Studio Composition

Live audiovisualisation using emergent generative systems

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Declaration

I hereby declare that the work presented in this thesis is my own.

Signature:

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Abstract

The aim of this research is to explore new creative outcomes of the use of emergent generative systems as material in audio and audiovisual experimental art. The portfolio includes the following compositions: *Construction in Self*, *Construction in Zhuangzi* and *Construction in Kneading*, the last two each comprising of three separate pieces. The mathematical systems used are the Lorenz dynamical system and the Mandelbox fractal. Through considering their potential for emergence, the aesthetic possibilities that generative systems offer in the context of experimental computational art are explored. The approach is initially investigated in the audio domain in *CiS*, a generative electronic music work. *CiZ* and *CiK*, the two main sets of works that comprise the portfolio, then explore the technique of “live audiovisualisation”: the simultaneous sonification and visualisation of the same source of data in real-time. Aesthetic considerations of the use of data as sound and moving image and their combination is discussed with reference to research into auditory displays, experimental film and perception. The techniques used include my approach of “self-similar sonification”: the presentation of data as audio at multiple time-scales, including at audio rate by means of non-standard synthesis or audification. All the works are implemented in the programming environment Max/MSP/Jitter.

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I would like to thank my supervisors, Michael Young and Mick Grierson, for their support and guidance during my time at Goldsmiths. I would also like to thank the various teachers, colleagues and friends who have helped me along the way.

A special thank you goes to my family and Tim and Kit Kemp for their generous support that made this PhD possible.

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y [-1,1] against time (as audio rate: [0,0.002-4] seconds; control rate: [0,16-128] seconds; or structural rate [0,0-15] minutes) for Figs. 1-24.

Notes on Movie examples

All extracts from *Construction in Zhuangzi* (2011). See the chapter "Live Audiovisualisation" for more details.

Movie example 1. Part 1a. Trajectories i and ii. Perturbations cause phase transitions alternating with resettings to initial coordinates. From 0:20, final states differ and they diverge as their initial coordinates belong to different basins of attraction. From 0:40, they converge on the same periodic attractor and final state. At the end, they converge on the same steady-state attractor.

Movie example 2. Part 1a. Trajectories i and ii. Starts with oscillations around a periodic attractor. Six perturbations occur, all being ordinary events except the final one at 0:44 which is a singular event that results in a phase transition.

Movie example 3. Part 1b. Trajectories i and iii. They converge on the same periodic attractor and final state as their initial coordinates belong to the same basin of attraction.

Movie example 4. Part 2. Trajectories i and ii. Begins with a resetting to initial coordinates. They diverge towards different final states as their initial coordinates belong to different basins of attraction.

Movie example 5. Part 3. Trajectory i-ii. Several perturbations cause phase transitions. From 1:05, i and ii converge on the same periodic attractor and final state, with their difference becoming an oscillation.

Movie example 6. Part 1a. Trajectories i, ii and iii. Starts with oscillations around a periodic attractor. The "slope" or time of ii is halved and that of iii doubled. They are then reset to their initial coordinates individually.

Movie example 7. Part 2. Trajectory i-ii. After being reset to initial conditions, a short moment of silence and inertia follows as i and ii take almost identical routes. But as their initial coordinates belong to different basins of attraction, they diverge and their final states differ.

Notes on Sound examples

All Sound examples from *Construction in Self* (2009). All the Figs. mentioned below represent only one dimension out of a total of three present in the Lorenz system. As “inflection point triggering” occurs in all three dimensions, for every peak or trough seen in the Figs. (in the *y*-dimension), two more occur in the *x*- and *z*- dimensions in close proximity. Therefore, three audifications as individual sounds are normally audible at every trough or peak shown in the Figs in Sound examples 6 to 11.

Sound example 1: One section from the work.

Sound example 2: Audification of Figs. 1 to 12.

Sound example 3: Audification of Figs. 1 to 12 transposed up two octaves.

Sound example 4: Audification of Figs. 13 to 24.

Sound example 5: Audification of Figs. 13 to 24 transposed up two octaves.

Sound example 6: Sonification of Fig. 4 r =19 (i) using audification of Figs. 1 to 12.

Sound example 7: Sonification of Fig. 7 r = 20.5 (i) using audification of Figs. 1 to 12.

Sound example 8: Sonification of Fig. 11 r = 23 (i) using audification of Figs. 1 to 12.

Sound example 9: Sonification of Fig. 16 r =19 (i-ii) using audification of Figs. 13 to 24.

Sound example 10: Sonification of Fig. 19 r = 20.5 (i-ii) using audification of Figs. 13 to 24.

Sound example 11: Sonification of Fig. 23 r = 23 (i-ii) using audification of Figs. 13 to 24.

Research outputs

Creative work

Below are the works included in the portfolio, with selected performances and competition results. Abbreviations used throughout the thesis are indicated inside brackets.

Construction in Self (*CiS*) – generative work

- noise=noise: the Basement Series, London, 26 October 2009 (noise=noise 2009).
- ICMC, New York, 5 June 2010 (ICMA 2013).
- Festival di Nuova Musica, Udine, 5 October 2011 (TEM 2011).

***Construction in Zhuangzi* Part 1 to 3** (*CiZ*) – live audiovisualisation

- Seeing Sound 2, Bath, 29 October 2011 (Seeing Sound 2011).
- Redsonic, London, 29 January 2012 (Redsonic 2012).
- PureGold, Southbank Centre, London, 11 May 2012 (Southbank Centre 2012).
- Toronto Electroacoustic Symposium, 17 August 2012 (CEC 2012).
- ICMC, Ljubljana, 13 September 2012 (IRZU 2012).

A fixed-media screening/installation version of *CiZ* was also produced:

- MADATAC Contemporary New Media Audio-Visual Arts Festival – official selection, Madrid, 11-15 December 2012 (MADATAC 2013).
- Videomedeja International Video Festival – official selection, Novi Sad, 14-16 December 2012 (Videomedeja 2013).

- Papay Gyro Nights Art Festival, Videotage, Hong Kong, 5-18 April 2013 (Papay 2013).
- Fresh Minds Festival – finalist, TAMU, Texas, 26 September 2013 (Fresh Minds Festival 2013).

CiZ is also featured in the *Electronic Music* volume of the *Cambridge Introductions to Music* series (Collins, Schedel, and Wilson 2013, 171-73).

Construction in Kneading **Part 1 to 3** (*CiK*) – live audiovisualisation

- *Perspectives on Daphne Oram*, part of Nonclassical's *Pioneers of Electronic Music* festival, London, 6 March 2013 (Nonclassical 2013).
- PureGold, Southbank Centre, London, 9 May 2013 (Southbank Centre 2013).
- Real-Time Visuals research network concert, London, 18 June 2013 (RTV 2013).

The Max/MSP/Jitter patches for all the works are included on the accompanying drive both as a collective – which requires a Runtime or a full version of Max/MSP/Jitter 5 – and as a standalone. Where possible, the use of the collectives over the standalones is recommended due to better performance. Mac OS X 10.5 or later on an Intel computer is required.

Peer-reviewed papers

Various parts of the thesis have been peer-reviewed and published in journals or conference proceedings.

The paper "Generative, Emergent, Self-Similar Structures: *Construction in Self*" (Ikeshiro 2010) was presented at ICMC 2010 and contains parts of the chapters "Data as Audio" and "*CiS*". It was later published in the festival catalogue *SNÆ* for Papay Gyro Nights 2013 (Ikeshiro 2013a).

The paper “GENDYN and Merzbow: the legacy of Xenakis’ late electroacoustic works on noise music today” (Ikeshiro 2011) was presented at Xenakis International Symposium 2011 and contains parts of the chapters ”Data as Audio”, “Emergence” and ”Aesthetics”.

The paper “GENDYN, Noise and the Virtual: smooth space-time and entropy in the stochastic synthesis of Xenakis” (Ikeshiro 2012b) was presented at the international symposium *Xenakis. La musique électroacoustique* 2012 and contains parts of the chapters ”Data as Audio”, ”Emergence” and “Aesthetics”.

The paper “*PulseCubes*: an interactive sound installation as interface and new media object” (Ikeshiro 2012c) was presented at the Toronto Electroacoustic Symposium 2012 and contains parts of the chapters “Computational Arts” and “Aesthetics”.

The article “Audiovisual Harmony: The realtime audiovisualisation of a single data source in *Construction in Zhuangzi*” was published in the visual music issue of *Organised Sound* (Ikeshiro 2012a), and contains parts of the chapters “Live Audiovisualisation” and “*CiZ”*.

The paper “Live Audiovisualisation of a 3D Mandelbox Fractal” will be presented at Notation in Contemporary Music: Composition, Improvisation, Performance Symposium 2013 (CMRU 2013), and contains parts of the chapters “Generative Moving Image Scores”, “Live Audiovisualisation” and “*CiK”*. It was also presented at the symposium for Real-Tim Visuals Workshop 2, 2013 (Ikeshiro 2013b).

Introduction

This thesis accompanies the portfolio which consists of the compositions listed above found on the accompanying drive. As well as serving as a commentary to the practice, it forms the theoretical component of the research undertaken. Thus the research employs two methodologies simultaneously: the aesthetic and technical exploration of the main concepts found in this thesis alongside its creative applications in the works in the portfolio.

The main contributions of the research are:

- a body of creative work demonstrating the application of the emergent generative systems based on the Lorenz dynamical system and the Mandelbox fractal as material in audio and audiovisual experimental art;
- the demonstration of the technique of live audiovisualisation as a valid aesthetic endeavour, as evidenced in both the thesis and the portfolio;
- the approach of “self-similar sonification”: the use of data as audio at multiple time-scales including at audio rate by means of non-standard synthesis or audification;
- an assessment of the aesthetic and technical implications of emergent behaviour in generative systems within experimental computational art.

The thesis is in three parts. In the first, the following topics are explored: generative art, emergence, computational aesthetics and the mathematical systems used. These are theoretical and relevant to all the works in the portfolio. The second deals with the background to the techniques employed in the works in the order that they appear in the portfolio. These are the use of data as audio, generative moving image scores and live audiovisualisation. Sound and Movie examples from the portfolio are used for demonstration purposes. This section also includes theoretical concerns encountered in specific works. The third part includes explanations of each work from the portfolio. These comprise of programme-notes style introductions, the key concepts outlined in the first two parts of the thesis that are explored, the technical implementation and evaluations.

The thesis concludes with the achievements of the research undertaken, and suggested future work.

Part I: Theory

Computational Art

Separation of technique and aesthetics

The development of the arts has always been inextricably linked to that of technology. Computers have introduced potential on a whole new scale to previous advances. Through the affordability of high-powered consumer hardware, digital technology is now widely available.

The majority of computer-aided art is produced using pre-packaged software. These act as invisible black boxes, essentially hiding the software code. This tendency is common in mainstream computing in general, where the “user-friendliness” of an interface has almost become the benchmark for progress in computing itself (Huhtamo 2003, Section 1). It also mirrors the often pre-conceived distinction between creative work – using software – and technical or assistive work – developing software.

According to Florian Cramer, reflection on the use of software in the arts has been limited, and its contribution to an art work has been sidelined and even omitted from definitions of the work of art. In addition, “programmers are frequently considered to be mere factota, coding slaves who execute other artist's concepts” (Cramer 2002, Software in the Arts). The scenario is also reflected in music, in institutions such as IRCAM, where a culture of collaborations reiterates the roles of the composer as artist and genius, whose grand vision however requires implementing by the technician as assistant in order for it to be materialised. According to Pierre Boulez:

> The creator’s intuition alone is powerless to provide a comprehensive translation of musical invention. It is thus necessary for him to collaborate with the scientific research worker. (quoted in Born 1995, 1)

Undoubtedly, the proliferation of GUIs (Graphic User Interfaces) that do not require specialist knowledge to use can be viewed as democratic, in that these GUIs increase accessibility to computing. However, it is imperative that their subtle but powerful influence on the ever-increasing number of activities performed involving computers is recognised especially considering their ubiquity. As Huhtamo states, “every software embodies a way of using”, paraphrasing John Berger’s famous expression on the study of images in art (Huhtamo 2003, Section 1).

Fortunately for musicians, flexible and extendible programming environments for creating sound have existed since the birth of digital audio. After Max Matthews’s MUSIC-N, a steady stream of highly developed programming languages have followed, such as Csound and SuperCollider (Howse 2007, Introductory section). Visual scripting environments such as Pure Data and Max, and later Max/MSP/Jitter have also offered similar capabilities without the need for scripting (Howse 2007, Maxed out).

In contrast to using pre-packaged software, writing one’s own programs enables the creation of algorithms (Huhtamo 2003, Section 2). Similarly, Les Goldschlager and Andrew Lister state that the algorithm “is the unifying concept for all the activities which computer scientists engage in” (quoted in Goffey 2008, 15). This opens up the possibilities of blurring what Geoff Cox, Alex McLean and Alex Ward refer to as the “undialectical separation of technical concerns over aesthetic ones” (Cox, McLean, and Ward 2004, 167). That is, instead of privileging *esthesis* (perception) at the expense of *poeisis* (construction) – a charge levelled by Cramer at the history of digital and computer-aided arts (Cramer 2002, Software in the Arts) – or vice versa, both must be considered simultaneously for a re-evaluation of “art-orientated programming” and “program-orientated art” (Cox et al. 2004, 167).

Cox makes a further analogy of the inextricability of technical and aesthetic or intellectual concerns inherent in code to the dialectical relationship of theory to practice that is *praxis* (Cox et al. 2004, 172). This is exemplified by how artists working with computational means regard their working method, such as Manfred Mohr who describes his creative process as “a dialogue between me and the programming language" (Fell 2013). As practice informed by theory that is reflexive, the writing of software for artistic purposes appears to complement practise-based research perfectly. Thus the enterprise of the "programmer-artist" (Magnusson 2002, 33), or the "artist-programmer", "end-user programmers in that they create software not for others to use as tools, but as a means to realise their own work" (McLean 2011, 14), is validated.

Institutional and underground

Kim Cascone states in his paper on the phenomenon of "glitch" that:

> Unfortunately, cultural exchange between nonacademic artists and research centers has been lacking. The post-digital music that Max, SMS, AudioSculpt, PD, and other such tools make possible rarely makes it back to the ivory towers, yet these non-academic composers anxiously await new tools to make their way onto a multitude of Web sites. (Cascone 2000, 12)

Although the statement was never strictly true, the situation has improved remarkably since Cascone's article. Academic institutions make full use of such software, whilst underground artists incorporate techniques developed by composers such as Iannis Xenakis and Curtis Roads using readily-available software and programming environments.

The "artistic stasis" of academic computer music which Bob Ostertag bemoans (Ostertag 1998) is also beginning to be resolved through the incorporation of aesthetic and technical developments outside institutions. One such influence is noise. Conceptually, it is at the limits of sonic and visual art, pushing and breaking down boundaries. Jacques Attali describes the possibility for the construction of new levels of organisation arising from the apparent absence of meaning that is noise (Attali 1985, 33). The most extreme sonically are Japanese noise or "Japanoise" artists such as Merzbow belonging to the subcategory of "power electronics" (Hegarty 2001, 194), a term first used by William Bennet on the cover of the album *Psychopathia Sexualis* (1982) by his band Whitehouse.

This portfolio is a further attempt to bridge the divide between the two worlds by using the visceral timbre and cutting-edge sonic elements of noise, glitch and drone that have developed out of power electronics, with rigour provided by algorithmic composition through the use of generative systems.

Software art and generative art

In referring to computational art, Inke Arns distinguishes generative from software art, which have sometimes become near synonyms. For her, the former is concerned primarily with the results of generative processes (Arns 2004b, 182) and the latter involves the reflection of itself as software and its cultural significance (Arns 2004a).[1] Within this second category of software art, Cramer identifies two strands: “software formalism” and “software culturalism”. The former strand identifies software as a medium for individual expression through algorithmic processes and the formal poetics and aesthetics of code, illustrated by Cox, McLean and Ward;[2] the latter identifies software as a cultural and politically coded construct, and refers to Matthew Fuller, Graham Harwood and I/O/D and Mongrel.[3] Cramer emphasises the necessity of both aspects in order to avoid the extremes of either software art as purely elegant code on the one hand or mere critique of computing practice on the other (Cramer 2002, Software Formalism vs. Software Culturalism).

These descriptions appear to correspond to Arns’s more general categories i.e. generative art as software formalism and software art as software culturalism. I would argue that these two facets of software art must also be considered within generative art. The difference between generative and software art would be characterised by the relative import between formalism and culturalism, and hence I believe the above critique of software art would also apply to generative art.

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[1] For a survey of definitions of generative art, see (Arns 2004a); for categories of a broader range of approaches to art made with computers, see (Boden and Edmonds 2009).

[2] This claim is, however, refuted by them (Cox et al. 2004, 162-63), as Cramer’s critique only refers to one particular article.

[3] These two types are of importance historically: there exists a multitude of various ontological stances regarding the use of computation in the arts (Cramer 2005, 126).

Due in part to the aforementioned writers, many of whom are practitioners, a critical body of theory concerning software art now exists. However, no such body of critical reflection can be found in relation to generative art, at least not to the same degree.

