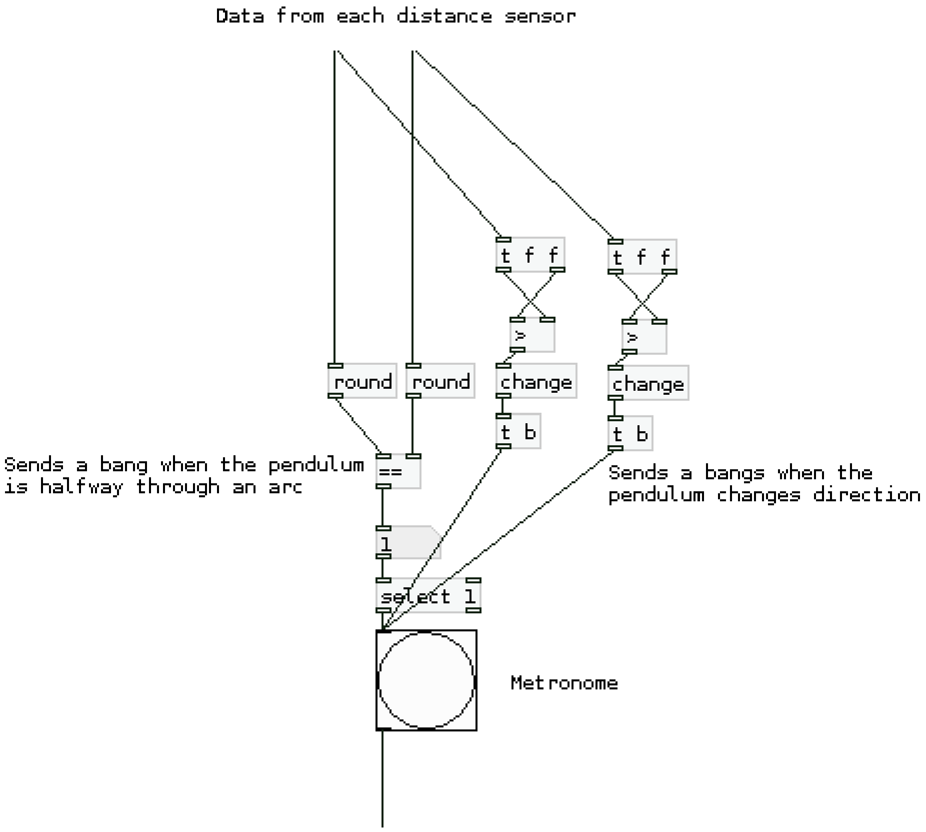
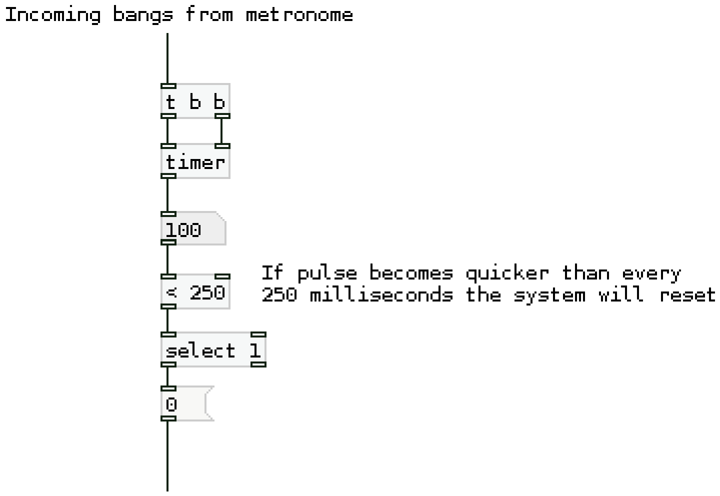
[84] John Cage, and Daniel Charles, *For the Birds: John Cage in Conversation with Daniel Charles* (London: Marion Boyars, 1980), p. 38.

To calculate the speed of the pendulum I created a chain that receives the data from each distance sensor and sends a [bang(message when the data changes its movement. This is done by comparing the data received to the previous figure and using the [change] and [>] objects so the chain can work out which direction the set of figures is moving and in doing so which direction the pendulum is moving . A [bang(message is also received when the pendulum is equidistant from each sensor, i.e. in the middle of its path. With these three messages combined a steady pulse describing the motion of the pendulum is achieved (see figure 5.6 below).



5.6 – Tap tempo detector finding the speed of the pendulum

The length of the piece is determined by the pendulum, when the pendulum has stopped moving the system will reset. This is achieved by a tap tempo counter I created that stops communication with the Arduino If the patch’s metronome reaches higher than four pulses per second (see figure 5.7 below).



5.7 – The system is reset when the pendulum stops moving

The aspect of the patch resetting itself completely closes the system meaning it is fully functioning as a linear piece obeying Reich’s aesthetic that process music should ‘determine all the note-to-note details and the overall form simultaneously. One can't improvise in a musical process, the concepts are mutually exclusive’.[85]

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[85] Steve Reich, ‘Music as a Gradual process’ <http://ccnmtl.columbia.edu/draft/ben/ feld /mod1/readings/reich.html> [last accessed 5 April 2013]

Conclusion

This research project set out to explore generative techniques in composition; we have discussed that a generative system could be as simple as an Aeolian harp vibrating with the wind or as complex as a piece of software that can analyse works of the great composers and produce music that recreates their styles. We have seen that the techniques used within generative composition can be varied and resourceful and can be traced back at least two thousand years. We have also discovered that the future adaptions of generative music seem optimistic, with generative media players, mobile phone apps and computer game soundtracks; this has led Paul Brown to suggest a new music-business model to accommodate generative music and its production,[86] and has led Brian Eno to suggest a third category for future music mediums:

> From now on there are three alternatives: live music, recorded music and generative music. Generative music enjoys some of the benefits of both its ancestors. Like live music, it is always different. Like recorded music, it is free of time-and-place limitations - you can hear it when you want and where you want.[87]

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[86] Paul Brown, 'Is the Future of Music Generative?', *Music Therapy Today*, vol. 6, 2 (2005), pp. 215-274, p. 272.

[87] Brian Eno, *Generative Music*, talk delivered in San Francisco, June 8, 1996 transcribed at <http://www.inmotionmagazine.com/eno1.html> [last accessed 5 April 2013]

It would be a reasonable conclusion that generative music, being generated by a system, would always sound formulaic and impersonal. What I found instead is that surprising, inspirational and contrasting pieces of music are being produced. This use of real-time generative music provided situations in which the degree of unpredictability and surprise could be as exciting on each rendition for the composer as it is may be for the audience.