Still, some claim a fundamental, irreconcilable difference between generative and software art. This arises from the negation of intention in the former, through the use of autonomous generative processes, as indicated by proponents of both generative art (Galanter 2003, 4) as well as software art (Arns 2004a, McLean 2011, 16). Admittedly, many practitioners have contributed to this impression for quite some time e.g. John Cage's attempt to remove himself, the composer, from the composition through consulting the *I-Ching*; Harold Cohen describing himself as merely a "first-rate" colourist and differentiating himself from his creation, AARON, which is in contrast a "world-class" colourist (Boden and Edmonds 2009, 13). Similarly, Lev Manovich states that intentionality can be removed from the creative process, at least in part (Manovich 2001, 53).

Perhaps a more productive question that arises concerns what constitutes the work: the program or the artefact. Michael Noll and the Japanese Computer Technique Group prioritise the former over the latter as where the work of art is situated, prefiguring the view of more recent software art (Huhtamo 2003, Section 2).

I would argue that in generative art, the artist-programmer does not necessarily concede intentionality to his/her creation.[4] However, the question of authorship is not of primary interest here: it would be more productive to consider what is made possible through the critical relationship between the artist-programmer and the systems/algorithm. This is explored through the concept of the machinic and the cyborg below.

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[4] Nick Collins also highlights the precursor of human design in programs and the programmer's presence acting by proxy, despite moment to moment execution being yielded to the machine. For him, generative processes are examples of what John Searle calls the derivative intentionality of writing (Collins 2008, 238).

Concept and conceptual

Cramer offers us an analogy found in conceptual art to the formalism/ culturalism or generative/software art distinction. He describes Sol LeWitt's *Plan for a Concept Art Book* (1971) as concept notation art, or blueprint art as he identifies its main material as being graphics and objects despite its realisation as a score. In fact, the score performs merely the same function as a traditional musical score. In contrast, La Monte Young's *Composition 1960 #10* and *Compositions 1961* ("Draw a straight line and follow it") qualify as being more rigorously conceptual for although the instruction is unambiguous enough to be executed by a machine, a thorough execution is physically impossible (Cramer 2002, Concept Art and Software Art).

Cramer does demonstrate in one example, a Perl code of a Dada poem, that some code can be read and executed even without running on machines (Cramer 2002, A Crash Course in Programming), perhaps a similar position to Adorno for whom the score reigns supreme. As Cramer highlights, this is in direct opposition to Friedrich Kittler's theory that there is no software, or at least no software without the required hardware for its running (Kittler 1999, 91). However, with technology, and computing in particular, blueprint becomes software, and as such, it is no longer merely a score. As Frieder Nake states:

> The descriptive power gained in writing executable concepts of pictures (also known as programs) is enormous. It is where computer art superseded concept art. (Nake 2005, 56)

In general, most software is impossible to run "mentally" in practice due to its complexity, and the aid of machines and computers for its execution is paramount as it relies on its capability of low-level automation, one of the main characteristics of New Media according to Manovich (Manovich 2001, 53). This is certainly the case with many examples of generative art including my own: hence, there is no software without hardware.[5]

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[5] This also relates to Thor Magnusson's description of processor art as "works of art that use the microprocessor as a necessary element in their development and execution: works that could not be made without its powers of calculation. . . . Processor art is a perspective rather than an art form, a view of looking at what is happening when art is created and executed, with a special attention paid to the medium or technology in which it is being created" (Magnusson 2002, 14).

In reference to works for instrumentalists and computers, Bob Ostertag dismisses algorithmic composition as merely an extension of serialism (Ostertag 1998). Such charges can be refuted in the works included in the portfolio. Automation alone allows for generative art to be of a fundamentally different paradigm through the sheer magnitude of the amount of computation possible. In addition, the inherent complexity of the processes may bring about unpredictable and surprising results through emergence as explained below.

Complexity

Although I disagree with Philip Galanter's definitions of generative art and his aesthetic views, his application of complexity science as a context for understanding systems – i.e. generative art – and their potential is relevant to my practice. He argues that the measure of algorithmic complexity (AC) or algorithmic information content (AIC) as independently developed by Kolmogorov, Solomonoff and Chaitin, does not correlate with what is understood as complexity within the science of complexity. Nor does the concept of entropy as used in information theory for the same reason. According to these scale, highly ordered and highly disordered or completely random systems are located at either limit, whereas, by complexity, the relatively new science indicates systems inhabiting the middle ground. Similarly in art such as music, he implies that the intention behind the use of generative systems is to capture the potential this offers, or at least this is the reason behind its success in its use (Galanter 2003, 8-10).[6] Instead, the potential of generative art can be best characterised through the concept of emergence.

[6] A possible solution he suggests is the use of effective complexity (EC), as defined by Murray Gell-Mann: "To measure EC Gell-Mann proposes to split a given system into two algorithmic terms, with the first algorithm capturing structure and the second algorithm capturing random deviation. The EC would then be proportional to the size of the optimally compressed first algorithm that captures structure'" However, as Galanter and Gell-Mann both concede, this notion of structure is subjective and cannot be defined rigorously (Galanter 2003, 11).

Emergence

Jeff Goldstein refers to this middle ground between order and chaos in describing emergence (Goldstein 1999, 67), and this concept illustrates the capabilities of generative systems. I believe one important potential of generative art using digital technology lies in harnessing emergence in the aesthetic realm. Jon McCormack and Alan Dorin also describe emergence as "one of the central concepts for developing and understanding generative art" (McCormack and Dorin 2001, 4).

There are many conflicting views on what constitutes emergence.[7] A general definition by Goldstein is the following:

> Emergence . . . refers to the arising of novel and coherent structures, patterns, and properties during the process of self-organization in complex systems. Emergent phenomena are conceptualized as occurring on the macro level, in contrast to the micro-level components and processes out of which they arise. (Goldstein 1999, 49)

History of emergence

A precursor to the concept of emergence is exemplified in Aristotle's famous phrase in *Metaphysics*: "The whole is something over and above its parts, and not just the sum of them all" (*Metaphysics* H6, 1045:8-10). Johann Wolfgang von Goethe's concept of "gestalt" which lead to gestalt psychology is another. However, they both imply a pre-defined form, whereas emergence is dynamically constructed (Goldstein 1999, 50-51). As a technical term, it originated in the mid-nineteenth century. John Stuart Mill had illustrated the principle with the example of how the combination of two substances, hydrogen and oxygen, produces a third substance, water, whose properties differ from the first two, either separately or together (Corning 2002, 20). The term "emergent" was subsequently coined by George Henry Lewes to describe similar phenomena, in contrast to "resultants" which displayed clear linear causality

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[7] For a long list of various opinions, see (Corning 2002, 24).

(Lewes 1875, 368-69). Then in the 1920s, in the hands of emergent evolutionists such as Conwy Lloyd Morgan, it became a philosophical task of relating domains studied by the various sciences without proposing any specific scientific mechanism (Corning 2002, 20-21). After its demise partly due to the rise in the theory of quantum bonding (Goldstein 1999, 60-61), interest resurfaced, most notably in the 1950s with the rise of general systems theory (Corning 2002, 22). The "re-emergence of emergence" proper is difficult to date precisely, but as an accepted mainstream concept, it coincided with the new science of complexity which gave it mathematical legitimacy (Corning 2002, 22). In place of the previously unexplained black box process of emergence, advances in mathematics and computing allowed a technical understanding for their occurrence, as they can now be modelled (Goldstein 1999, 54).

The philosophical use of the term now is still reminiscent of the notion invoked by the so-called "proto-emergentists" of the evolutionary scientists in 1920's Britain (Goldstein 1999, 53, Chalmers 2006, 244). Instead, by "emergence", I refer to its more recent usage by those described as "neo-emergentists" by Goldstein (Goldstein 1999, 54-57). Through replicating emergent processes in generative systems, I attempt to produce the phenomena in the domain of audio and visuals.

Strong and weak emergence

Along with differing definitions, various categories of emergence have been proposed. David Chalmers describes two types:

> A high-level phenomenon is strongly emergent with respect to a low-level domain when the high-level phenomenon arises from the low-level domain, but truths concerning that phenomenon are not deducible even in principle from truths in the low-level domain. . . . A high-level phenomenon is weakly emergent with respect to a low-level domain when the high-level phenomenon arises from the low-level domain, but truths concerning that phenomenon are unexpected given the principles governing the low-level domain. (Chalmers 2006, 244-45)

The strong variety applies to its use by the British emergentists and in philosophy as mentioned; the weak variety is more applicable to its use in recent science and complex systems theory. With strong emergence, if its occurrence is not deducible from the facts, it suggests that our conception of nature and its fundamental laws need modifying or expanding in order to accommodate and explain these phenomena. However, weak emergence may still require further explanation for its comprehension. The only example of strong emergence for Chalmers is consciousness. Most other examples cited in association with the science of complexity are instances of weak emergence, such as cellular automata (Chalmers 2006, 244-47). Eventually, he arrives at the following definition: “A weakly emergent property of a system is an interesting property that is unexpected, given the underlying principles governing the system” (Chalmers 2006, 254).

Generative art based on recent science and complex systems theory such as the works in the portfolio are weakly, rather than strongly, emergent. This distinction is important in avoiding misunderstandings of the capabilities of generative art. For instance, complex results may be produced which are surprising given the simplicity of the process. However, a completely “undeducible” phenomenon analogous to human consciousness cannot be expected. Partly in following the possibilities of weak emergence, I believe the aim of generative art should not be the emulation of “humanly-produced” art, or art produced by human consciousness. This point is developed further below.

Areas which have been described as emergent include nonlinear dynamical systems theory and far-from-equilibrium thermodynamics. I have mainly used examples from the former, with reference to the latter, in the works submitted for the portfolio. Although there are historical precedents for the use of dynamical and stochastic systems in music, in many cases I believe their implementation can be developed further, not only through advances in technology, but also through the use of a more appropriate form to the process used. These include their use at audio rate for audification, and a generative work taking on the property of sensitive dependence on initial conditions.

Noise

As mentioned, Galanter dismisses complexity and entropy in the context of information technology as not being useful as criteria for generative systems. These are also terms that are often used to describe noise, and similarly, such features alone are inadequate in characterising noise for the same reasons.

Experience confirms how unchanging and unrelenting white noise or continually complex music becomes predictable over longer time-scales and ceases to be as noisy. For noise to remain noise – or to at least attempt to do so – it requires alterations or unpredictability in the level of complexity or entropy, or noisiness, itself. This is not possible through consistently high complexity and entropy i.e. noise is more noisy if its level of noisiness is itself noisy. As Paul Hegarty states:

> The disruptiveness of this “form” . . . through volume, unpredictability and relentless change, makes a settling or dwelling difficult. This ecstatic non-music continually structures and destructures both the listening subject and music. . . . It is the movement and alternation between that makes it noise. . . . As listener and performer alike find and lose structures, find and lose repetitions and recurrence. (Hegarty 2007, 139)[8]

Emergence was proposed as a concept that occupies the middle ground between order and disorder. I would like to extend this claim and state that emergence offers the potential for both order and disorder in addition to the middle ground in between. By dynamically navigating through the spectrum of order and disorder in a manner that is unpredictable, it provides an effective vehicle for the production of noise as experimental art.

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[8] Michael Nyman also describes how both Stockhausen and Christian Wolff state that continuously unchanging complexity results in sameness, which was problematic for the former but not to the latter (Nyman 1999, 27).

Aesthetics

Noise could be considered as the extreme or limiting case within abstract experimental art. Through the possibility of emergent behaviour, generative systems are very much suited to the creation of noise. However, despite this potential gained through the use of generative systems, computational art generally is often not used to produce experimental art. There are, of course, exceptions which are discussed throughout this thesis. But much work carried out in this field mistakenly identifies computational research into existing artistic practice with the practice of new computational art itself e.g. David Cope's well-known Experiments in Musical Intelligence software, which should be considered as an attempt at a formalisation of existing music and not as a work of new music. The justification for middle-of-the-road approaches within computational art are more often or not due to a naïve understanding of art in general. A close examination of these arguments can be used to advocate experimentation and abstraction within computational art.

Artificial Life

The area of research that most explicitly uses the term emergence in describing their work is complex adaptive systems theory which includes the fields of Artificial Life, emergent computation, boolean networks and genetic algorithms (Goldstein 1999, 55-56). There has been an increase in its application as generative systems in music and art in recent times.[9]

Concerning AL, Christopher Langton states that its study could extend beyond "life-as-we-know-it" to include "life-as-it-could-be" (Langton 1991, xv). There is no reason why biology must restrict itself to the study of carbon-based life. Additionally, in order to distinguish universal properties of life to those that are incidental to life on earth, other kinds of life must be studied, with the only practical solution being its creation on machines (Langton 1992, 189).

[9] See for example (Miranda and Biles 2007).

An essential characteristic behaviour of living things is believed to be self-reproduction which was successfully replicated by the von Neumann machine (Langton 1992, 197-98). Langton also believes that "life is a property of form, not matter" i.e. behaviours or effects rather than stuff that is life (Langton 1992, 203). Hence life itself becomes achievable by machines. The immediate objection to this reasoning stems from the problem of defining life itself, and specifically to its restriction to behaviour alone. John von Neumann was aware that the axiomatisation of automata did not account for organic matter that consists of existing elementary or higher chemical molecules, and he concedes that this may be more important than behaviour (Von Neumann and Burks 1966, 77). Langton does address this issue by explaining that he is only after lifelike behaviour (Langton 1992: 49), but somewhere along the way this takes a leap in logic and behaviour becomes synonymous with life itself.[10]

Art-as-it-could-be

McCormack and Dorin's paraphrasing of the term "life-as-it-could-be" to "art-as-it-could-be" appears to elude this predicament. However, they state that just as any creation of life-as-it-could-be significantly different to life-as-we-know-it would be difficult to recognise as life (McCormack and Dorin 2001, 3), art-as-it-could-be would be unrecognisable in addition to being "incomprehensible, or just plain uninteresting" (McCormack and Dorin 2001, 7).

Yet this describes a typical scenario within abstract experimental art where new developments may initially be incomprehensible, extend beyond accepted notions of art and be difficult to recognise as art. In the case of noise which could be taken as an extreme or limiting case within experimental art, this is illustrated by its negative characteristics. According to Hegarty, noise is negative i.e. unwanted, other, not ordered. It is negatively defined i.e. "by what it is not (not acceptable sound, not music, not valid, not a message or a meaning)". Noise is thus a negativity, existing only in relation to what it is not, and as Hegarty states: "in turn, it helps to structure and define its opposite (the world of meaning, law, regulation, goodness, beauty, and so on)" (Hegarty 2007, 3-5).

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[10] N. Katherine Hayles describes Langton's reasoning as not only a tautology but a reinscription of the assumption in Western thought that form can be logically separated from, and is privileged over, matter. For other similar criticisms, see (Hayles 1999, 231-35).

Moreover, being defined against a dynamic entity such as music – as in traditional or already-existing music – noise itself is unstable i.e. as what is or is not music shifts, so too does noise.

Thus due to the very reason that an emergent system may produce art that may be difficult to recognise as art or be incomprehensible, computational art offers much potential in the creation of abstract experimental art.

McCormack and Dorin continue:

> Bowerbirds might be considered autonomous systems that make "art", but such activities remain principally of interest to biologists, not art critics. The creation of evolving agents that develop their own artistic practices should not be confused with the goal of widening the scope of art for human appreciation. (McCormack and Dorin 2001, 7)

Again, I disagree with their view and the general premise of their conception of art from which it stems. But their claims can be argued against on their own terms. First of all, the use of generative systems, in the context referred to by McCormack and Dorin, usually involves the "modelling" or at least the creation of the system i.e. the equivalent of a translation from a carbon to a computation base. In this case this would be the creation of an artificial bowerbird. Secondly, this reveals the aforementioned conservative conception of art similar to John Blacking's famous definition of music as "humanly-organised sound" (Blacking 1973, 10), the term "human" denigrating anything new, unfamiliar, unexpected or progressive.[11]

This view is reflected in research into computational creativity. The standard definition of artificial intelligence is usually given as thus: "The performance of tasks, which, if performed by a human, would be deemed to require intelligence". From this, Geraint Wiggins proposes a working definition of creativity: "The performance of tasks which, if performed by a human, would be

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[11] Cf Messiaen who considered birds to be not only virtuosos but artists (Deleuze and Guattari 1987, 316-17), and Deleuze's inclusion of the wren's courtship rituals which are similarly complex as the bowerbird's in the various descriptions of the refrain, not to mention other non-human behaviour and characteristics (Deleuze and Guattari 1987, 323-25).

deemed creative" (Wiggins 2006, 450-51). Although this is perhaps useful in researching human creativity, it is unable to distance itself from the anthropomorphism of the statement on which it is based. Margaret Boden's approach also involves investigating the creative potential of computers, beginning with the premise that creativity is an intrinsically human attribute (Boden 2004, 1).[12] And as Ian Bogost states: "The field of AI . . . pledges fealty to the human correlate [of human thinking] in its very name [of intelligence]" (Bogost 2012a, 15).

This conservative perspective also pervades seemingly experimental artists. For example, in criticising Cage's supposed removal of intention to allow all sound to be music, Francisco López states that:

> music is human, while sound existence is not. . . . The essential difference, what converts a sound into music, is a human, subjective, intentional, non-universal, not necessarily permanent, aesthetic decision. (López 1996)

Such terms are obviously relevant within the context of the arts, both in its production and its reception. However, restricting aesthetic discourse exclusively to what is accepted as representing human creativity severely limits and underestimates the potential of experimental art.

Experimental art

Through the radical novelty of emergence (Goldstein 1999, 50), generative art provides the very possibilities of extending what can be appreciated and accepted by not being restricted to the human or creations solely by human consciousness. As Xenakis states:

> In musical composition, construction must stem from originality which can be defined in extreme (perhaps inhuman) cases as the creation of

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[12] One example of such models being all too readily used in the creation of new music through computational means could be Richard Voss and John Clarke's findings on 1/*f* characteristics in existing music, which are interesting, but whose application to composition in order to replicate humanly acceptable traits found in traditional music is misguided (Voss and Clarke 1978).

> new rules or laws, as far as that is possible; as far as possible meaning original, not yet known or even foreseeable. (Xenakis 1992, 258)

Max Bense described the works displayed in the world's first digital or generative visual art exhibition in the Studiengalerie of the University of Stuttgart in 1965 as "artificial art" in order to pacify artists attending the opening who reacted unfavourably to the non-human art presented (Nake 2005, 54). The creation of such "artificial art" would be an appropriately more radical use of Artificial Life. Moreover, its implications could be furthered to include art not merely produced by artificial means, but also intended for reception and consumption by artificial life rather than human beings. This is akin to Goodiepal's tongue-in-cheek notion of "Radical Computer Music" catering for speculative alternative life-forms (Goodiepal 2009, 10-16).

This is not to deny the presence of human elements in computational art. After all, humans are still responsible for their programming and operation. But conceptually limiting the use of generative systems to the human is misguided for two reasons already mentioned. The first is due to the fact that their behaviour is only weakly emergent, meaning that a replication of phenomena comparable to consciousness is impossible. Secondly, due to their level of complexity and unpredictability, such systems are ideal for creating experimental results that may not have been possible through human intuition alone. Thus conceptualising its potential as also being non-anthropocentric in combination with the human element acknowledges their suitability to producing experimental art. This could also be considered as mirroring the aforementioned necessity of considering aspects of both culturalism and formalism in software and generative art.

This view is reflected in the use of emergent systems in the works in the portfolio. The programs for each work should not be considered as a replacement for a human performer as they are not capable of emulating such behaviour. Instead, they take advantage of their computational capabilities in producing emergent phenomena beyond those that are humanly possible.

Machinic

As mentioned, software allows for the programming of algorithms and, by extension, generative art, which operate upon machines, humans and themselves. Andrew Goffey describes the proper understanding of such concerns stemming from the functioning of algorithms as a “sort of machinic discourse” (Goffey 2008, 17-18). One form of aesthetics which takes the capabilities of digital technology into consideration appropriately is the machinic. It is a concept originally associated with Gilles Deleuze and Félix Guattari. One explanation he offers involves the notion of autopoiesis, a term coined by Humberto Maturana and Francisco Varela to convey autonomy of creation and production, a central feature in the organisation of the living (Maturana and Varela 1980, xvii). Guattari’s conception of the machinic involves the rethinking of autopoiesis,

> in relation to entities that are evolutive and collective, and that sustain diverse kinds of relations of alterity, rather than being implacably closed in upon themselves. (Guattari 1993, 17)

Furthermore, when self-organisation, or autopoiesis, began to be understood as the springboard to emergence, the science of complexity was born (Hayles 1999, 11). The machinic is thus a fitting characteristic to evoke in generative art that makes use of emergence, as both are dynamic, concern relations between its constituents and are built on plurality. I believe it is appropriate, productive and necessary for the creation of experimental art, or art-as-it-could-be.

Andreas Broeckmann uses the notion of the machinic within aesthetics and states that:

> Machinic art acts as the facilitation of aggregations of bodies and forces in which no meaningful differentiation can be made between human and machine. The functionality of the machinic itself becomes the core of the aesthetic force it exerts, creating a phylum that does not distinguish between human and machine agency. (Broeckmann 1997a)

Examples given by Broeckmann of a variety of machinic art shows that the term implies the refusal to be constricted to anthropomorphic criteria alone pointing towards a combination of human and non-human elements (Broeckmann 1997a), in contrast to the aforementioned views of Blacking and Wiggins. Through considering the machinic, matters such as whether computers are capable of creativity or the balance of intentionality between humans and computers in generative art become less paramount in comparison to the nature of the processes by which the technical and the human combine and produce as stated previously.

It is also a shift “from the level of fascination with technical hardware to the level of movements, of processes, of dynamics, of change” (Broeckmann 1997b, 55), echoed by Goodiepal’s dismissal of most technology-based art works for novelty’s sake (Goodiepal 2009, 10-16). This is a charge that could be levelled at many art works that employ interactivity or generative systems as mere gimmicks without any aesthetic justification. In contrast, the implications and results made possible through their use are carefully considered in the works from the portfolio by exploring generative systems and emergence as artistic material to produce new forms, and approaches. Furthermore, the aforementioned notion of praxis in the creative use of software that interweaves both theory and practice is encapsulated within the machinic.

Cyborg

As a hybrid of machine and organism, the concept of the cybernetic organism or the cyborg (Haraway 1991, 149) also resonates with the machinic aesthetics outlined. Donna Haraway notes how certain dualities have been deeply ingrained within traditional Western thought. These oppositions include:

> self/other, mind/body, culture/nature, male/female, civilized/primitive, reality/appearance, whole/part, agent/resource, maker/made, active/passive, right/wrong, truth/illusion, total/partial, God/man. (Haraway 1991, 177)

Gradually, boundaries between human and animal, animal-human (organism) and machine, and the physical and the non-physical have been breached

(Haraway 1991, 151-53). High-tech culture challenges accepted dualisms. As Haraway states, within a cyborg:

> It is not clear who makes and who is made in the relation between human and machine. It is not clear what is mind and what body in machines that resolve into coding practices. (Haraway 1991, 177)

Beyond its original socio-political context, her call for a confusion of such boundaries (Haraway 1991, 150) can also be productive and a responsibility for the experimental artist using technology such as emergent systems as outlined. It reiterates ideas previously mentioned regarding the importance of what becomes possible through technology rather than who – the programmer or the program – produced it.

The notion of the machinic and the cyborg relate to the approach taken in the works in the portfolio. Whether through providing an initial "seed" from which an iteration is calculated in *CiS* or carrying out real-time manipulation of parameters throughout a performance in *CiZ* and *CiK*, the outcome of each rendering is clearly influenced by both human input and the program. But due to the emergent nature of the generative systems used, the results cannot be accurately attributed to each agency. Instead, the creative possibilities due to their combination are assessed together. Moreover, this uncertainty in intentionality also contributes to maintaining interest in the works for both the performer and the audience.

(New) Aesthetic

The New Aesthetic (Bridle 2011) may be considered as a recent example of the machinic and the cyborg within the visual arts and design. It is a stylistic predilection for the effects of processes via which computers receive, display and transmit data. For Bruce Sterling it includes the following:

> Information visualization. Satellite views. Parametric architecture. Surveillance cameras. Digital image processing. Data-mashed video frames. Glitches and corruption artifacts. Voxelated 3D pixels in real-

> world geometries. Dazzle camo. Augments. Render ghosts. And, last and least, nostalgic retro 8bit graphics from the 1980s. (Sterling 2012)

Greg Borenstein highlights perhaps its most promising aspect in reference to Ian Bogost's concept of alien phenomenology:

> New Aesthetics is not simply an aesthetic fetish of the texture of these images, but an inquiry into the objects that make them. It's an attempt to imagine the inner lives of the native objects of the 21st century and to visualize how they imagine us. (Borenstein 2012)

Many of the examples above have obvious counterparts in music: data sonification, field recordings at different scales of amplitude, hacking/scanning of radio/mobile communication, digital signal processing, sampling/mash-up, glitch and the aesthetics of failure, and 8-bit "chiptune" audio from games consoles. The notion of the alien can illuminate the aesthetic basis for these techniques – in particular, sonification (including audification) which is employed throughout the works in the portfolio.

Alien phenomenology

However, the scope of the New Aesthetic is restrictive for Bogost due to its limitation to computational media and their relationship to human beings. He concedes the special status afforded to computers due to their influence and import, but nevertheless regards them as only one type among many others. Likewise, there are many other relationships that exist between things as well as with ourselves. The irreducibility of objects does mean that humans may never be able to fully comprehend computers or other things and their relations on their own terms. But there is no reason why this should not be speculated upon. This is the general basis for "alien phenomenology" (Bogost 2012a, 32-34), his version of object-oriented phenomenology (Bogost 2012a, 5-6):

> A *really* new aesthetics might work differently: instead of concerning itself with the way we humans see our world differently when we begin to see it through and with computer media that themselves "see" the world in various ways, what if we asked how computers and bonobos and toaster

> pastries and Boeing 787 Dreamliners develop their own aesthetics. The perception and experience of other beings remains outside our grasp, yet available to speculation thanks to evidence that emanates from their withdrawn cores like radiation around the event horizon of a black hole. The aesthetics of other beings remain likewise inaccessible to knowledge, but not to speculation – even to art. (Bogost 2012b)

This is comparable to Goodiepal's notion of composing music for hypothetical "alternative life" such as sewage and electrical systems as well as for comoputers (Goodiepal 2009, 15-16).

Alien music

Throughout the history of electronic music, new developments have been described as strange, other-worldly and "alien". The soundtrack by Louis and Bebe Barron for the film *Forbidden Planet* (1956) is just one such case in point where *musique concrète* is used to conjure an unearthly atmosphere. Kraftwerk and Afrofuturism including dub and Detroit techno evoking the imminent age of the machine and the future – and intentionally playing up to this image – is another (Goodman 2009, 1, 201).

Works of algorithmic composition or sonification/visualisation such as those found in the portfolio can be described as being alien in a more precise way. They present the generative systems behind the works directly as audio or visuals. Thus they are speculation into how abstract phenomena such as a trajectory approaching different attractors may be experienced.

Algorave, or algorithmic rave, are a recent series of club nights featuring performances of generative beat-based music. In promotional material, they state that:

> alien sounds of rave music are augmented with the alien structures of algorithmic composition and the audience finds new ways to enjoy and dance to the music. (Algorave 2013)

Their description conveys a feeling of discontent which many experimental electronic artists can perhaps relate to: namely the use of inappropriately traditional structures (such as the pop song or classical sonata form to regular meter and traditional western harmony) framing what are at least initially novel timbres. In addition, I would contend the opposite to also be the case: that the alien structures of algorithmic composition for far too long have relied on inappropriately traditional timbres, the worst offender perhaps being the conventional use of samples of piano sounds within otherwise innovative control rate systems. Thus “alien” synthesis strives for the production of hitherto unheard timbres instead of the emulation of acoustic instruments, and “alien” structure attempts novel and previously unthought constructions of longer durations.

The previous chapter described how one possibility of making appropriate use of the potential of computational art is through the use of generative systems. As such algorithms are not capable of recreating strongly emergent behaviour, it is misguided to attempt to replicate art created by human-consciousness through their use. Their capacity for weakly emergent behaviour is instead very much suited to producing noise and experimentation.

The aesthetic potential of emergence can be characterised by non-anthropocentric conceptions of aesthetics introduced in this chapter. The works in the portfolio operate in this domain by directly using emergent behaviour as material. The resulting audio and audiovisuals are therefore a product of the combination of the human – i.e. myself, as artist and programmer – and the non-human – i.e. the emergent generative systems used.

Systems

Two typical examples of emergent phenomena given by Crutchfield are deterministic chaos and a fractal structure produced by a self-avoiding random walk (Crutchfield 1994, 13). These are the systems that were used in the works for the portfolio.

The following section refers to Movie examples from *CiZ* in order to illustrate the properties of the system described.

The Lorenz system

The first of these is the Lorenz dynamical system, a representation of forced dissipative hydrodynamic flow and a model for convection currents proposed by Edward Lorenz (Lorenz 1963, 130). It is governed by the following ordinary differential equations (Lorenz 1963, 135):

$$dx/dt = \sigma(y - x),$$

$$dy/dt = x(r - z) - y,$$

$$dz/dt = xy - bz.$$

These represent the rate of change of each dimension, the variables being the Prandtl number σ, the Rayleigh number r , and parameter b related to the physical size of the system (Hirsch, Smale, and Devaney 2004, 304).

The inclusion of the coordinate value (e.g. x) in calculating its rate of change (e.g. dx/dt) represents a form of feedback similar to those found in autocatalytic processes where its presence is required for its further synthesis by acting as an enzyme for its own production in chemical reactions. The inclusion of other coordinate values in each of the equations is analogous to crosscatalysis, where substances are mutually dependent on the presence of the other for its own production (Prigogine and Stengers 1984, 134-35). Thus similar mechanisms are found in real-world examples.[13] In fact, the Lorenz equations have been shown to occur in many other fields of research such as biology, circuit theory and mechanics (Sparrow 1982, 4).

Lorenz sought to model the unpredictability of the weather. The workings of the equations suggest that complex and unpredictable behaviour of real-world systems, such as the atmosphere, can be modelled by simple deterministic finite-dimensional systems (Sparrow 1982, 1-3). He stated that the equations do not produce realistic representations at large values of the Rayleigh number *r*. They do however demonstrate how even simple deterministic short-term rules can account for the long-term unpredictability of the weather. The extension of such parameters beyond their original real-world limits provides the perfect opportunity for the development of experimental art, or art-as-it-could-be.

Sensitive dependence on initial conditions

In addition to the values of the three parameters, initial coordinates are necessary from which *x*, *y* and *z* coordinates can be generated forming trajectories which describe their change of state (DeLanda 2002, 14). At typical parameter values σ=10, *b*=8/3 and *r*=28, the system produces the well-known lemniscate shape. It could be described as turbulent i.e. not periodic, not settling to either periodic or stationary behaviour and not intersecting itself (Sparrow 1982, 2-3). The initial conditions do not affect the general form of the figure i.e. most starting coordinates with the same parameter values will produce a similar lemniscate shape. This complicated set that all trajectories tend towards is known as the Lorenz attractor (Hirsch et al. 2004, 305). It is a “strange” attractor because it has a non-integer dimension i.e. it has zero volume, like the Cantor set. However, the exact trajectory is highly dependent on the initial location (Sparrow 1982, 2-3): no matter how close two initial points are, their trajectories will eventually diverge completely and thus it has the hallmark of sensitive dependence on initial conditions (Hirsch et al. 2004, 305). It is generally assumed that the term “butterfly effect” was coined after Lorenz’s address to the American Association for the Advancement of Science in 1972 entitled: “Does the Flap of a Butterfly's wings in Brazil Set Off a Tornado in

[13] E.g. in the Belousov-Zhabotinsky reaction (Prigogine and Stengers 1984, 152).

Texas?” in which he briefly discussed the implications of his discovery (Lorenz 1972).[14]

With typical parameter values, the trajectory is emergent: short of actually calculating the values, its trajectory cannot be determined, which corresponds to the ostensive nature of emergent phenomena (Goldstein 1999, 50). It is unpredictable as it cannot be solved analytically due to its inherent nonlinearity, and thus demonstrates how emergence is not merely a provisional construct due to the inadequacies of our current understanding which is assumed to become unnecessary as science progresses (Goldstein 1999, 59-62).

Attractors and basins of attraction

In general, the trajectories eventually reach a steady state or a periodic orbit at lower values of the Rayleigh number *r*. The starting coordinates are not necessarily reliable indicators of their trajectory and a minute variation may result in different final states e.g. the trajectories may converge towards different attractors. This occurs from 0:20 in Movie example 1, towards the end of Movie example 4, and also in Movie example 7 in which after a period of silence and inertia when the two trajectories are almost identical, they diverge causing chaotic gestures in the audiovisuals. Conversely, distant initial coordinates may result in the same final state and converge towards the same attractor as in Movie example 3. This is dependent on the basin of attraction the initial points are located in (DeLanda 2002, 15).

The fact that attractors of stable systems are also applicable to chemical systems was known long before the discovery of the Lorenz attractor (Prigogine and Stengers 1984, 151-52). Regular periodic orbits or limit cycles occurring in these instances are capable of producing “chemical clocks” (Prigogine and Stengers 1984, 147). The Lorenz equations are derived from Rayleigh-Bénard convection cells (Lorenz 1963, 130-35), exemplars of such “dissipative structures” and behaviour, and probably one of the simplest physical mechanisms for communication (Prigogine and Stengers 1984, 148).

[14] Others claim, however, that the term originally referred to the lemniscate shape of the attractor (Wikiversity 2011).

Arrow of time

Another fundamental difference is in regard to entropy, in the original thermodynamic context. When in “turbulent” orbit, it is possible to calculate its past trajectory from its current state due to the method for solving the Lorenz equations.[15] As its path is never crossed, it effectively “stores” its trajectory as far back as its initial coordinates. There is no increase in entropy and hence the process is reversible as with classic examples of dynamical systems such as a pendulum, where its starting point is never forgotten as it determines its subsequent trajectory in ideal conditions (Prigogine and Stengers 1984, 121).

In contrast, in a steady state or a periodic orbit, its past trajectory is forgotten and the final state is determined by its basin of attraction rather than its precise starting coordinates, analogous to an evolution towards equilibrium or a stationary state in linear and equilibrium thermodynamics (Prigogine and Stengers 1984, 139). There is an increase in entropy and hence the process is irreversible as the correspondence from one point to the next is no longer a one-to-one mapping.