Over all I'm happy with my generative systems, I had some design issues during the making of my autonomous machine (please refer to www.thegenerativepiano.com), but it ended up working how I hoped it would when I was prototyping it. If I were to revise this project I would look at the macroscopic structure of the compositions as there may not have been much movement throughout the pieces. I would also look into ways of shielding the piano keys from the machine as every note played comes with a hitting sound.

If I were to revise my individual compositions, I would have possibly explored the use of at least a second-order Markov chains for the creative/procedural piece to add recurring themes and more predictability, but perhaps it is the unpredictability that adds to the aesthetics of generative music. I am still happy with the results though and believe you can hear some Bach-like qualities in the piece. My biological/emergent piece I would say overall is the piece I am most proud of, the outcome of something being decided by nature instead of probability tables, to me is very interesting. For the linguistic/structural piece I would possibly review the sound levels of the samples. I thought it was interesting to use other mediums for data storage and it produced some interesting results, but the data stored would no longer be accessible. For my interactive/behavioural piece I would possibly rethink the design of the pendulum and have the LED circuitry separate as this caused a lot of design problems within the system. Because of this I believe this piece to be the most uninteresting, which is a shame as out of all four compositions it is the only one where the audience could see the process.

Overall my preferred method would have been using Markov chains, I believe probability tables are an interesting way to create music, being able to look at a composition as a list of probabilities is very interesting. It has been suggested by Volchenkov and Dawin that the 'reliance on random note selection tends to obscure the practices of music compositions',[88] but I have found the opposite, discovering varied but yet stylistically similar products. Because of this I'd suggest that stochastic techniques were preferable over my other compositional approaches.

If I were to develop my project further, I would like to add the ability for a wider musical range, I was limited to two and a half octaves for each piece and although due to the design of my machine this range could be anywhere on the piano it still would be nice to cover the full range of the piano. I would also like to add an audio input to my systems so the machine could react to other musicians, creating an autonomous accompanist.

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[88] Dima Volchenov, and Jean Rene Dawin, 'Musical Markov Chains', in *Internatinal Jounal of Modern Physics,* vol.16, (2012), pp. 116-135, p. 118.

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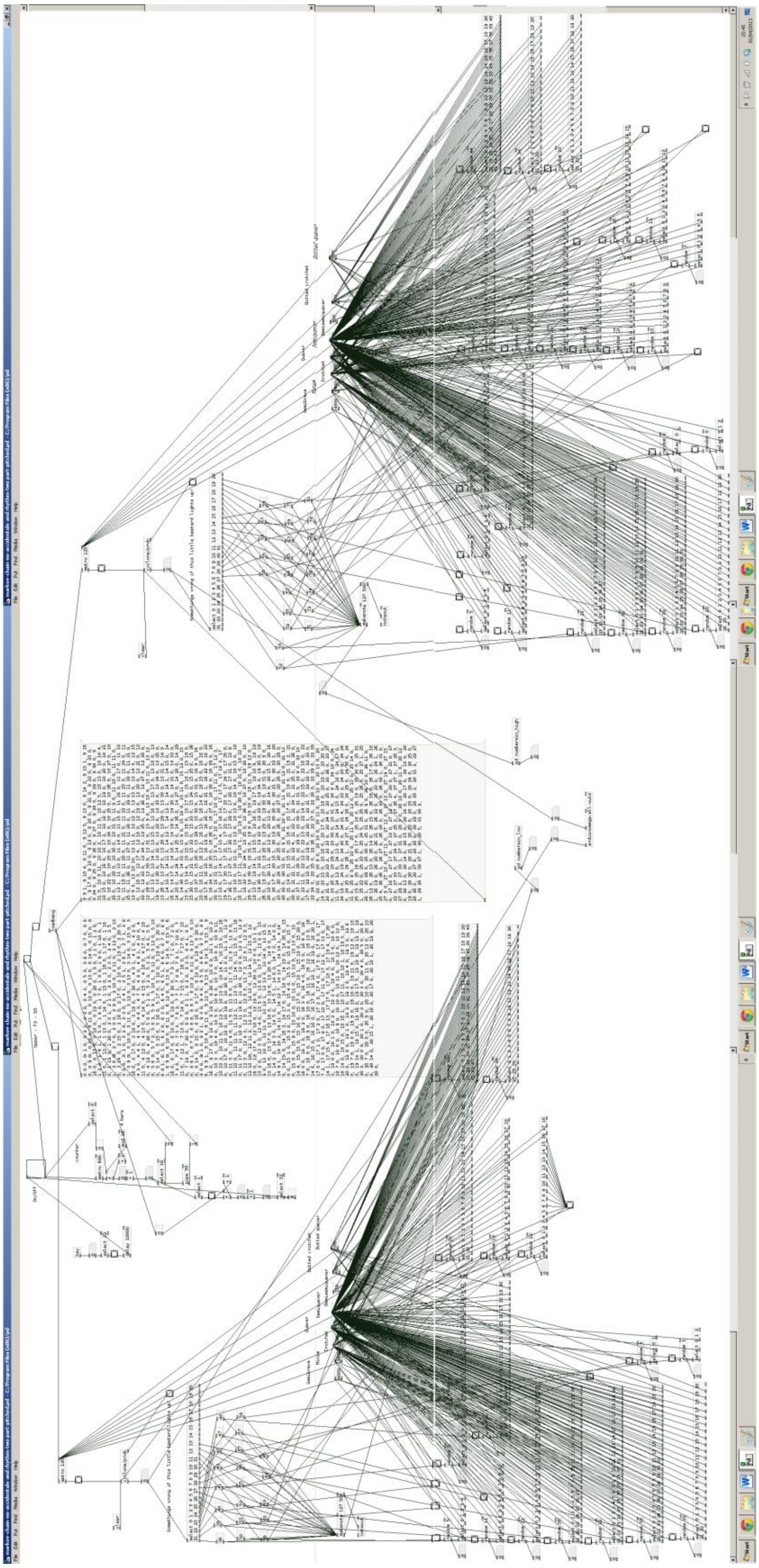
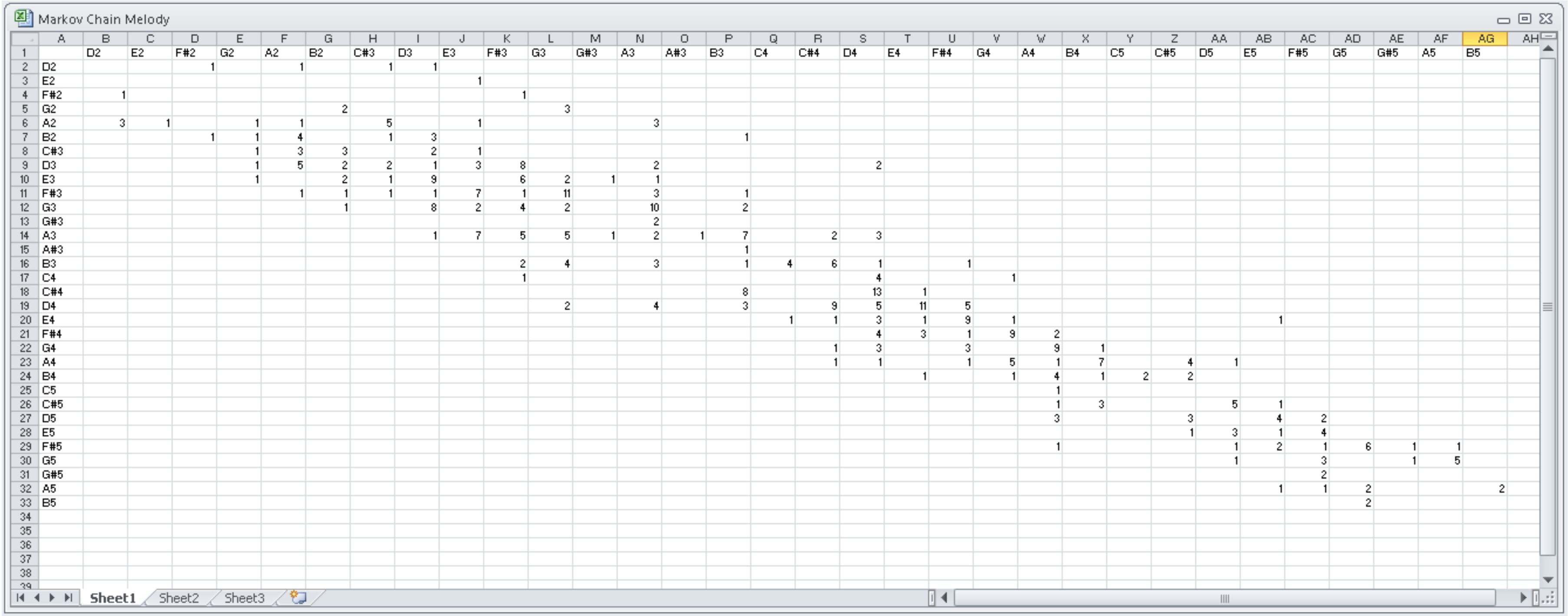
Appendices