This also applies to trajectories that are initially chaotic but eventually reach a steady state or a periodic orbit. After a certain point when its change in state becomes regular, the entropy price becomes too high and the initial conditions become irretrievable (Prigogine and Stengers 1984, 284). This is evident at the beginning of *CiK* Part 1 where after 50 seconds of turbulence, it enters a periodic orbit.

The change in entropy is significant as it represents a qualitative alteration to the behaviour of the system in terms of computability, which could be regarded as an example of emergent phenomena. The incomputability of its past also introduces the arrow of time, situating the process in the real-world of experience and real-time.

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[15] Its accuracy is restricted by the precision of the values which are dependent on the bit rate and the solving method for the differential equations.

Vector fields, perturbations, phase transitions

The presence and the effects of attractors and their basins of attraction can be represented in a vector field (DeLanda 2002, 30), usually displayed in a grid of arrows referring to the direction and magnitude of the rate of change at those particular points. The alteration in parameters such as changes in the Rayleigh number *r* subjects the vector field to "external shocks" or "perturbations" (DeLanda 2002, 19) e.g. in Movie examples 2 and 5.[16] These cause a temporary colour inversion in the visuals – the "negative effect" – and often an audio "glitch", indicating moments of human interaction on the generative process. Depending on the magnitude of the external shock, a phase transition or bifurcation may occur where the positions and the type of attractors and basins of attraction are transformed and a new vector field emerges (DeLanda 2002, 19) as evident in Movie examples 1 and 5 and at 0:44 in Movie example 2. Thus a system may have numerous different vector fields, representing the possibility for the variety in the trajectories of the Lorenz system.

Ordinary and singular events

A good analogy for the parameters is the temperature of a substance such as water. Between 0 and 100ºC, any change in the temperature will result in an approximately proportional alteration in properties such as the amplitude of vibration of each molecule, but will not cause a change in state i.e. it will remain a liquid. Similarly, most stepwise changes in the variables only result in approximately linear shifts in the spatial coordinates if the trajectory has reached a limit cycle e.g. after the first five perturbation in Movie example 2 caused by progressively increasing *b*. These can be described as ordinary events. However, crossing either the boiling or melting points will result in a significant structural modification and a change of state to either a gas or a solid that is no longer an ordinary, but a singular event. Likewise, the variables traversing a critical threshold will result in a phase transition (DeLanda 2002, 61), altering the vector field and hence the trajectories through it, as seen after the final external shock in Movie example 2. In addition, the use of such a model need not be constrained by reality, and the continuity in variables is

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[16] Trajectories may also be returned to their initial coordinates e.g. in Movie examples 4 and 7. Perturbations and "resets" alternate in Movie example 1.

disregarded in the perturbations of Movie examples 1 and 5, usually causing immediately visible and audible changes due to the occurrence of a phase transition. This is an example of art-as-it-could-be.

Second type of first-order emergence

The manner in which attractors form, are modified and mutate through bifurcations illustrates the dynamical characteristic of emergence that is contrary to the pre-given sense of a gestalt (Goldstein 1999, 52). It could be considered analogous to the second type of first-order emergence. According to Luc Steels, the first type of first-order emergence is a side effect of behaviour systems within environments. The second type is based on a first-type emergent temporary structure that is then exploited to establish new emergent behaviour (Steels 1994, 90-93). In the analogy, as the metamorphosis of the attractors account for the emergent behaviour of the trajectories, the former are the first type while the latter are the second. This is evident in Movie examples 1 and 5 when parameters are changed, producing a different attractor which alters the trajectories.

Mandelbox

The second system used is the Mandelbox fractal. The term fractal was coined by Benoit Mandelbrot and popularised through computer-generated images. He defines a fractal as a set for which the Hausdorff Besicovitch or fractal dimension exceeds the (standard) topological dimension. Every set with a non-integer fractal dimension is a fractal, such as the aforementioned Cantor set and Lorenz attractor. But a fractal may still have an integer fractal dimension such as the trail of Brownian motion. The best fractals according to Mandelbrot are those that exhibit the maximum possible invariance under displacement, and the maximum invariance under scaling (for scaling fractals) (Mandelbrot 1983, 15-18).

Being relatively new, relevant resources on the Mandelbox are scarce and generally limited to internet forum posts. Previous works of its visualisations may be found online – see for example (Lowe 2010). But to the best of my knowledge, *CiK* is the first example of its sonification. Hence it is also the first time that it has been used as a generative system in order to produce audiovisuals.

The Mandelbox is one example of a recent fractal inspired and based on the famous Mandelbrot set. It is an escape-time fractal like the Mandelbrot. The recursive algorithm involves the following four steps (Lowe 2010):

1. Fold in area past length L from the origin along each axis.

2. Fold out circle past radius R from origin in each dimension.

3. Multiply by scale S.

4. Add constant C.

The values of the variables for the standard Mandelbox are S=2, R=0.5 and L=1.

As with the Lorenz system, the data from the Mandelbox are emergent: they are dynamical and unpredictable, producing ostensive macro-level coherence. A few of the aforementioned features of the dynamical system are also applicable to the fractal to varying degrees. Below are characteristics of the Mandelbox not found in the Lorenz, which contribute to the traits of the fractal set and to the results of its presentation as audiovisuals.

Dimensions

The creator of the Mandelbox, Tom Lowe, describes it as a multi-fractal i.e. its fractal dimension can vary (Lowe 2010). To a certain extent, this reflects the variety in the patterns which it can generate.

The Mandelbrot set is usually displayed in two-dimensional space, with the axes corresponding to real and imaginary components. Its translation – and that of the related Julia set – to three dimensions whilst retaining the same level of complexity in the patterns created has not been straightforward. The most successful attempt has perhaps been through the use of quaternions resulting in four dimensions, out of which three are visualised (WikiBooks 2010, Quaternions). The Mandelbox is inspired by such attempts and extends the number of dimensions available. Its implementation in three-dimensions is very much suited to being represented visually via the three-dimensional environment available in OpenGL, as seen in *CiK*.

The baker's map

The iterative process of the Mandelbox is similar to the well-known baker's map whose algorithm involves flattening a square into a rectangle, then folding in half to form a square. After a sufficient number of transformations, any section of the original square regardless of its size or location will become fragmented. Any transformed region thus contains different trajectories due to the complexity of basins of attraction. Therefore, although the procedure is deterministic, a description of a particular area is statistical (Prigogine and Stengers 1984, 269-70).[17]

Squares and circles

The iteration involved in calculating escape-time fractals generally could be considered as a characteristically computational and non-human operation: its incessant repetitions appear machine-like and inorganic, and it is very much suited to being facilitated by digital technology through low-level automation.

Partly as a result of such procedures, ordered repetitions can often be observed in the data from the Mandelbox. Visually, these areas might resemble straight lines, flat surfaces or grids depending on the number of dimensions visible. As audio, these correspond to timbres with strong pitches, repetitive rhythms or sections depending on the time-scale it operates on. These regular patterns stem from step 1 of the recursive algorithm which produce straight edges. Similar figures can also be generated by the aforementioned baker's map.

The major difference between the two iterative processes of the Mandelbox and the baker's map is the second step. Whereas the baker's map involves a stretching out that replicates existing straight edges, the Mandelbox iteration uses a circle and thus introduces round edges. As a result, the mixture of

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[17] Prigogine and Stengers use the baker's transform to demonstrate the necessity of the arrow of time, or the second law of thermodynamics, and how entropy must always increase (Prigogine and Stengers 1984, 272-80).

curves and straight lines produces a fractal composed of a variety of contours. This is one reason why the Mandelbox appears to contain a diverse range of approximations of other existing fractals.

The characteristics of the data produced by the Mandelbox – from smooth curvatures and square waves to a mixture of the two resulting in chaotic patterns – is also suited to being used as audio due to the variety of audible features they correspond to. Thus a whole range of behaviours become possible, from the aforementioned regularity, smooth oscillations and gradual changes, to noisy timbres, chaotic rhythms and complex structures.

Part II: Techniques

In this section, the techniques used in the works are discussed in order of their appearance in the portfolio.

Data as Audio

This chapter refers to techniques first used in *CiS*, the first work in the portfolio, and developed in *CiZ* and *CiK*.

Auditory display and music

	All rates (inc. control)	Audio rate
Real-world data	Sonification	Audification
Generative system	Algorithmic composition	Non-standard synthesis

Table 1. Categories of the use of data as audio.

Table 1 describes categories of presenting data as audio used in auditory displays and music. It shows different ways in which the processes used in the works in the portfolio can be described.

Auditory displays present information using non-speech sounds. According to Bruce Walker and Gregory Kramer, they consist of five main categories: alerts/notifications, earcons, auditory icons, audification and sonification. Audification is the direct transposition of data into the audible range. Sonification is the use of data to change parameters of a sound, sometimes containing elements of the other approaches mentioned: hence it is often used interchangeably with the general technique found in auditory displays as a whole (Walker and Kramer

2004, 152-55). These approaches have also been used in aesthetic contexts, examples of which are given below.

Audification operates at audio rate i.e. data is typically sampled at around 44,100 Hz or more. It is one particular category within the broader field of sonification which can also operate at other data rates such as control rate (typically from around 1000 Hz to a lot less).

Analogous approaches in the context of music are non-standard synthesis and algorithmic composition. As Di Scipio notes, the distinction between non-standard synthesis and algorithmic composition is a matter of degree (Di Scipio 1994, 203-4): the former could be described as an example of the latter at audio rate. This corresponds to the distinction between audification and sonification.

In the digital realm, data is data, regardless of whether they originate from sensors taking readings from the external world or from processes occurring within a computer. Thus in terms of operation, the presentation as audio of real-world phenomena and the presentation as audio of simulations of phenomena become equivalent processes. Consequently, sonification of data from the real-world is analogous to algorithmic composition, the sonification of generative systems. In addition, audification of data from the real-world is analogous to non-standard synthesis, the presentation of data at audio rate.

The distinction between the use of data from the real-world and the use of generative systems can be characterised metaphorically by the aforementioned concepts of life-as-we-know-it and life-as-it-could-be. The use of data generated from systems allows for real-world simulations to be modified and even for models with no basis in reality to be constructed within algorithmic composition. Thus sonification equates to the presentation as data of life-as-we-know-it with potential to create art-as-we-know-it, while algorithmic composition equates to the presentation as data of life-as-it-could-be with potential to create art-as-it-could-be.

Self-similar sonification

In *CiS*, *CiZ* and *CiK*, I have presented data at audio rate and other data rates such as control rate simultaneously through an approach I describe as "self-similar sonification" (SSS). This refers to the use of data as sound at multiple time-scales. Audio rate use generally affects timbre, and control rate use results in alterations in "rhythms" or "pitches". In addition, data is used at the "phrasal" level (relating to phrases at time-scales of 1 to 30 seconds approximately) and at the level of structure (relating to sections and their progression in the work).

SSS is a combination of the different elements found in existing works mentioned in this chapter. It provides the possibility of emergent behaviour and hence the scope for noise and applying the alien at different time-scales through sonification (or algorithmic composition) techniques including audification (or non-standard synthesis). The approach could also be described as "total" sonification – the term being used in the same sense as total serialism – as many parameters of the work are determined by the sonification of the same data. It is also an attempt at using sonic elements found in underground electronic music through non-standard synthesis, whilst maintaining the formal organisational rigour found in algorithmic composition.

Self-similarity

Xenakis suggests the use of generative processes at both audio and control rate: "sound molecules produced by . . . methods [based on probability distributions] could be injected into the ST(ochastic) program . . . forming the macrostructure", implying that both time-scales could be governed by the same generative process (Xenakis 1992, 249). Examples of such practice are, however, uncommon. It is evident to some extent in *GENDY3* (1991), where the microlevel is determined by his dynamic stochastic synthesis program GENDYN, and the larger scale structure is controlled by an additional program PARAG. However, only the start and end times of each of the 16 synthesis "voices" are controlled stochastically, the remaining parameters such as the location of mirror boundaries or the probability distribution used being decided intuitively.[18]

Self-similarity as a concept has been used in the description and analyses of existing music, from classical works conforming to Schenkerian analysis (Degazio 1986, 435) to György Ligeti (Steinitz 1996a, b). Tom Johnson is an example of a composer who explicitly forms self-similar structures inside his works (Johnson 2006). These examples are representative of the majority of its application in being instrumental works where the smallest possible unit is the note. In contrast, digital audio allows for its audio rate use, significantly extending the scale at which self-similarity can be applied. Fractal processes have been used at the scale of audio samples by Shahrokh David Yadegari (Yadegari 1991) and by Gordon Monro through fractal waveform interpolation producing characteristics similar to the Shepard tone (Monro 1995, Risset 1986). Otherwise, however, its application has been limited.[19]

Audio rate

What differentiates the presentation of data at audio rate from other rates is the increased possibility of the production of higher-order time structures such as timbre and amplitude envelope. Working at audio rate results in alterations in the spectral properties of the wavetable as by-products of its manipulation at the sample level. Di Scipio describes this process as “sonological emergence” (Di Scipio 1994, 205), due to macro-level epiphenomena being created through micro-level dynamic processes. Previously, Xenakis described the same procedure as the production of sonorities of higher-orders through “microcomposition” (Xenakis 1992, 47).[20]

These higher-order time structures have proved to be a rich source of material for use in an aesthetic context, and are used extensively in *CiS*, *CiZ* and *CiK*. Their use is informed by both the contexts of auditory displays (as audification)

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[18] EVOL’s *Fart Synthesis* (Presto!?, 2009) and *Untitled Anthem Study* (2010) were inspired by the work of Mandelbrot, and their musical structures use self-similarity and iterated function systems (Fell and Gilmore 2010), although to what extent is unclear.

[19] For an extensive survey of all things self-similar in music, see (Pareyon 2011).

[20] These could also include the formation of certain pitches as found in *GENDY3* (1991) (Hoffmann 2004, 138).

and music (as non-standard synthesis) which provide related but different potential. On the one hand, as per the aims of audification, these macro-level features reveal properties of the micro-level data or formalised process, serving a didactic function in explaining the underlying system behind the works. On the other hand, as per the aims of non-standard synthesis, formal processes are used in providing richness and variety in the new sonorities produced.

Audification

Christina Kubisch's *Electrical Walks* (2003) is an example of audification of real-world data in real-time. The piece involves the participants walking through a city or a town wearing a specially designed device with headphones that convert electromagnetic waves into audio. They are free to follow a prescribed route or explore the streets of their own accord. It has been presented in various countries.

Kubisch states that her work reveals a previously hidden and undetected world (IKON 2006). However, Seth Kim-Cohen is dismissive of such claims which he finds to be typical of interpretations of *Walks*. The uncovering of the presence of electromagnetic waves alone is insufficient as an aesthetic validation of the work for Kim-Cohen as the resulting sounds cannot be understood by humans in any meaningful way:

> To "read" the work as if it is conveying a message – as if it is the product of a legible intention – seems forced. . . .
>
> As far as the experience of art is concerned, the revelation of phenomena is not enough. Kubisch's walks may introduce us to a normally inaudible by-product of the city's activities. But what can we do with those sounds? What kind of aesthetic value do they deliver? (Kim-Cohen 2009, 111-12)

As Kim-Cohen also rightly notes regarding the use of EEG data as a source of audio, sonification in aesthetic contexts often fails to make full and appropriate use of the information contained in the data (Kim-Cohen 2009, 100-1).

By contrast, in the context of scientific research as attested to by the work of ICAD, a well-implemented application of sonification can reveal not just the presence of phenomena but also their features which may not otherwise be apparent through other methods of display; see for example (Kramer, Walker, Bonebright, Cook, Flowers, Miner, and Neuhoff 1997). One commonly cited explanation is the ear's capacity for monitoring a large number of changing variables and/or temporally complex information simultaneously (Kramer et al. 1997, 5).

Similarly, my use of data as audio takes advantage of such possibilities through the use of the aforementioned formation of higher-order time-structures which convey characteristics of the underlying generative system. One example of the production of timbre and amplitude envelopes similar to those found in my works is in seismology where it can reveal information concerning earthquakes. In such cases, loudness corresponds to the magnitude and the distance of the earthquake as might be expected. But additionally, timbre is a good indicator of the material e.g. metallic sounds indicate sediments and wooden sounds indicate bedrocks. Furthermore, its tectonic source mechanism can be inferred from its amplitude envelope e.g. a sharp hard beat indicates one plate subducting the other and a "plop" indicates two plates moving apart (Dombois 2002, 28).

Moreover, such features form a central part in dictating numerous aspects of the works produced. For further details, see the chapter on *CiS* in particular. Thus an additional way in addressing the lack of rigour that Kim-Cohen finds in *Walks* is provided by carefully considering the context provided by the generative system used.

Non-standard synthesis

The use of generative systems at audio rate equates to what Steven Holtzman first described as "non-standard" synthesis (Holtzman 1979, 53).[21] Most synthesis methods can be considered as being "standard", in the sense that they follow acoustic models. These include additive and subtractive synthesis, waveshaping, FM, RM, AM and physical modelling. In contrast, the "non-

[21] Otto Laske has also used this term (Laske 1989, 55).

standard" approach involves no pre-existing acoustic model (Di Scipio and Prignano 1996, 31), corresponding with what Xenakis described as "a new path in microsound synthesis research" (Xenakis 1992, 246). The main early examples of its implementation are Gottfried Koenig's SSP, Herbert Brün's SAWDUST and Xenakis's GENDYN.