1

Patch 1 creative/procedural

2



Markov Chain Melody

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	AA	AB	AC	AD	AE	AF	AG
1		D2	E2	F#2	G2	A2	B2	C#3	D3	E3	F#3	G3	G#3	A3	A#3	B3	C4	C#4	D4	E4	F#4	G4	A4	B4	C5	C#5	D5	E5	F#5	G5	G#5	A5	B5
2	D2			1		1		1	1																								
3	E2									1																							
4	F#2	1									1																						
5	G2						2					3																					
6	A2	3	1		1	1		5		1				3																			
7	B2			1	1	4		1	3							1																	
8	C#3				1	3	3		2	1																							
9	D3				1	5	2	2	1	3	8			2					2														
10	E3				1		2	1	9		6	2	1	1																			
11	F#3					1	1	1	1	7	1	11		3		1																	
12	G3						1		8	2	4	2		10		2																	
13	G#3													2																			
14	A3								1	7	5	5	1	2	1	7		2	3														
15	A#3															1																	
16	B3										2	4		3		1	4	6	1		1												
17	C4										1								4			1											
18	C#4															8			13	1													
19	D4											2		4		3		9	5	11	5												
20	E4																1	1	3	1	9	1						1					
21	F#4																		4	3	1	9	2										
22	G4																	1	3		3		9	1									
23	A4																	1	1		1	5	1	7		4	1						
24	B4																			1		1	4	1	2	2							
25	C5																						1										
26	C#5																						1	3			5	1					
27	D5																						3			3		4	2				
28	E5																									1	3	1	4				
29	F#5																						1				1	2	1	6	1	1	
30	G5																										1		3		1	5	
31	G#5																												2				
32	A5																											1	1	2			2
33	B5																													2			