The sonic results could be regarded as a further development of abstraction in sound, and an attempt at art-as-it-could-be, where:

> the sounding result is not necessarily a predictable, linear function of the control-structure: since no pre-existing, known acoustic phenomenon is simulated, the composer cannot operate in a straightforward, goal-driven manner (at least not before the observation of the process behavior). (Di Scipio 1995, 40)

In contrast, the emulation of pre-existing acoustic models would be analogous to art-as-we-know it.

Agostino Di Scipio and Ignazio Prignano describe this as an example of the "microstructural time-modelling of sound" (Di Scipio and Prignano 1996, 32) which has certainly been facilitated by the digital medium. Compositional concerns at the timbral-level are also addressed in works of *elektronische musik* and *musique concrète* that predate the widespread use of computers. However, in addition to significantly increasing the scope for complexity through automation, digital technology decreases the minimum time-unit at which sound can be manipulated, allowing digital audio samples to directly become material upon which compositional processes can be applied (Di Scipio 1995, 39-40).

Recent examples of non-standard synthesis include the use of Chua's Circuit (Mayer-Kress, Choi, Weber, Barger, and Hubler 1993), iterated functions (Di Scipio and Prignano 1996, Di Scipio 2001), waveform segmentation (Chandra 1994, 1996) and Lindenmayer systems (Manousakis 2009).[22] These are, however, the exceptions rather than the rule in computer music practice within

[22] However, Di Scipio does sometimes includes these in the broader category of "microstructural time-modelling of sound", reserving the term non-standard for the three historical examples mentioned (Di Scipio 1995, 39-40). For more examples, also see (Di Scipio 1994, 205-6).

academia. Although they are frequently used at control rate generally, their use at audio rate is less common, as Florian Hecker also remarks (Hecker 2006).

Just as audification appears to be far more widespread among amateurs for science popularisation or general amusement rather than professional scientific research (Dombois and Eckel 2011, 316), its use in the arts appears to be more common outside academic institutions. This is evident in a whole variety of practices found in alternative settings, from hardware hacking to software implementations of chaotic systems at audio rate found in audio programming environments such as Supercollider and Max/MSP, to a combination of the two as with Martin Howse's "data carvery" involving the audification of discarded harddisks (Reboot FM 2011). As the sound-world evoked contains elements of noise, glitch and drone typically found in underground electronic music exemplified by artists such as Hecker, this may be unsurprising.[23]

Control rate

In contrast, algorithmic composition or sonification at control rate has its roots in academic computer music (Ostertag 1998) through its rigorous formal organisation. Consequently, the simultaneous use of both audification specifically (or non-standard synthesis) and other sonification techniques (or algorithmic composition) within SSS is an amalgamation of the two approaches: the underground and the academic. It is an attempt at producing results that are both sonically cutting-edge and structurally engaging.

Examples of works that make use of sonification of real-world pre-stored data include Charles Dodge's *Earth's Magnetic Field* (1970), Bob L. Sturm's *Music From The Ocean* (2002) and Johannes Kreidler's humorous *Charts Music* (2009). Real-time sonification has also become possible within recent years in installation-type works e.g. John Eacott's *Flood Tide* (2008) which generates an improvisatory score from the tide of the Thames for instrumentalists, and Jonathan Howse and Mark Fell's *Scale Structure Synthesis* (2012) which

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[23] Hecker has uses chaotic systems such as the the Hénon Map and the Gingerbread Man function in *Recordings for Rephlex* (2006). He has also used GENDYN in collaboration with Russell Haswell on Hecker and Haswell's *Kanal GENDYN* (2011).

involves a high-powered optical microscope to track movements of nanoparticles that are mapped to synthesis parameters.

Examples of control rate use of generative systems similar to those found in the portfolio include early uses of fractals such as in Bruno Degazio's *FRACTAL* works (Degazio 1986) and Charles Dodge's *Profile* (1985) (Dodge 1988), and the use of nonlinear dynamical systems (Pressing 1988). However, these are exactly the cases of "alien" control rate structures of algorithmic composition using inappropriately traditional form and timbres such as dodecaphony and piano samples mentioned previously.

Marcus Schmickler's audiovisual installation, *the Bonn Patternization* (2009), is a sonification of astrophysical data at control rate. Through the use of subtractive synthesis, the sound world evoked is certainly more congruous with the art-as-it-could-be control rate data. However, the audio rate data has been assigned intuitively and is unrelated to the sonified control rate data. Instead, a formally more appropriate timbre may be provided through the use of audification or non-standard synthesis

Inflection point triggering

As much of the data is generated to be suitable for audio rate use in the works in the portfolio, some form of downsampling was necessary to facilitate their use at other time-scales. "Inflection point triggering" is a technique I used extensively in *CiS* and *CiZ* for this purpose. It refers to the triggering of parameter mappings according to only the coordinates at points of inflection where the rate of change equals zero in any of the three dimensions, typically occurring at peaks and troughs. An outline consisting of locations is formed where the trajectory changes direction, and applied at control rate and the structural level in works based on the Lorenz dynamical system. At control rate, by only parameter mapping coordinates at peaks and troughs, continuous siren-like sounds – such as those found in Henri Pousseur's *Eight Parabolic Studies* (1972) that quickly become tedious – are avoided. Nevertheless, the movement between points of inflection determine both the duration between triggers and their coordinates, implicitly influencing the rhythm produced by the sonification and its parameter mappings. Furthermore, in addition to the entire trajectory being used for additional parameter mappings such as spatialisation, the same data is used without downsampling at audio rate.

Elegance

The use of SSS is partly a response to common characteristics of new media such as "scalability" – a basic case of variability – where the same data can be used at various sizes, levels or detail (Manovich 2001, 58), and "modularity" described as the "fractal structure of new media", as evident in independent media elements that form larger-scale objects, the World Wide Web and structured computer programming styles (Manovich 2001, 51-52). It also resonates with Fuller's recent development to the concept of elegance in software. The four historical criteria of the quality of elegance are defined by Donald Knuth as leanness, clarity, spareness and most suitable implementation (Fuller 2008, 87). Fuller offers variations of these characteristics that have become applicable more recently as effective results with an economy of means becomes desirable e.g. sprites or bitmapped fonts working at multiple scales. Whilst this constrains possibilities in some respects, it also frees up computational resources for other purposes (Fuller 2008, 90). There are obvious parallels with music where an economy of means is taken to be indicative of the composer's skill and musicality, and with art generally where constraints often provide creative impetus.

The use of the same generative process at different time-scales is also inspired by the fractal nature of the systems used. This is most evident in *CiK* based on the Mandelbox fractal, but also in the fractal dimension of the Lorenz attractor on which *CiS* and *CiZ* are based.

Live Audiovisualisation

This chapter refers to the two main sets of works, *CiZ* and *CiK*.

In addition to the use of data as audio in *CiS*, the use of data as both audio and visuals occurs in *CiZ* and *CiK*. In the two collections of audiovisual works, the moving image is no longer a score for performers but intended to be experienced in tandem with the sound.

“Audiovisualisation” is simultaneous sonification and visualisation, where sonification consists of both direct audification – translation of data into the audible range – and parameter mappings at control rate related to the production of audio. In both *CiZ* and *CiK*, all audio and visuals are derived from the same system; hence, they are audiovisualisations of the same data source, a category within a wider range of current audiovisual practice. I describe the two sets of works as “live audiovisualisation”. They are live in the sense that the audiovisuals are generated in real-time, the ensuing temporality having implications on interaction as mentioned.

Many examples of audiovisual work involve visuals that are produced and/or controlled by features of the audio (or sometimes vice versa). Historical precedents display such tendencies e.g. Rubens’ tubes, and Chladni plates and other Cymatics work by Hans Jenny (Jenny 2001) as well as its continuation in projects such as Z’EV’s *cine-cussion* (Z’EV 2011). This practice is also evident in much VJ practice – see for example (Faulkner 2006) – and in visualisers that are now common in media playback software.

Audiovisual works by artists such as Carsten Nicolai (aka Alva Noto) and Ryoji Ikeda evoke a similar sound and moving image world to my live audiovisualistion works through the use of glitches, noise and sine waves at extreme frequencies often tightly synchronised to detailed visuals in monochrome or a limited number of colours.

Nicolai's *spray* (2004-6) is one such example. In the installation, the correspondence between the audio and the visual spatialisation contribute to producing a tightly integrated audiovisual entity. However, onset and panning appear to be the only features related to the visuals.

Ikeda's *datamatics [ver.2.0]* (2006-8) employs many combinations of sound and moving image that become perceived as integrated audiovisual objects through the successful pairing of audio and visual characteristics. But again, the sole audio feature strictly corresponding to the visuals in an obvious manner is onset i.e. audio and visual synchronisation.

A significant amount may be achieved through synchronisation alone as is discussed below. In addition, works by the above artists exhibit a careful coordination between the two media. Due to the limited discernibility of explicit parameter mappings, in a sense, the visuals could be described as offering an evocative and metaphorical interpretation of the audio. In the case of Ikeda's recent output such as the aforementioned work, it would be no exaggeration to state that the visual element provides a notable extension or a development inspired by the audio. These methods are perfectly valid in themselves and the results are highly commendable.

In contrast, in the live audiovisualisation works in the portfolio, both the audio and the visuals are derived from the same process. Thus in addition to metaphorical interpretations of the relationship between the two media which are of course perfectly possible and valid, the system responsible for structuring the audiovisuals can be conveyed

Integration of sound and image

The direct precedent to audiovisualisation became possible through the inclusion of the optical soundtrack alongside film. Works such as Walter Ruttmann's *Lichtspiel: Opus I* (1921), Hans Richter's *Rhythmus 21* (1921) and Viking Eggeling's *Diagonal-Symphonie* (1924) heralded the possibilities of abstract animation using film. Later, pioneering work in optical sound, in which waveforms were represented visually, was carried out around 1930 in Russia by Arseny Avraamov, Evgeny Sholpo and Mikhail Tsekhanovsky (Smirnov and

Pchelkina 2011, 10), and in Germany by Rudolf Pfenninger and Oskar Fischinger. The combination of the two media allowed for the creation and reproduction of both audio and visuals. As John Whitney stated, his early collaborations with his brother on *Five Abstract Film Exercises* (1941-44) provided an:

> unequalled opportunity to integrate image and sound . . . [because] the procedures of frame by frame production were alike for both sound and image. Despite many difficulties, design ideas for image somehow stimulated counterpart sound ideas, and in turn sound pattern was literally mirrored, figure for figure, in an image/sound dialog. (Whitney 1980, 92)

Other notable works made through drawing directly on the film and the optical soundtrack include Norman McLaren's *Dots* (1940) and *Synchromy* (1971), Lis Rhodes's *Dresden Dynamo* (1971), Steve Farrer's *Ten Drawings* (1976) and other structural films of the 1960s and 70s. Such examples exhibit a level of integration between the audio and the visuals on a par with contemporary audiovisual works.

Structural/Materialist film

The two sets of audiovisual works in the portfolio share similarities with Structural/Materialist film as defined by Peter Gidal:

> In Structural/Materialist film, the in/film (not in/frame) and film/viewer material relations, and the relations of the film's structure, are primary to any representational content. The structuring aspects and the attempt to decipher the structure and anticipate/recorrect it, to clarify and analyse the production-process of the specific image at any specific moment, are the root concern of Structural/Materialist film. (Gidal 1978, 1)

Many examples given by Gidal are themselves built on processes: the gradual change of the amount of light during printing (*Shepherd's Bush* (1971) by Mike Leggett); time-lapse long-exposure (*Broadwalk* (1972) by William Raban);

zooming (*Wavelength* (1967) by Michael Snow); permutation of shots (*Film No. 1* (1971) by David Crosswaite).

The main difference stem from the material: film for Structural/Material film (Gidal 1978, 2-3), and generative process and interaction in *CiZ* and *CiK*. As Structural/Materialist film attempt to demystify the film process (Gidal 1978, 1), my works attempt to demystify the generative process.

Gidal stresses the necessity of reflexiveness, “a condition of self-consciousness which invigorates the procedure of filmic analysis *during* the film viewing event” (Gidal 1978, 10), a view echoed by Malcolm LeGrice: “It is in eliciting a conscious, structuring mode in the audience that the systemic direction has most validity” (LeGrice 1978, 25).

Structural/Materialist film relies on “an aesthetic that tries to create didactic works (learning not teaching, i.e. operational productions not reproductive representations)” (Gidal 1978, 14). Gidal explains that instead of giving meaning in an ideological and idealist system as with most audiovisual media which then posits them as being natural, Structural/Materialist film makes meaning during the fluid encounter with the work abandoning associations formed by hegemonic mass culture (Gidal 1978, 8). In audiovisualisation, the audiovisual relationship arises as a result of independent presentations of the same data in the audio and the visual media. They both relate directly to the underlying process. Furthermore, they relate indirectly to each other via their individual relationship to the underlying process.

This is also in contrast to the call for a universal aesthetics much like a language for abstract moving image set out in the *Universelle Sprache* in 1920 by Eggeling and Richter, now lost (Richter 1965, 144).

Certain dualities are erased in Structural/Materialist film according to Gidal. As with audiovisualisation where both the sensory characteristics and the underlying process are essential to the work, Structural/Materialist film can be described as being both object and procedure (Gidal 1978, 14). It also “break[s] the illusion of [the] necessary separation [between feeling and thinking] and the illusion of their automatic oneness" (Gidal 1978, 10). This also relates to the inseparability of technical and aesthetic issues (Gidal 1978, 11), also as outlined concerning art/programming as praxis.

Recent examples

Mark Fell's *Attack on Silence* (2008) consists of sustained timbres and colours that evolve concurrently and slowly for much of the work as with his collaborations with Ernest Edmonds. The rate of modification of the two domains correspond perceptually, and are combined together as audiovisual entities. The complementary nature of the audio and the visuals would suggest that their development is related to the same process, in a similar manner to my live audiovisualisation works.

The main difference stems from Fell's advocation of minimalism, not in terms of the austere nature of the sonic and graphic elements, but in the process governing their change. This would appear to be a gradual and linear gradient at varying degrees of incline for the most part in addition to intuitive decisions pertaining to the relatively fast-paced sections. Thus it is not the process in itself that is of interest but its effect as audiovisuals. The success of the work does not rest on an understanding of the underlying principle or system, which is taken for granted, but purely in terms of sound and light. Put differently, if one cannot appreciate how the work looks and sounds, then an explanation of its mechanisms cannot obviate for this lack of engagement as it should already be evident.[24]

In contrast, the generative process is of equal importance in both the production and the reception of the work in my live audiovisualisation works. A similar approach is evident in the works of chdh and Mick Grierson.

chdh's *vivarium* (2009) employs audiovisualisations of physical models through their pmpd Pure Data library (Henry 2004). Correspondences between the audio and the visuals are usually very apparent, and the aesthetic success of the work is reliant on this fact. Visually, I feel that clarity has been prioritised

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[24] These comments are, however, not in any way meant to denigrate *Attack on Silence* or minimalist music in general where a large part of their appeal and success is precisely by virtue of their apparent simplicity.

over, or sometimes at the expense of, pure sensory appeal i.e. the communication of the models governing the audiovisuals takes precedence over how it looks and sounds.

Perhaps the opposite may be more apt in describing some of the works of Mick Grierson where the balance is shifted in favour of sensory appeal and stimulus. In works such as *Delusions of Alien Control* (2006-9), escape-time fractals through recursive iterations are employed for the simultaneous generation of both sound and moving image. The tight synchronisation and the complexity of the underlying data that result in equally noisy audio and visuals allow the correspondence between the two domains to become apparent, but the work can still be appreciated on a purely physical level without being aware of the underlying process.

Clarity and sensory appeal could form opposite poles of a scale that is comparable to the spectrum of cross-modal phenomena mentioned below consisting of synergy and interference at either end respectively. My live audiovisualisation works would be situated in between *vivarium* and *Delusions* on this axis. However, each part of *CiZ* and *CiK* differs in their location on the scale.

Musical texture metaphors

The musical texture that Whitney used as a metaphor to describe his solution for the integration of image and sound towards the end of his career was counterpoint:

> I aspire to compose both visual and audio “voices” independently, discovering and creating while performing a counterpoint or dialog between these voices. (Whitney 1994, 50)

This is partly a return to the momentary and short-lived ideals of late silent film and early sound film makers.

However, this counterpoint model largely disappeared. As Michel Chion notes,

> films tend to exclude the possibility of such horizontal-contrapuntal dynamics . . . [as] harmonic and vertical relations . . . are more salient – i.e., the relations between a given sound and what is happening at that moment in the image. (Chion 1994, 36)

For him, most examples of supposed counterpoint are effectively “dissonant harmony” (Chion 1994, 36-37). This is perhaps the best description for the practice of juxtaposing unrelated images to dance music that permeates the VJ scene: see for example (Faulkner 2006).