Probability table for melody

3	0 0 0, 0 1 0, 0 2 1, 0 3 0, 0 4 3, 0 5 0, 0 6 0, 0 7 0, 0 8 0, 0 9 0, 0 10 0, 0 11 0, 0 12 0, 0 13 0, 0 14 0, 0 15 0, 0 16 0, 0 17 0, 0 18 0, 0 19 0, 0 20 0, 1 0 0, 1 1 0, 1 2 0, 1 3 0, 1 4 1, 1 5 0, 1 6 0, 1 7 0, 1 8 0, 1 9 0, 1 10 0, 1 11 0, 1 12 0, 1 13 0, 1 14 0, 1 15 0, 1 16 0, 1 17 0, 1 18 0, 1 19 0, 1 20 0, 2 0 1, 2 1 0, 2 2 0, 2 3 0, 2 4 0, 2 5 1, 2 6 0, 2 7 0, 2 8 0, 2 9 0, 2 10 0, 2 11 0, 2 12 0, 2 13 0, 2 14 0, 2 15 0, 2 16 0, 2 17 0, 2 18 0, 2 19 0, 2 20 0, 3 0 0, 3 1 0, 3 2 0, 3 3 0, 3 4 1, 3 5 1, 3 6 1, 3 7 1, 3 8 1, 3 9 0, 3 10 0, 3 11 0, 3 12 0, 3 13 0, 3 14 0, 3 15 0, 3 16 0, 3 17 0, 3 18 0, 3 19 0, 3 20 0, 4 0 1, 4 1 0, 4 2 0, 4 3 0, 4 4 1, 4 5 4, 4 6 3, 4 7 5, 4 8 0, 4 9 1, 4 10 0, 4 11 0, 4 12 0, 4 13 0, 4 14 0, 4 15 0, 4 16 0, 4 17 0, 4 18 0, 4 19 0, 4 20 0, 5 0 0, 5 1 0, 5 2 0, 5 3 2, 5 4 0, 5 5 0, 5 6 3, 5 7 2, 5 8 2, 5 9 1, 5 10 1, 5 11 0, 5 12 0, 5 13 0, 5 14 0, 5 15 0, 5 16 0, 5 17 0, 5 18 0, 5 19 0, 5 20 0, 6 0 1, 6 1 0, 6 2 0, 6 3 0, 6 4 5, 6 5 1, 6 6 0, 6 7 2, 6 8 1, 6 9 0, 6 10 0, 6 11 0, 6 12 0, 6 13 0, 6 14 0, 6 15 0, 6 16 0, 6 17 0, 6 18 0, 6 19 0, 6 20 0, 7 0 1, 7 1 0, 7 2 0, 7 3 0, 7 4 0, 7 5 3, 7 6 2, 7 7 1, 7 8 9, 7 9 1, 7 10 8, 7 11 0, 7 12 1, 7 13 0, 7 14 0, 7 15 0, 7 16 0, 7 17 0, 7 18 0, 7 19 0, 7 20 0, 8 0 0, 8 1 1, 8 2 0, 8 3 0, 8 4 1, 8 5 0, 8 6 1, 8 7 3, 8 8 0, 8 9 7, 8 10 2, 8 11 0, 8 12 7, 8 13 0, 8 14 0, 8 15 0, 8 16 0, 8 17 0, 8 18 0, 8 19 0, 8 20 0, 9 0 0, 9 1 0, 9 2 1, 9 3 0, 9 4 0, 9 5 0, 9 6 0, 9 7 8, 9 8 6, 9 9 1, 9 10 4, 9 11 0, 9 12 5, 9 13 0, 9 14 2, 9 15 1, 9 16 0, 9 17 0, 9 18 0, 9 19 0, 9 20 0, 10 0 0, 10 1 0, 10 2 0, 10 3 3, 10 4 0, 10 5 0, 10 6 0, 10 7 0, 10 8 2, 10 9 11, 10 10 2, 10 11 0, 10 12 5, 10 13 0, 10 14 4, 10 15 0, 10 16 0, 10 17 2, 10 18 0, 10 19 0, 10 20 0, 11 0 0, 11 1 0, 11 2 0, 11 3 0, 11 4 0, 11 5 0, 11 6 0, 11 7 0, 11 8 1, 11 9 0, 11 10 0, 11 11 0, 11 12 1, 11 13 0, 11 14 0, 11 15 0, 11 16 0, 11 17 0, 11 18 0, 11 19 0, 11 20 0, 12 0 0, 12 1 0, 12 2 0, 12 3 0, 12 4 3, 12 5 0, 12 6 0, 12 7 2, 12 8 1, 12 9 3, 12 10 10, 12 11 2, 12 12 2, 12 13 0, 12 14 3, 12 15 0, 12 16 0, 12 17 4, 12 18 0, 12 19 0, 12 20 0, 13 0 0, 13 1 0, 13 2 0, 13 3 0, 13 4 0, 13 5 0, 13 6 0, 13 7 0, 13 8 0, 13 9 0, 13 10 0, 13 11 0, 13 12 1, 13 13 0, 13 14 0, 13 15 0, 13 16 0, 13 17 0, 13 18 0, 13 19 0, 13 20 0, 14 0 0, 14 1 0, 14 2 0, 14 3 0, 14 5 0, 14 5 1, 14 6 0, 14 7 0, 14 8 0, 14 9 1, 14 10 2, 14 11 0, 14 12 7, 14 13 1, 14 14 1, 4 14 0, 14 15 8, 14 16 3, 14 17 0, 14 18 0, 14 19 0, 14 20 0, 15 0 0, 15 1 0, 15 2 0, 15 3 0, 15 4 0, 15 5 0, 15 6 0, 15 7 0, 15 8 0, 15 9 0, 15 10 0, 15 11 0, 15 12 0, 15 13 0, 15 14 4, 15 15 0, 15 16 0, 15 17 0, 15 18 1, 15 19 0, 15 20 0, 16 0 0, 16 1 0, 16 2 0, 16 3 0, 16 4 0, 16 5 0, 16 6 0, 16 7 0, 16 8 0, 16 9 0, 16 10 0, 16 11 0, 16 12 2, 16 13 0, 16 14 6, 16 15 0, 16 16 0, 16 17 9, 16 18 1, 16 19 0, 16 20 1, 17 0 0, 17 1 0, 17 2 0, 17 3 0, 17 4 0, 17 5 0, 17 6 0, 17 7 2, 17 8 0, 17 9 0, 17 10 0, 17 11 0, 17 12 3, 17 13 0, 17 14 1, 17 15 4, 17 16 13, 17 17 5, 17 18 3, 17 19 4, 17 20 3, 18 0 0, 18 1 0, 18 2 0, 18 3 0, 18 4 0, 18 5 0, 18 6 0, 18 7 0, 18 8 0, 18 9 0, 18 10 0, 18 11 0, 18 12 0, 18 13 0, 18 14 0, 18 15 0, 18 16 1, 18 17 11, 18 18 1, 18 19 3, 18 20 0, 19 0 0, 19 1 0, 19 2 0, 19 3 0, 19 4 0, 19 5 0, 19 6 0, 19 7 0, 19 8 0, 19 9 0, 19 10 0, 19 11 0, 19 12 0, 19 13 0, 19 14 1, 19 15 0, 19 16 0, 19 17 5, 19 18 9, 19 19 1, 19 20 3, 20 0 0, 20 1 0, 20 2 0, 20 3 0, 20 4 0, 20 5 0, 20 6 0, 20 7 0, 20 8 0, 20 9 0, 20 10 0, 20 11 0, 20 12 0, 20 13 0, 20 14 0, 20 15 1, 20 16 0, 20 17 0, 20 18 1, 20 19 9, 20 20 0,