As mentioned, most synchronised audiovisuals involve the standard procedures of amplitude following or frequency analysis at best. As Whitney stated:

> this would be a partnership that is valid only if the combinations produce interest greater than the separate contribution of either the aural or the visual member. (Whitney 1980, 92)

This is often not the case in this more commercial end of audiovisual practice. In the more experimental field, a few practitioners producing pioneering work involving either deriving the video from the audio, or the audio from the video, or both did emerge from the 80s onwards: see for example (Abbado 1988, Ritter 1993, Rudi 1998). Continuing with Whitney and Chion’s musical texture metaphors, audio to video and video to audio following would constitute unison or monophony, whereby notes are merely doubled or paralleled.

The audiovisualisation of a single source (if successful) would be the equivalent of homophony: much like a melody and its harmonisation where each part by itself would merely be a line whilst its combination would create new depth by producing or implying a chordal structure, the effect of the audio and the video together would “combine to make an inseparable whole that is much greater than its parts” (Whitney 1991, 599).[25]

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[25] If the audio and the video are not strictly sychronised, the effect may be more akin to heterophony.

In John Coulter's categorisation of the possible permutations of the relationship between the audio and the video, it is the last method mentioned in the eighth and final category of isomorphic pair of abstract video and abstract audio. His example of "the real time synthesis of audio and video materials from a single data source" is the "use of an electronic device to track the unique eye movements of individual users and translate the data in real time into sounds and moving images" (Coulter 2010, 29, 32). This is an emerging field that is yet to be explored fully; practitioners include Golan Levin (Levin 2000), Edmonds (Edmonds 2003) and the aforementioned Grierson (Grierson 2005).

The combination of audio and visual produces more besides redundant representation of data. Whereas with audio to visual following, the visuals can only contain data already present in the audio (and vice versa for visuals to audio following), in audiovisualising a single source, the audio and the visuals can both potentially contain information not present in the other due to technical or perceptual limitations in the number of possible parameter mappings in each medium. Furthermore, whereas audio to video following results in either a mirroring of what can already be heard or, at best, information on the final product through audio analysis, the audiovisualisation of the same source may produce data in the form in which it is parameter mapped, explaining the process of their construction rather than the end product. Hence it can contribute to its didactic function, but it can also alter perception and contribute to sound affecting vision and vice versa in a misleading manner.

Auditory displays and perception

A similar practice of the simultaneous visualisation and sonification of the same data source has been studied for the research into auditory displays e.g. a combination of an auditory and a visual display suggested for the analysis of seismic data (Saue and Fjeld 1997, 50) and the effectiveness of such systems: see for example (Gröhn, Lokki, and Takala 2003, Bouchara, Katz, Jacquemin, and Guastavino 2010). Their *raison d'être* differs somewhat as their main purpose is the creation of alternative, more effective, efficient, accurate and suitable forms of data representation as mentioned, and furthermore, their findings may be considered preliminary: see for example (Walker and Kramer 2004, 169-79, Ghirardelli and Scharine 2009, 602). Nonetheless, important factors are highlighted that should be taken into consideration in understanding the potential of the audiovisual medium.

Cross-modal phenomena

The homophonic model can contain more than the doubling of data in the audio and the video as discussed previously. But even the redundant presentation of information can cause cross-modal "synergy" or "interference" i.e. the improvement or the deterioration of ability to extract data (Walker and Kramer 2004, 169-70), and thus it provides great potential for exploiting in aesthetic contexts.[26]

Cross-modal synergy through the audivisualisation of a single source further assists in explaining the underlying structure of the work. As mentioned, research into auditory displays has demonstrated that certain features can be better detected in different modalities. The duplication of data in different modes of display therefore offers the possibility of one modality filling in for another in case of data being missed, increasing the likelihood of its detection and comprehension. This is not restricted merely to the domain of research and data representation. An example of its everyday occurrence is in lip reading, or speech reading, used unconsciously in order to clarify ambiguous speech data (Ghirardelli and Scharine 2009, 605), although this is not always beneficial as explained below.

Synergy therefore enhances the didactic function for the furthering of the aesthetic understanding of the work which may be useful for abstract art of this nature in order to establish its new form. This is apparent in most of the Movie examples, namely 1, 2, 4, 6 and 7. In particular, in Movie examples 1, 2 and 6, the visualisation is the most straight-forward where curves are plotted in three-dimensional space and inflection point triggered audio are indicated by crosses and small cubes. This direct correspondence serves to confirm the relation between the audio and the visual domains as well as to the Lorenz system.

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[26] For further discussions on the aesthetic legitimacy and the benefits obtained from this practice of "mickey-mousing", see (Grierson 2005, 14-17).

This facilitative effect is perhaps more beneficial in Movie example 4 where the audiovisual relationship is less clear. In the visuals, in place of a curve as in the previous examples is a cube in a mesh structure. There are two instances of the Lorenz system coloured blue and orange that initially follow an almost identical path, combining to become white; the audio is also effectively doubled. The two trajectories later diverge but in an undefined way: in the visuals, the blue and the orange do separate but the Moiré effect makes this far from obvious; in the audio the two parts no longer double each other but their individual voices are difficult to distinguish, the occasional treble-frequency “blips” being the only components whose separate panning is clearly noticeable. The combined presence of the audio and the visuals does, however, enable the divergence of the two trajectories to be more apparent.

Cross-modal interference is obviously undesirable in the field of auditory and visual display but for aesthetic purposes, depending on the context, consistent clarity might not necessary be effective. Early levels of perception may be affected in extreme cases (Vroomen and De Gelder 2004, 142). These explain auditory and visual “capture” effects (Ghirardelli and Scharine 2009, 603-6), the former resulting from sound affecting vision as evident in the “freezing” phenomena (Vroomen and De Gelder 2004, 146-48), and the latter from vision affecting sound e.g. in the famous McGurk-effect (McGurk and MacDonald 1976, 746-48), whereby our unconscious dependence on lip reading actually impedes our ability to distinguish speech. Although the aim of audiovisual art should not necessary be to merely replicate these illusory effects which are perhaps of a more spectacular rather than aesthetic nature and analogous to special effects evident in blockbuster films, similar phenomena of a more subtle nature can contribute to the audiovisual medium becoming more than the sum of its parts.

Cross-modal interference is evident in Movie example 3 where two trajectories are present with their difference visualised as a set of straight and white lines connecting the corresponding points of the two curves. The visuals alone could be interpreted either as one integrated whole or two separate trajectories i.e. foregrounding either the lines depicting difference or the two independent curves. In the audio, although the two trajectories are sonified separately, their amplitudes are both controlled by the same visualised difference and heard as one combined, parallel voice rather than two separate parts. This “captures” or influences our perception of the visuals to be seen as one audiovisual element.

The ventriloquist-effect (Radeau and Bertelson 1977, 137) is primarily an auditory rather than a visual capture effect, whereby the visual stimuli affects the localisation of the sound. Although to a much smaller degree, studies have shown that the visual localisation can also be drawn towards that of the audio stimuli (Bertelson and Radeau 1981, 578-84, Vroomen and De Gelder 2004, 142) i.e. as audio capture. It is often difficult to establish an instance of cross-modal interaction as being either synergy or interference exclusively: many would fall under the category of a combination of the two.

Added value and synchresis

The phenomena of combined cross-modal interactions are supported by Chion’s notion of added value in cinema:

> the expressive and informative value with which a sound enriches a given image so as to create the definite impression, in the immediate or remembered experience one has of it, that this information or expression "naturally" comes from what is seen, and is already contained in the image itself. (Chion 1994, 5)

This concept operates reciprocally between the two media (Chion 1994, 21), alluding to auditory and visual capture effects described above. Furthermore, as research into auditory displays suggests that some information is better suited to being analysed aurally, Chion states that: “what we hear is what we haven’t had time to see” (Chion 1994, 61). He also notes how the most important factors that result in the successful perceptual combining of the audio and the visuals are synchronisation foremost, followed by verisimilitude dictated by film and television convention rather than the realism of the pairing (Chion 1994, 22-23). This forms the basis for his principle of “synchresis”:

> the spontaneous and irresistible weld produced between a particular auditory phenomenon and visual phenomenon when they occur at the same time. (Chion 1994, 63)

This is confirmed by findings of studies into cross-modal perception that with visual capture, the desynchronisation of the auditory and the visual data was found to reduce its effect significantly while the degree of realism of the context of the auditory and the visual pairing did not (Radeau and Bertelson 1977: 137). The effectiveness of this integration of the pairing is further strengthened through the audience paying attention to the stimuli (Talsma and Woldorff 2005: 1098) which should ideally be the case for cinema and audiovisual art.

The following sets of examples demonstrate the notion of synchresis. In Movie examples 1, 2 and 6, only a purely formal correspondence between the triggered audio samples and the visuals exists, the former resembling a conventional graphic plot of the Lorenz system and the latter being its direct audification. The effectiveness of the pairing arises foremost out of their synchronisation and not over their realism, the possible argument of audification being a “true” sonic representation as its oscilloscope-like visual counterpart being irrelevant (however appealing). This is also the case in Movie examples 4 and 7. In Movie example 7, as parameters become 0, silence is produced and the movement of the mesh completely ceases but for a slow rotation. These absent representations combine through a reciprocal articulation through their simultaneous occurrence: the silence establishes the “zero” state of the visuals as a slow rotation as opposed to other options such as complete stillness or darkness; this in turn signals the “zero” state of the audio as silence instead of, for instance, a sustained tone or a repeating loop.

Superfield

The combined cross-modal interaction in the ventriloquist effect demonstrates how localisation in the audio and the visual domains does not necessarily have to correspond exactly for them to be perceived as an audiovisual entity through synchresis: depending on the aesthetic context, even a complete left-right inversion can be entirely plausible (Coulter 2010, 32). Furthermore, it is possible for the effect of synchresis to be prolonged even after the removal of one of the stimuli e.g. when an entity moves off-screen but can still be heard, thus creating what Chion describes as a "sort of superfield, a general spatial continuum or tableau . . . that can issue from loudspeakers outside the physical boundaries of the screen" (Chion 1994, 150).

This occurs in Movie example 5 where the moving image forms a combined audiovisual entity with the sonification partly due to sufficient correlation in their panning. Later, the visual shape moves off-screen with only the paired synthesis instrument remaining perceptible. However, it remains combined and its subsequent reappearance on-screen is perceived as the same entity that disappeared previously. Conversely, an audiovisual entity could also remain combined when it moves further away causing it to become inaudible but still visible.

Camera position

The camera position introduces an additional variable, revealing different perspectives quite literally in the visuals. This also affects the audio in both *CiZ* and *CiK*, with either the view corresponding to the spatial mappings of panning and reverb, with the remaining parameter mappings left unaltered (Movie examples 2, 3, 4 and 6), or the spatial mappings being left unaltered and the view corresponding to the remaining parameter mappings (Movie examples 1, 5 and 7).

Synaesthesia

These are not, however, imitations of mild forms of synaesthesia, a condition in which a blending of two or more senses is experienced e.g. seeing the colour blue from hearing the note C sharp played on a piano (Ramachandran and Hubbard 2003, 53). Partly due to subjective differences in its effects and a lack of structured "mappings" between the senses, Whitney disapproved of its recreation in audiovisual art (Whitney 1994, 47). Chion is also clear that added value depends on "transsensorial" perception and not an imitation of synaesthesia which he describes as "intersensorial" (Chion 1994, 137). Perhaps it is more accurate to describe audiovisual art as being "cross-modal", and inspired by synaesthesia rather than being synaesthetic art (Cádiz 2004, 2).[27]

[27] See also (Goodman 2009, 215-16).

Live performance

The use of the visual medium is partly a response to the problematic nature of the use of laptops in performances. In the past, musicians were placed on a stage due to practicalities: to be seen and to be heard. These reasons are obviously no longer applicable to laptop performances. Yet this unconsidered, meaningless practice of recreating an obsolete form of spectacle continues in the form of “performers” sat motion-less in front of computer screens, as López notes (Gangemi and López 2003, 31-32).

In *CiZ* and *CiK*, the visuals become a replacement to this spectacle by presenting the data in a different modality. It performs analogous functions to an acoustic instrumentalist on stage by offering an alternative and independent rendering that serves a didactic purpose of explaining the underlying system behind the work. This also allows for more complex processes to become understandable.

Part III: Practice

The final part of the commentary describes each of the works in the portfolio in chronological order.

Construction in Self

Introduction

Construction in Self is a generative work based on the Lorenz dynamical system. It has sensitive dependence on initial conditions, giving rise to what is commonly known as the “butterfly effect”. The generative form of the work is suggested by this property and *CiS* takes an input prior to performance as initial conditions from which a different piece is produced each time. A diverse variety of behaviours are observed ranging from periodicity to chaos that yield interesting results as signal, control and meta data, suggesting a self-similar microcosm that is complex yet deterministic which can be replicated from the same initial input.

The title is a reference to Cage’s *Construction in Metal* series (1939-42) in which simple sequences of numbers – referred to as “rhythmic structures” – are used as a basis for structures at different time-scales (Cage 1961, 19, Pritchett 1988, 52-54).

Key concepts

CiS investigates the possibilities of the sonification of generative systems. The use of generative processes allows for the possibility for emergence. As a well-known chaotic dynamical system, the Lorenz provides potential for producing such phenomena in audio.

The Lorenz system is a simplified model of real-world phenomena. As a simulation, the equations' variables can be altered to values beyond those considered realistic. As such, the work is inspired by reality and also its extension, or life-as-it-could-be. Similarly, as a possible use of this model in organising the audio, it is an attempt at art-as-it-could-be.

Both the underlying processes and the sonic result are integral to the work and one's experience of it. The process and the product are inextricably linked and hence theory and practice – and technique and aesthetics – were considered simultaneously in the creation of this work.

The data is used through the approach of self-similar sonification in order to explore their potential at different time-scales. This involves the use of audification at audio rate and sonification at control rate. In this respect the work could be considered an amalgamation of the concerns and styles of both institutional and underground electronic music.

As a sonification of the Lorenz, the work may be conceptualised as a speculative effort in presenting the inner workings of a dynamical system. Through encountering the work, some form of experience of the otherwise alien system is possible through the medium of sound. This occurs at a sensual and an intellectual level, which could crudely correspond to audio/control rate in the former and control/structural rate in the latter – or perhaps to underground and academic computer music respectively.

Form

CiS is a generative work. An input prior to performance as a number entered manually by a "performer" determines every aspect of the ensuing performance. As mentioned, its form as a generative work is also informed by the Lorenz system's property of sensitive dependence on initial conditions. The smallest variation in the input may produce a completely different performance. Similarly to the unpredictability of the detailed trajectory of the Lorenz system, the effect of altering the initial input is unpredictable and emergent. However, all processes are deterministic and the same input will produce identical performances.

Calculation

Three different sets of initial conditions determined by the initial input prior to performance (y_0, in the range [-1,1]) produce three different trajectories. These are named i, ii and iii and have the following initial coordinates respectively:

(-1, y_0, 9),

(-1, $y_0 - 1\times10^{-6}$, 9),

(-1, -y_0, 9).

Trajectories i and ii begin at close proximity to each other, and trajectory iii starts on the opposite side of the *y*-axis to trajectory i. The difference between i and ii represents a rounding off to six decimal places: a far smaller discrepancy than that of Lorenz's which would lead to his discovery of sensitive dependence on initial conditions (Gleick 1987, 16-17). Yet, it is sufficient in demonstrating the butterfly effect.

From the three trajectories, two further trajectories are calculated from the difference between trajectories i and ii (i-ii) and between trajectories ii and iii (ii-iii). This is in order to harness the difference in behaviour for trajectories starting at close proximity and far apart from each other as described above. These difference trajectories themselves are emergent as shown below.

Data as audio

Through SSS, *CiS* uses the above data from the Lorenz dynamical system at three different time-scales: signal, control and structural. The data will be described and discussed in reference to each in turn.

Figs.1 to 12 show the *y*-values of trajectory i for twelve values of the Raleigh number (in set A) plotted against time. The audification of the data can be heard in order in Sound Example 2, and also transposed higher in Sound Example 3.

y [-1,1] against time (as audio rate: [0,0.002-4] seconds; control rate: [0,16-128] seconds; or structural rate [0,0-15] minutes) for Figs. 1-24.