Collected data for the bass melody

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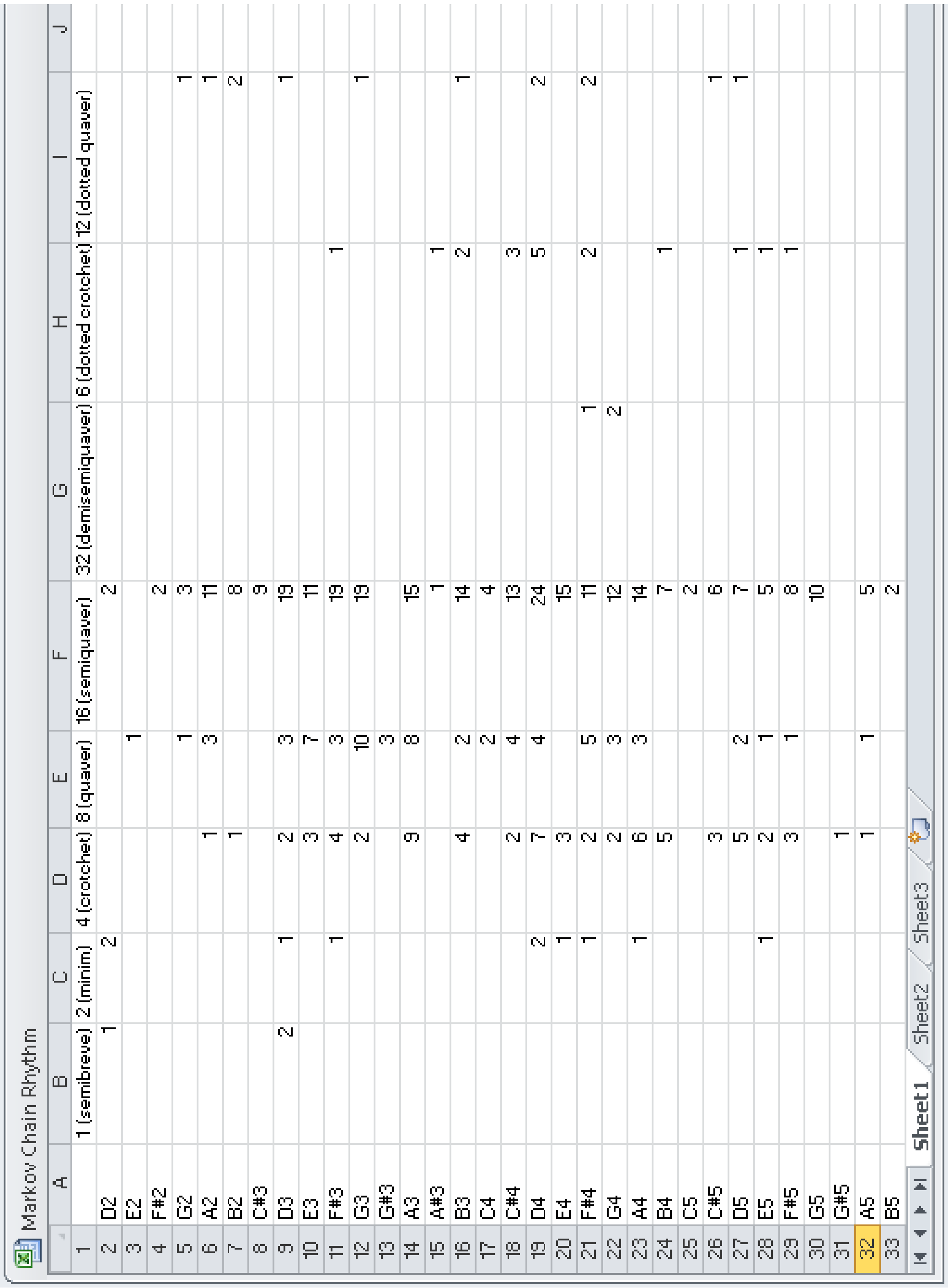
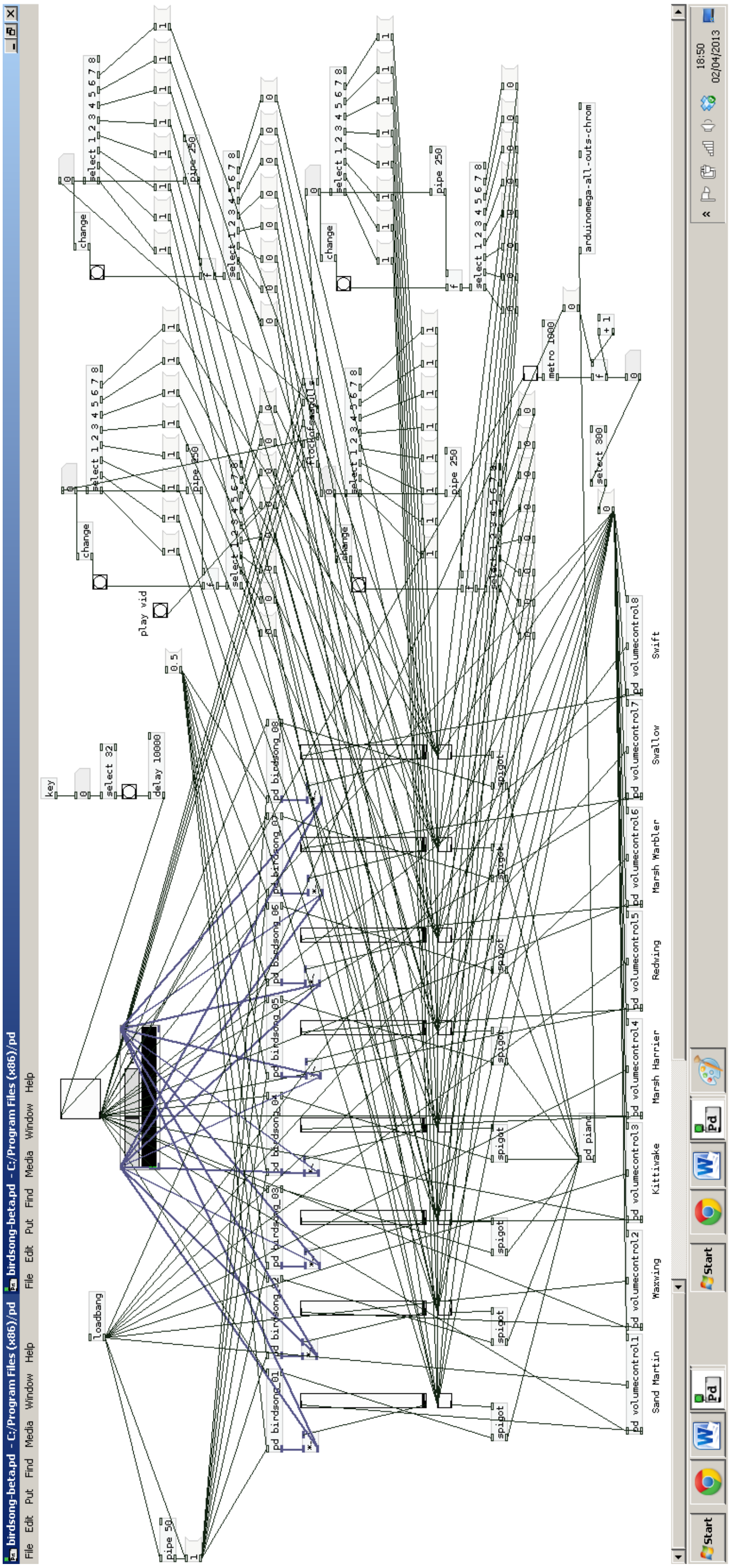
Collected data for the upper melody