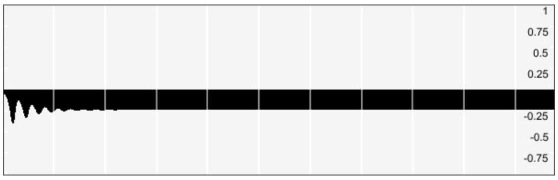

Figure 1. *r* =10 (i)

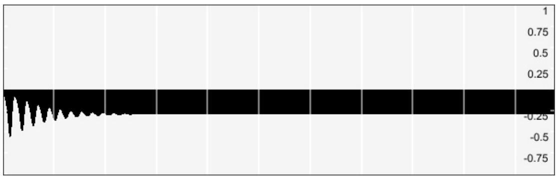

Figure 2. *r* =14 (i)

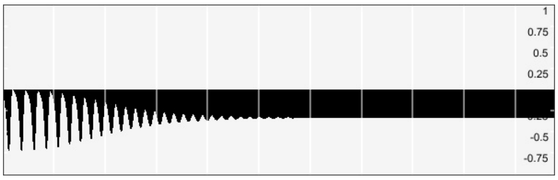

Figure 3. *r* =18 (i)

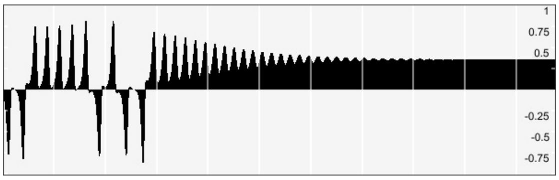

Figure 4. *r* =19 (i)

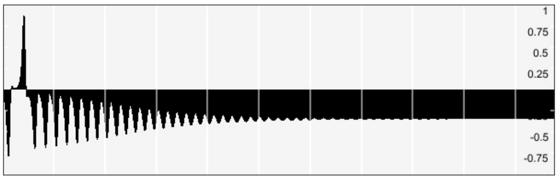

Figure 5. *r* =19.5 (i)

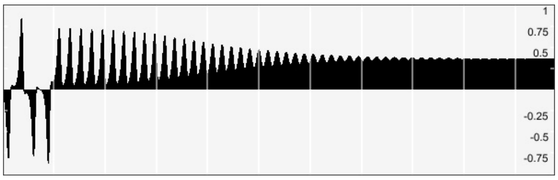

Figure 6. *r* =20 (i)

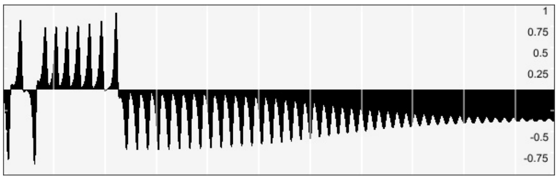

Figure 7. *r* =20.5 (i)

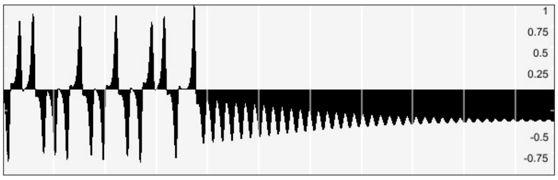

Figure 8. *r* =21 (i)

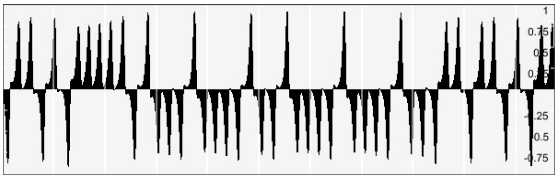

Figure 9. *r* =21.5 (i)

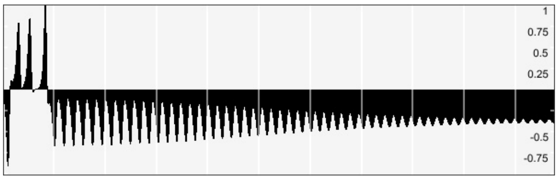

Figure 10. *r* =22 (i)

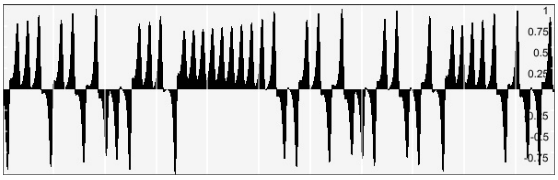

Figure 11. *r* =23 (i)

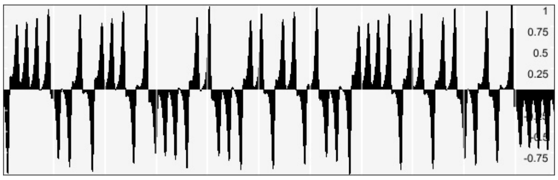

Figure 12. *r* =24 (i)

At low values of *r* (Figs.1 to 3), the trajectory forms an orbit around only one fixed point which it approaches, and resembles the slope of the attenuation of percussion sounds. Here, only one half of the butterfly-shape is visible. These are heard as percussion-like sounds in the first three sounds in Sound Examples 2 and 3.

As *r* is increased (Figs. 4 to 8), the trajectory becomes the famous lemniscate-shape and it initially alternates irregularly between the two available orbits. Then it approaches a fixed point on either “wing” of the butterfly-shape. Thus a qualitative change in the nature of the trajectory occurs. Correspondingly in the fourth to the eight sounds in Sound Examples 2 and 3, a short amount of noise arising from the aperiodicity is heard, followed by the same percussion-like sound.

At higher values of *r* (Figs, 9, 11 and 12), the trajectory no longer converges on a fixed point. Instead, it alternates chaotically between the two orbits producing the well-known butterfly shape. As the trajectory is no longer periodic, the ninth to the twelfth sounds – i.e. the last three sounds – in Sound Examples 2 and 3 are noise for their whole duration.

Although an increase in *r* generally results in a longer period of aperiodicity, the effects are not linear as evident, in particular in Fig. 10 (the tenth sound in Sound Examples 2 and 3) that appears to revert to periodic oscillations.

As with the aforementioned example of the use of audification in seismology, alterations in the data produce changes in higher-order features such as timbre, amplitude envelope and pitch. Through direct audification alone, a rich timbral variety of material is possible

Figs.13 to 24 show the *y*-values against time of trajectory i-ii (the difference between trajectories i and ii) for twelve values of the Rayleigh number (in set A). The audification of the data can be heard in order in Sound Example 4, and also transposed higher in Sound Example 5. The initial minute difference between i and ii is sufficient in demonstrating the butterfly effect and after following near-identical paths, trajectories can diverge suddenly as a result of the initial difference. The data as audio in Sound Examples 4 to 5 are the direct audification of the sensitive dependence on initial conditions of the Lorenz system, reflected in the variety in higher-order features of timbre, amplitude envelope and pitch, providing a rich source of material for compositional purposes.

Figure 13. *r* =10 (i-ii)

Figure 14. *r* =14 (i-ii)

Figure 15. *r* =18 (i-ii)

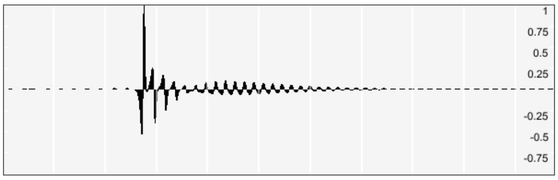

Figure 16. *r* =19 (i-ii)

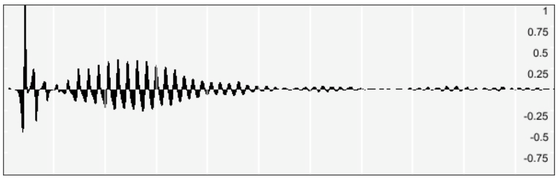

Figure 17. *r* =19.5 (i-ii)

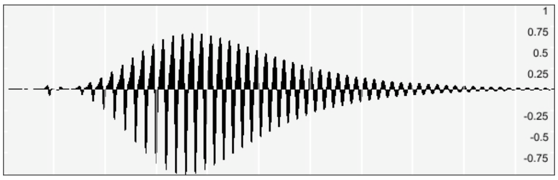

Figure 18. *r* =20 (i-ii)

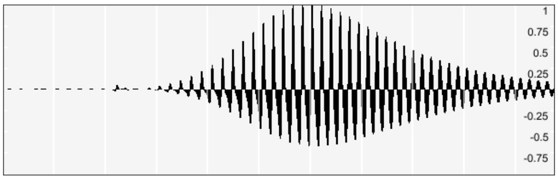

Figure 19. *r* =20.5 (i-ii)

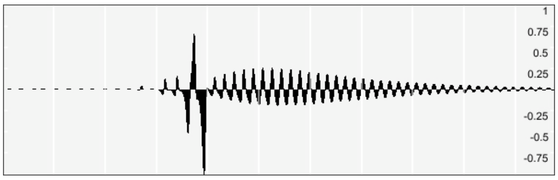

Figure 20. *r* =21 (i-ii)

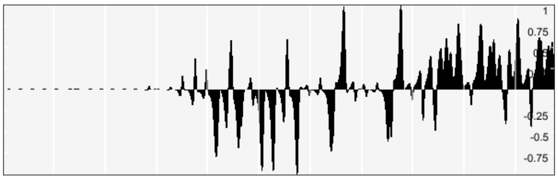

Figure 21. *r* =21.5 (i-ii)

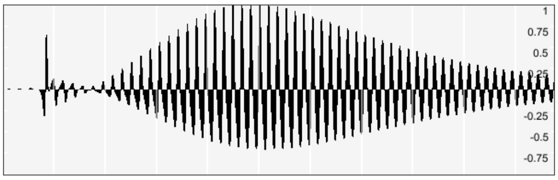

Figure 22. *r* =22 (i-ii)

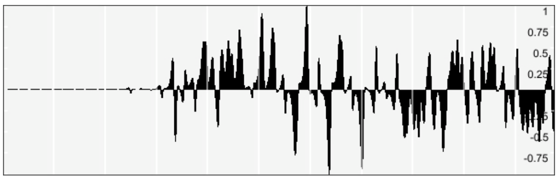

Figure 23. *r* =23 (i-ii)

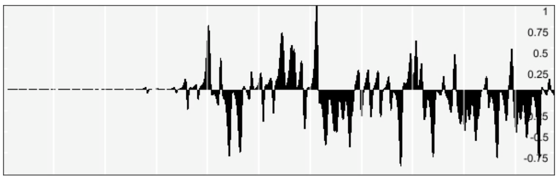

Figure 24. *r* =24 (i-ii)

At control rate, the above data of 44,100 calculations lasts either 16, 32, 64 or 128 seconds. With the exception of panning, parameter mappings at control rate for sonification are carried out through inflection triggering. Its simplest use is the triggering of the data as amplitude at signal rate (i.e. audification) where the parameters of amplitude, speed/pitch and *r* (affecting the periodicity or the "noisiness") correspond to the *x*, *y* and *z* coordinates at the inflection point.

All the examples of control rate sonification provided (Sound Examples 6 to 11) use one of the trajectories shown in the Figs. over a duration of 64 seconds. Each point of inflection triggers an audification of a trajectory from the set that the sonified trajectory belongs to. Sound Examples 6 to 8 are sonifications of Figs. 4, 7 and 11 respectively and belong to trajectory set i. Each point of inflection triggers an audification of one of the trajectories from the same set (Figs. 1 to 12). In the case of Sound Examples 9 to 11 sonified in Figs 16, 19 and 23 respectively, audifications of trajectories from set i-ii (Figs. 13 to 24) are triggered at inflection points.

Panning

CiS can be played back over a quadraphonic setup. Panning is carried out by the same trajectory used at control rate for sonification. The *x*-dimension with range [-1,1] controls the "balance" (left-right) with -1 corresponding to left, and the *z*-dimension with range [-1,1] controls the "fade" (front-rear) with -1 corresponding to rear. The listener is thus situated in the centre at the origin (0,0) marked by an X in Fig. 25.

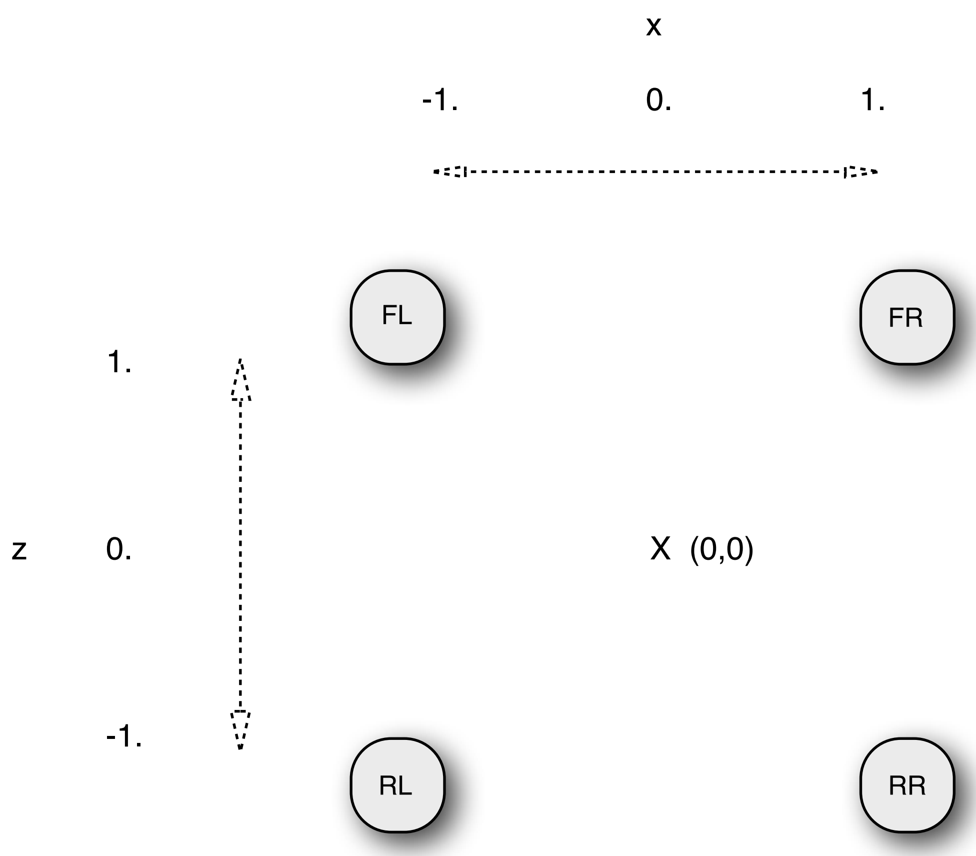

Figure 25. Panning in *Construction in Self*

As the dimensions are mutually dependent, the *x*- and *y*-coordinates are closely related. Thus in the control rate sonification Sound examples, the *y*-coordinate (represented in the Figs.) approximately corresponds to panning, with -1 being left and 1 being right. In addition, the lemniscate shape is transferred using just the *z*- and one other dimension, although the *y*-dimension could perhaps be incorporated into the spatialisation for three-dimensional audio systems to correspond to height.

Structure

SSS can also involve the use of sonification to determine the structure of one rendering of the work. The sonification examples (Sound Examples 1 and 6 to 11) demonstrate one possible sonification method used in *CiS*, of which there are five in total. Sound Example 1 is also one possible section from a performance typically comprising of between ten to fifteen sections. A trajectory from set i-ii is sonified to govern the structure of each performance, controlling the ordering of sections, their durations, combinations of sonification methods and the trajectories to be used at audio and control rate. In effect, a trajectory is sonified at structural rate.

Implementation

CiS is implemented in the programming environment Max/MSP. It is available as a Max collective or a standalone application. The procedures necessary to perform the work are straightforward, requiring the operator to set initial conditions, begin calculations by clicking on a button and waiting (for several minutes until the relevant message in the Max window), and then starting playback by clicking on a toggle box.

The calculations occur inside the LcalculateAB subpatch where the data of the trajectories are stored inside the buffer~ objects. These are edited and analysed in the LdlBufferEdits AB and LjitAnalysis subpatches. The buffer~ objects are used at control and structural rate inside the Lsequencer subpatch, which drive the audio rate manipulation of the same data contained in the instruments subpatch.

Documentation

Four iterations of the work in stereo with different initial values are included in the documentation. They illustrate the variety of performances that are possible. An iteration in quadraphonic sound is also included to demonstrate the aspect of spatialisation in a multi-channel setup.

Evaluation

The use of data from the Lorenz system at audio rate produces a wide variety of timbres ranging from regular to chaotic oscillations. At control rate, a range of patterns are also generated. The panning sometimes becomes repetitive, oscillating between extremes. But in most cases, it depicts the butterfly shape of the Lorenz system appropriately. As mentioned, the *y*-dimension could have been used; this is incorporated in later works in the portfolio to control reverberation.

At both the above rates, the correspondence between the regularity of the trajectory and the resulting audio is apparent in most cases. With the aid of the

Figs above, however, they become more clear. It is partly for this reason that subsequent works in the portfolio use audiovisualisation to produce a simultaneous visual output to serve a didactic purpose.

At the structural level, mechanisms are in place to prevent numerous repetitions of similar sections. Oscillations that cause these repetitions are an important characteristic of the Lorenz systems, and are used without such "interventions" at shorter time-scales. At audio rate, this poses no such problems, leading to a stable timbre. At control rate, this can lead to monotonous repetitive "rhythms", but only until the end of that particular section after which a different section can start. Allowing for such loops at the structural level creates the possibility of a monotonous performance every now and then. If audience members were to hear numerous playings of the work, one such repetitive performance would not be a problem. However, this ideal situation is often unrealistic as most audience members are only likely to hear the work once. Furthermore, a boring performance may also discourage further listenings. Thus I felt that it was necessary for one performance to contain a sufficient proportion of the variety possible from the work.

The most successful type of trajectory in terms of "alienness" seemed to be the following: little or no activity that is repeated for a significant amount of time before a sudden "spike" in values, which is then followed by another prolonged period of inertia. This category was labelled as "attack" e.g. Figs. 16 and 20. I felt that such a structure may not have been thought of through intuitive means alone without the use of generative processes. A trajectory with gradual *crescendos* and *diminuendos* were labelled as "bulb", and comparatively, these appear to be shapes associated more with notions of musicality and organicism e.g. Figs. 18 and 19.