	A	B	C	D	E	F	G	H	I	J
1		1 (semibreve)	2 (minim)	4 (crotchet)	8 (quaver)	16 (semiquaver)	32 (demisemiquaver)	6 (dotted crotchet)	12 (dotted quaver)	
2	D2	1	2			2				
3	E2				1					
4	F#2					2				
5	G2				1	3			1	
6	A2			1	3	11			1	
7	B2			1		8			2	
8	C#3					9				
9	D3	2	1	2	3	19			1	
10	E3			3	7	11				
11	F#3		1	4	3	19		1		
12	G3			2	10	19			1	
13	G#3				3					
14	A3			9	8	15				
15	A#3					1		1		
16	B3			4	2	14		2	1	
17	C4				2	4				
18	C#4			2	4	13		3		
19	D4		2	7	4	24		5	2	
20	E4		1	3		15				
21	F#4		1	2	5	11	1	2	2	
22	G4			2	3	12	2			
23	A4		1	6	3	14				
24	B4			5		7		1		
25	C5					2				
26	C#5			3		6			1	
27	D5			5	2	7		1	1	
28	E5		1	2	1	5		1		
29	F#5			3	1	8		1		
30	G5					10				
31	G#5			1						
32	A5			1	1	5				
33	B5					2				

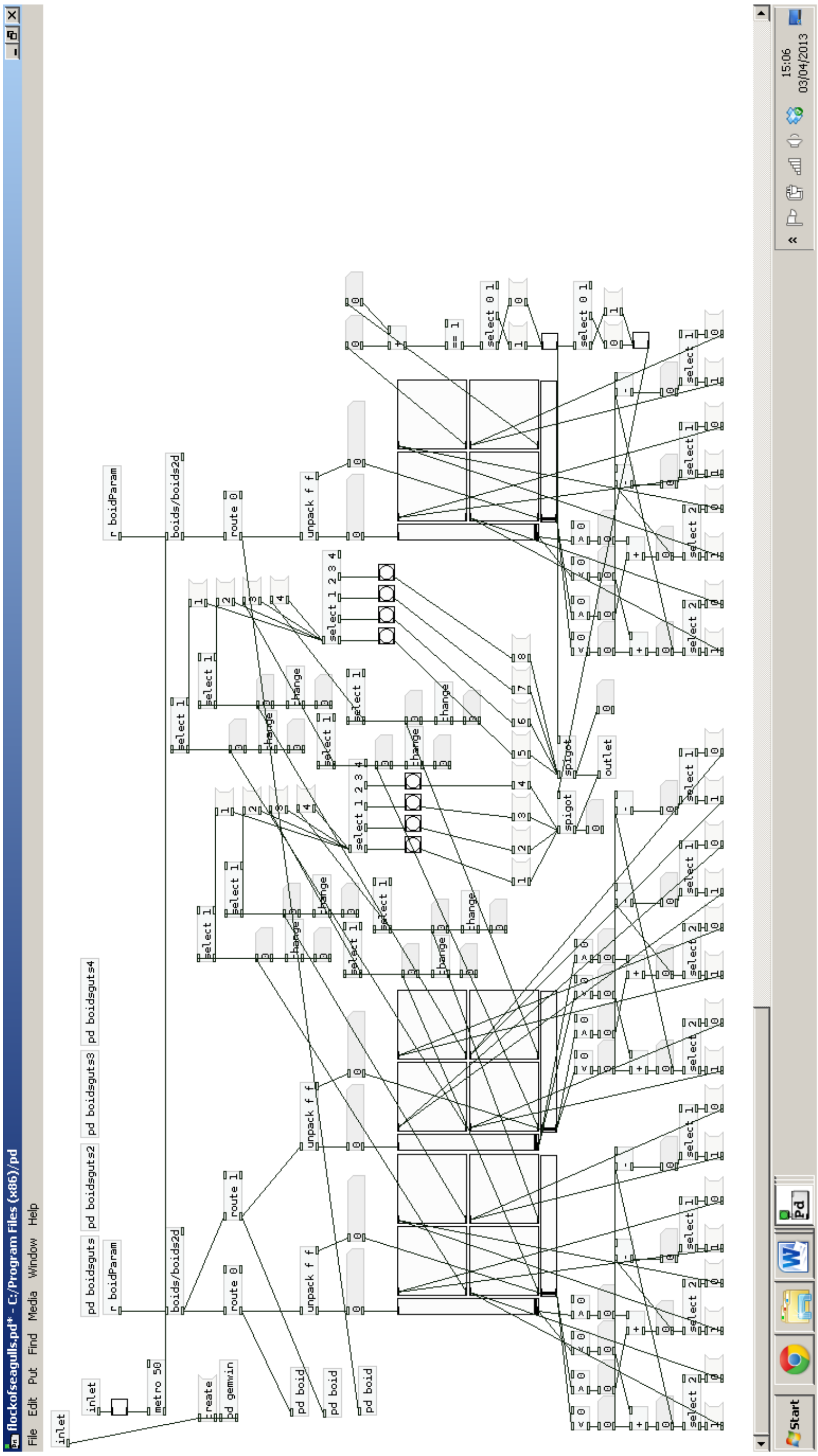
5

Probability table for each notes duration



6

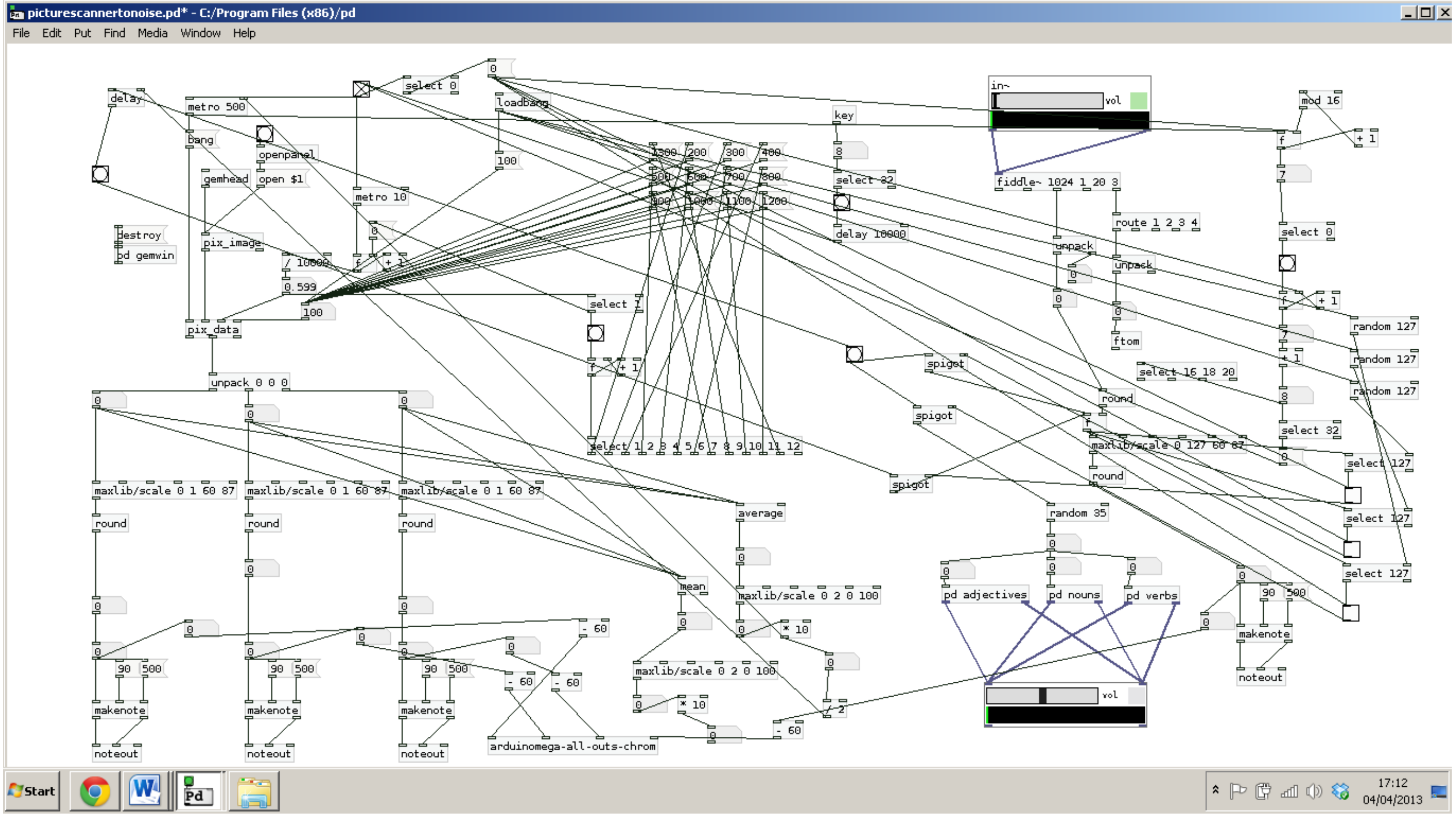
Patch 2 biological/emergent



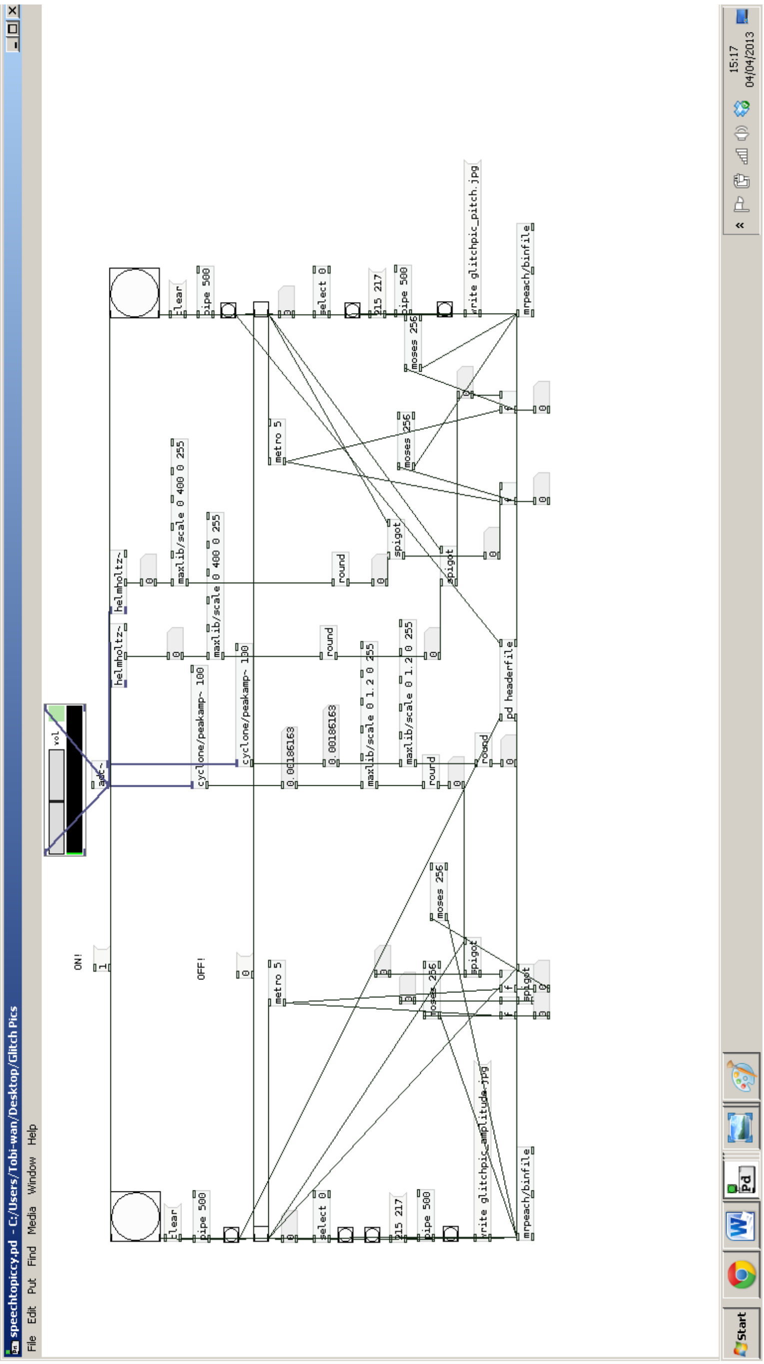
7

Using simulated flight paths of birds to control an audio stream (this system is replicated four times in the patch)

8



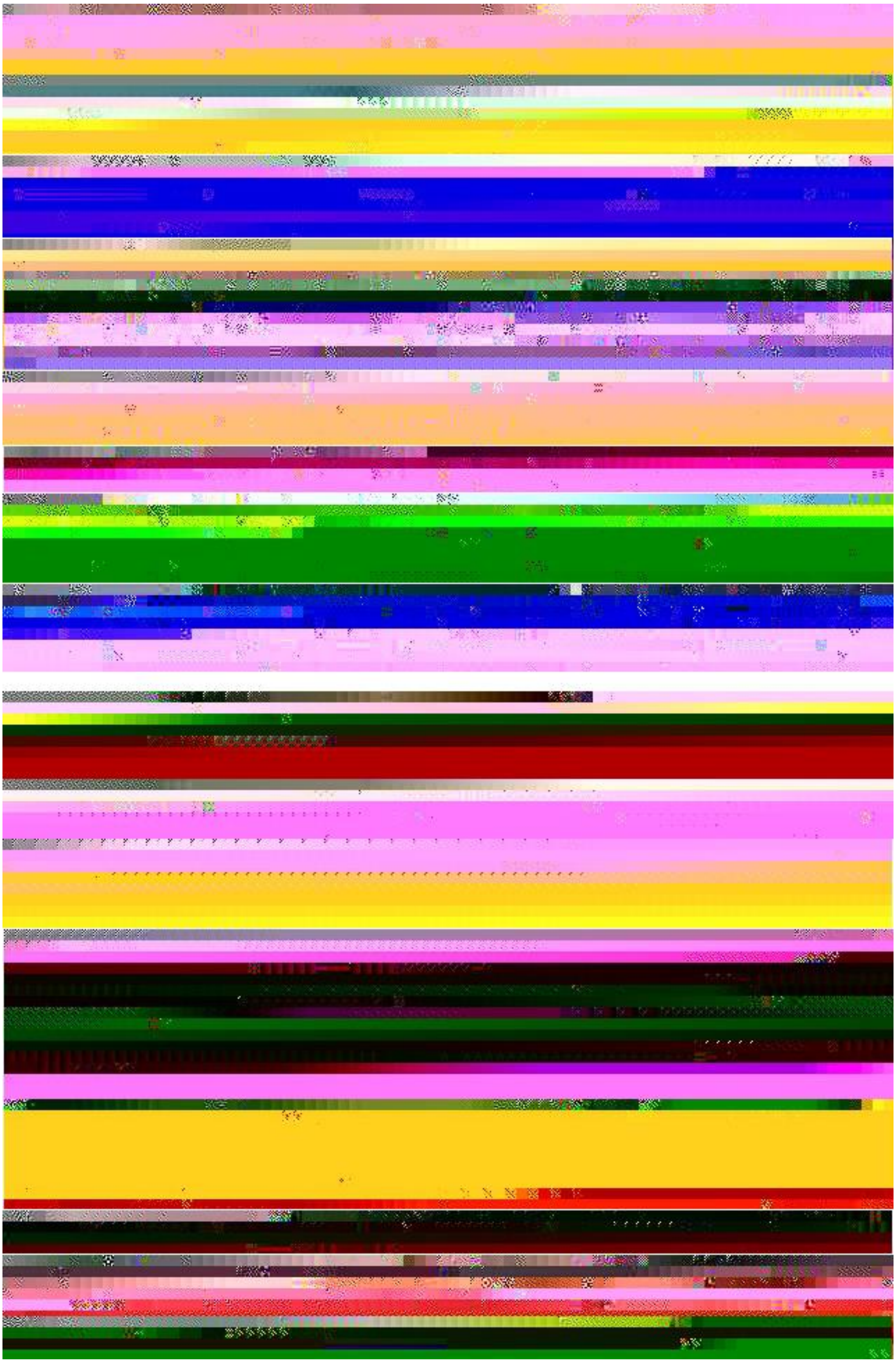
Patch 3 linguistic/structural



9

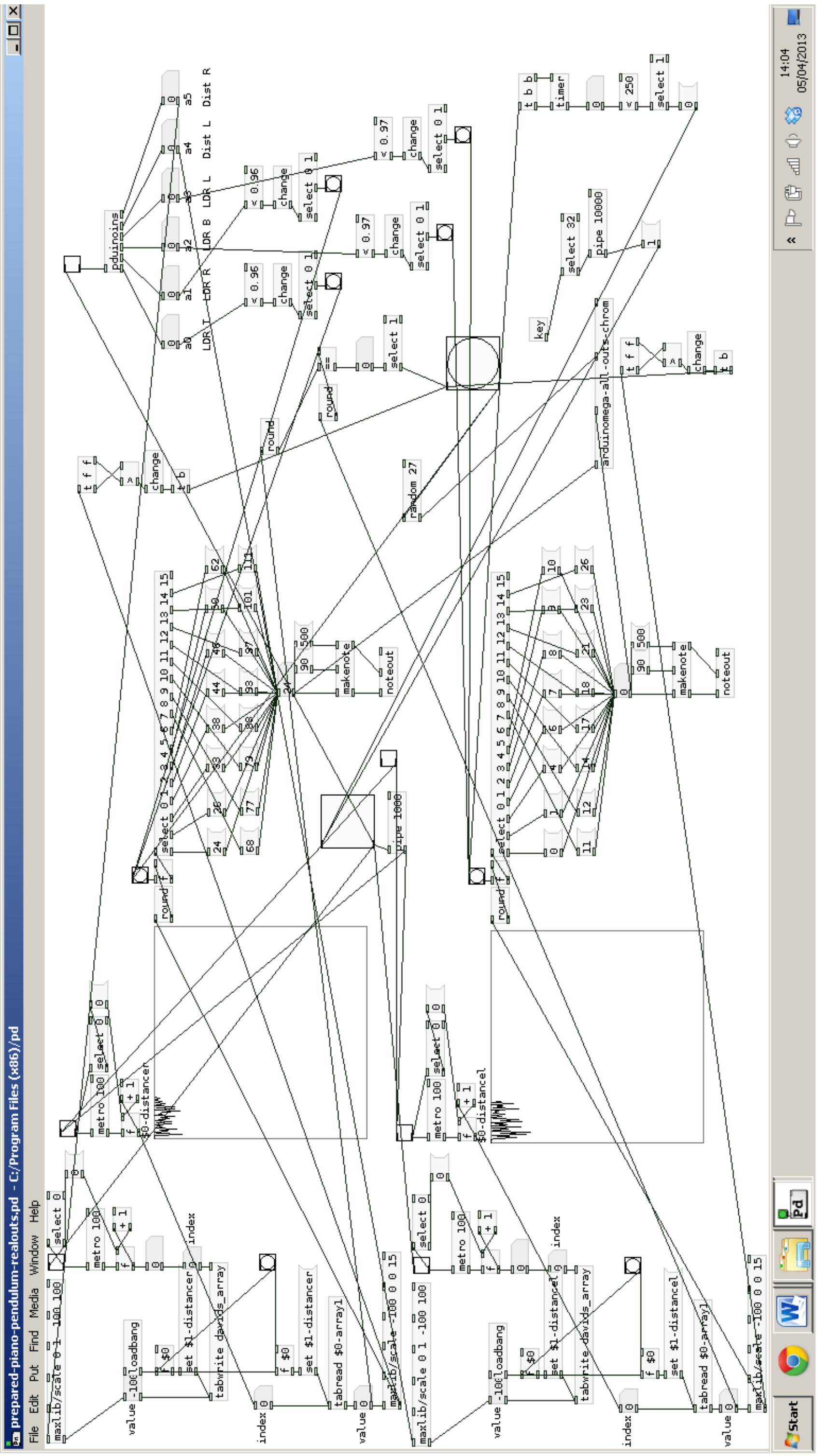
Creating jpegs out of amplitude and pitch data.

10



Jpeg created from the combined pitch and amplitude data.

11



Patch 4 interactive/behavioural