Allowing for such phenomena is an important aspect of machinic aesthetics. However, there is a danger that there may not be a sudden "spike" at all to validate the preceding period of monotony. The following are three possible solutions. The first is through the possibility of overriding the data within the generative process, which was the approach taken in *CiS*. The second is through a long-duration context as found in installation works where the possibilities of structural organisation may only become apparent over a period of time equivalent to several performances of a “concert” work. The third is through the real-time control or interaction, where the performer is able to override the system if necessary. This last solution is explored in the later live audiovisualisation works.

Despite the popularisation of the term generative music by Brian Eno, some audience members have found difficulties in grasping how a performance of *CiS* could be considered live. My usual practice at concerts of the work has been to make apparent the fact that there was no input to the computer on my part affecting the outcome of the performance. To many, despite the generally problematic nature of laptop performances, it appears the spectacle of a human being scrolling with a trackpad or tapping the keyboard is still reassuring. Thus I feel an unattended computer rendition of the work highlights the inappropriateness of watching a laptop performer on stage: the processes and interactions occurring involving a performer and a computer are often as equally incomprehensible to the audience as a solitary laptop.

One technical issue with the work is the length of “off-line” time required to generate a performance. Due to its implementation, specifically the fact that calculations occur between Max objects and hence within the Max scheduler, approximately five minutes of preparation time is necessary before it is possible to commence playing. This has not been a major problem, being more a matter of convenience. However, this also restricts values to single-precision floats. As the system has sensitive dependence on initial conditions, the use of double-precision would provide a much more accurate and “smoother” trajectory. For this reason, externals were developed for solving the differential equations of the Lorenz system in the subsequent work, *Construction in Zhuangzi*. The massive reduction in time necessary for the calculations was also necessary in order to create a system that allowed for real-time interaction.

Construction in Zhuangzi (Part 1 to 3)

Introduction

Construction in Zhuangzi is a live “audiovisualisation” of a modified Lorenz dynamical system, a three-dimensional model of convection that is nonlinear, chaotic and sensitive to initial conditions. A performance takes the form of an improvisation involving the modification of parameters of the system, the human interaction being indicated by momentary colour-inversions. The real-time, generative audiovisuals establish a perceptual feedback loop between the performer and the near-autonomous algorithm, or perhaps a duet or a duel between these two elements due to the “butterfly effect” and the emergent behaviour of the dynamical system. Interesting results are obtained both as sound through self-similar sonification and as moving image through 3D visualisation. Being representations of the same data source, coherence between these two domains are maintained without either being subservient to the other as it is neither the audio triggering the visuals nor vice versa as is often the case. The outcome is an integrated audiovisual, real-time, generative, interactive, and improvised live performance.

Key concepts

CiZ is a development of *CiS* with the addition of a corresponding visual element and the possibilities of real-time interaction. Thus it explores similar concepts to the previous work. In addition, the simultaneous use of audio and visuals offers new possibilities through an integrated audiovisual medium.

Emergent phenomena is presented in both the audio and the visuals simultaneously, enabling much more transparency in the processes underlying the work. In particular, properties and behaviours of the mathematical equations are more apparent than in *CiS*, allowing them to form the basis for the content of the work more successfully. Interactivity introduces a temporal dimension with additional emergent and the arrow of time.

The combination of real-time interactivity and generative systems further highlights the blurring of the human/machine duality. The performer alters the variables of the equations, but the effect of the human input is emergent due to the complexity of the underlying process. Working within machinic and cyborg aesthetics, instead of attributing intentionality, the audiovisuals made possible through the use of such a system is explored.

Modified Lorenz system

Instead of Lorenz's classic system, a modified version was used, governed by the following equations (Petržela and Hanus 2005, 1):

$$dx/dt = -ax - y^2 - z^2 + ac,$$

$$dy/dt = x\,(y - bz) + d,$$

$$dz/dt = -z + x\,(by + z).$$

The introduction of quadratic terms increases the complexity of the trajectory.

Trajectories

As with *CiS*, three trajectories and their differences are calculated from which the performer may choose any combination to make audible and visible. They all share the same values for the variables *a*, *b*, *c* and *d* in the equations above but with different initial *y*-coordinates. Visually, they differ in colour: trajectory i is blue, trajectory ii is orange and trajectory iii is green. Blue and orange were selected for the reason that their superimposition produces white as evident in Movie examples 1, 2, 4 and to some extent in 6 i.e. their combined trajectories appear monochrome if almost overlapping, with their individual colours becoming visible as they diverge.

ii starts from a point just slightly off from i; iii starts on the other side of the *y*-axis to i i.e. the difference between the initial coordinates of i and ii appears to be insignificant and minute, whilst that of i and iii appears to be larger and more significant as with *CiS*. In the default configuration, i starts from (0.1, 0.1, 0.1), ii from (0.1, 0.1 + $1\text{x}10^{-10}$, 0.1) and iii from (0.1, -0.1, 0.1). Additionally, the distance in each of the dimensions between trajectories i and ii and between i and iii may also be used as trajectories in themselves. These are designated as i-ii and i-iii respectively, both being white e.g. in Movie example 5 and 7.

Audiovisualisation

The simplest form of audiovisualisation occurs in Part 1a. Audio is generated by self-similar sonification through inflection point triggering.[28] Each trajectory is visualised in 3D space, along with the previous time frame (the default duration being 250 ms). This creates a tail effect whose visibility varies depending on its straightness. At points of inflection when audification is triggered, crosses appear. The previous 49 triggers in each dimension are visible with the most recent being illuminated by a small, flashing sphere. Rhythmic features are most prominent in Part 1a.

Straight white lines connect two trajectories along with the previous time frame in Part 1b. Audio is produced through a modified version of the two-oscillator feedback FM instrument (Roads 1996, 246) with the carrier and the modulator using wavetables of direct audification of the equivalent trajectories (either i-ii or i-iii) replacing the standard sine wave. I describe this as “frequency waveshape modulation of waveshape synthesis with feedback”. The carrier frequency, the harmonicity ratio (modulator frequency/carrier frequency) and the modulation index (modulator amplitude/modulator frequency) are mapped through inflection point triggering i.e. its position affects both the pitch and the timbre of the audio. Again, crosses appear at these points. Additionally, the amplitude is proportional to the duration since the last inflection point in the difference between the trajectories, limited after 4 seconds during fade in, with the fade out being a quarter of the fade in time i.e. the volume is effectively louder the more the trajectories diverge corresponding to the length of the lines. Along with the noisy timbre, the resulting sound is reminiscent of the ebbing and flowing of sea waves.

In Part 2, the coordinates of the trajectory correspond to the location of a cube structure, the number of points in each dimension ranging from 15 to 50. Audio is again produced through a similar method to Part 1b, but without amplitude alterations which produces a far more visceral sound.[29]

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[28] A similar process can be found in *CiS* in Sound example 1.

[29] A similar method is used in the second section of *CiS* (where $y_0 = -1$, included in the documentation), which does not include feedback.

The coordinates of the previous 49 inflection points in each dimension are visualised using non-uniform rational basis spline (NURBS) in Part 3. Audio is produced through a method I describe as “frequency waveshape modulation synthesis with feedback”, with the carrier remaining a sine wave and only the modulator using the wavetables of direct audification.[30] Crosses appear at points of inflection. The same control rate mapping procedures as Part 1b are used, with similar amplitude alterations based on the coordinate in each dimension. The use of sine waves results in far more regular oscillations and hence a more harmonic character than Parts 1 to 2.

Implementation

CiZ is implemented in Max/MSP/Jitter and available as a Max collective or a standalone.

Externals were developed in order to solve the above differential equations (Ikeshiro 2013c). They both drive the sonification inside the subpatch lorenz.mod~calc3d in real-time, and store the data into buffer~ objects inside the subpatch lorenz.mod.multi.buf~1b. As the calculations are carried out at a significantly faster rate, the far more accurate common fourth-order Runge-Kutta method (Vetterling, Teukolsky, Press, and Flannery 1992, 705-6) could be used. Additionally, parameters and initial conditions can be altered during performance whereas in *CiS*, they were fixed for the whole duration of the piece. This allows for further variety within a single playing of the work. The use of externals also enabled calculation in 32 bits rather than 16 bits, providing greater accuracy generating smoother waveforms for regular oscillations.

The subpatch l.m.instruments contains the sonification methods. Externals were also developed in order for the audio spatialisation to correspond to the visual spatialisation carried out within the 3D environment of OpenGL (Ikeshiro 2013d). The work can be performed with either a stereo or a quadraphonic setup.

[30] A similar process is used in the *Coda* from *CiS*, which does not include feedback. However, the control rate method differs considerably.

The subpatch r.manip.gl contains the visualisation methods. The main objects used were jit.gl.sketch (Part 1 and 3), jit.gl.mesh (Part 1 and 2) and jit.gl.nurbs (Part 3).

Evaluation

The audiovisual “figures” in *CiZ* are describable by extra-musical and extra-visual terms such as the following:

- convergence towards periodic attractors in Movie examples 2 and 6;

- convergence towards steady-state attractors at the end of Movie example 1;

- divergence of trajectories belonging to different basins of attraction (DeLanda 2002, 15) from 0:20 in Movie example 1 and at the end of Movie example 4;

- perturbations resulting in ordinary events in most of Movie example 2;

- perturbations resulting in singular events (DeLanda 2002, 19, 73) in Movie examples 1 and 5 and at 0:44 in Movie example 2;

- heterochrony (DeLanda 2002, 97) in Movie example 6.

As evident, the Lorenz provides a complex but coherent formal organisation of sound and image that takes advantage of the possibility for emergent behaviour through the implementation of algorithmic processes. At the same time, the audiovisuals convey the various characteristics of the dynamical system.

Due to cross-modal interactions often being combined, a sliding scale ranging from the facilitative to the inhibitory can be conceptualised. As these effects are not mutually exclusive, a topological or “fuzzy” manifold is perhaps a more accurate model. The navigation inside this continuum of the tension between synergy and interference is an important determining factor of the nature of an audiovisual work and its relative aesthetic success. In *CiZ*, this is evident in the method of audiovisualisation that approximately traverses this manifold from synergy to interference, from Part 1 through to Part 3 (Movie examples 2, 6, 1, 3, 4, 7 then 5).

Construction in Kneading (Part 1 to 3)

Introduction

Construction in Kneading is a live audiovisualisation of a Mandelbox fractal, one of several recent multi-dimensional fractals inspired by the famous Mandelbrot set. The recursion formula upon which the escape-time fractal is based is similar to that of the so-called baker's map and resembles the actions of kneading dough in bread making. Through this relatively simple process carried out in three dimensions and controlled through the real-time manipulation of the variables, complex patterns arise from which all the audio and the visuals are generated.

Key concepts

CiK develops many of the same concepts explored in *CiZ*, the previous live audiovisualisation work.

The visualisation of the data corresponds more to the audio rate characteristics of the sonification rather than its control rate features as in *CiS* i.e. the visuals relate more to timbre in *CiK*, and to "rhythm" and "pitches" in *CiS*. Thus the visualisation of a shorter time-scale is investigated in this work.

Data from the fractal is used as audio through SSS at three different time-scales: at audio rate, control rate, and at the level of phrases comprising of time durations of approximately one to thirty seconds. Thus it introduces an additional layer of control to the two found in *CiZ* (of audio and control rate), and an intermediate time-scale of the phrasal level between control rate and the structural level used in *CiS*. The parameter mapping of the the shorter time-scale of the phrasal level was felt to be more appropriate than that of the structural level in a work involving real-time interaction.

Implementation

CiK is implemented in Max/MSP/Jitter and is available as a Max collective or a standalone.

Inside the subpatch Julia_quaternion_test20, a set of coordinates evenly distributed in a unit cube or 3D-space (121x121x121) are stored within the Jitter object jit.matrix. These are ray marched to determine the boundary of the Mandelbox set using distance estimation. The outline can thus be calculated in greater detail by not considering points towards the middle of the fractal. The process is carried out within the GPU by implementing it in the OpenGL Shading Language in the Jitter object jit.gl.slab. This takes advantage of the fast parallel processing speed of graphics cards. The cube of data may be recalculated with different variables during the performance.

The subpatch mandel.point~ generates data in real-time to be used in Parts 1 and 2 at control rate at approximately 20 to 360 bpm through the same baker's map-like iteration used to calculate the fractal. An additional stream of data is also generated at a slower rate (described here as the phrasal level) by the same process every 1 to 30 seconds. These alter the methods of audiovisualisation and their parameters in Part 1, and the variables for calculating the fractal in Part 2 and 3. Externals are used to carry out the "kneading" procedure described.

In Part 1, the audiovisualisation is carried out within the subpatch matrixiFFT12. jit.peek~ objects read data from the aforementioned 3D jit.matrix to be used at audio rate. ifft~ objects are used for sonification and jit.gl.mesh objects are used for visualisation.

The audiovisualisation in Part 2 occurs within the 3m.n.slice.audifi.col.rot06~ subpatch. jit.peek~ objects again access data from the cube matrix which are used as audio. jit.gl.mesh and jit.gl.nurbs objects are used for the visuals.

In Part 3, the audiovisualisation occurs inside the subpatch m.n.demultiplex04. The jit.gl.mesh object is used for the visualisation, the results of which are then read back using jit.gl.asyncread and then sonified using jit.peek~ and ifft~.

Methods of audiovisualisation

The cube of data is audiovisualised using an increasing number of dimensions in each part of the work.

In Part 1, a line or one dimension of data is used, these being parallel to either the *x*-, *y*- or *z*-axis. There are three sonification methods in total. Each has its own visualisation method that correspond in character. The wispy, almost dotted line matches the generally high-pitched audification method, whilst the slightly bolder lines complement the generally low-pitched audification method. The most complex visualisation method is reserved for inverse FFT synthesis whose timbre is correspondingly the richest of all the sonification methods. Wider lines or bars indicate a faster data rate and hence higher pitch.

Being deviations from a straight line, the visualisations resemble a typical one-dimensional amplitude waveform against time. The use of up to three separate lines in white against a black background produces an effective austere opening to *CiK*.

In Part 2, a slice or two dimensions of data are used, these being perpendicular to either the *x*-, *y*- or the *z*-axis. These are used through direct audification, with the visualisation traversing slice by slice through the cube of available data. The amount and pattern of deviation from a perfectly flat slice is related to the timbre produced, with the rate of traversal across the cube having some bearing on the pitch heard.

The increase in the number of dimensions effectively means a greater quantity of data is audiovisualised at any one time. Visually, a greater proportion of the screen is filled in comparison to Part 1. With the addition of colour, the punchiness and the more beat-based rhythmic structure of the audio, the result is far more visceral.

In Part 3, a cube or three dimensions of data are visible as points, returning to the monochrome scheme of Part 2. The slowly-shifting 2D image formed on the screen is sonified through direct audification or inverse FFT synthesis. The panning (either left/right or front/rear), corresponds to the particular area on the screen being sonified.

No control or phrasal rate data is used in this part, the only automated movement being the gradual rotation. Thus the final part to *CiK* is meditative, slow-paced and drone-like.

Evaluation

The relationship between the methods of sonification and visualisation is perhaps most coherent in Part 1 where an analogous amount of variety is present in the two modalities. Only one sonification method is available in Part 2, but due to larger ranges in the parameters possible, there is greater variety in the timbres produced. The visualisation does not however share this wider range of possibilities. In Part 3, as the underlying data is recalculated or different amounts are assigned to be audiovisualised, both the audio and the visuals are modified, although alterations in the audio are not always obvious. In addition, the sonification method may be controlled without changing the visualisation in contrast to the previous two parts.

The greater variety possible in sound than in moving image in Parts 2 and 3 could be balanced through a correspondingly wider range of possibilities in the visualisation. However, my approach of live audiovisualisation does not necessary require a close correspondence between the methods of sonification and visualisation. As mentioned regarding *CiZ*, the gradual growing disparity between the audio and the visuals from Part 1 through to Part 3 could represent a transition from synergy to interference. Indeed, in a Structural/Materialist film reading, the alteration in the relationship between sound production and moving image production is where the work is situated, and what forms “meaning”. In this respect, the three parts to *CiK* are complementary in providing variety through different possibilities in live audiovisualisation.

Conclusions

The main contributions of the research as outlined in the abstract are expanded, and possibilities for future work are also noted.

The first contribution of this research is practical. It is the body of creative work in the portfolio demonstrating the application of the emergent generative systems of the Lorenz dynamical system and the Mandelbox fractal as material in audio and audiovisual experimental art.

The systems are used as material in order to present their emergent behaviour as sound and moving image. They also form the basis for the construction of the works such that their features can be described in mathematical terms as demonstrated in the Sound and the Movie examples. Thus they provide appropriate form as well as material.

Although dynamical systems and fractals have been used within generative art previously, the works in the portfolio differ significantly from the historical examples mentioned through considering new aesthetic and technical possibilities of live audiovisualisation, self-similar sonification and computational aesthetics. These are outlined below.

The second contribution is the demonstration of the technique of live audiovisualisation as a valid aesthetic endeavour, as evidenced in both the thesis and the portfolio.

This is the simultaneous sonification and visualisation of the same data in real-time. Far from being a redundant doubling of information, research in perception and auditory displays shows that the two modalities become perceived as a combined audiovisual entity through the possibilities of cross-modal phenomena. This also forms the basis of Chion's theory of *synchresis*. These have been demonstrated in the two sets of works (*CiZ* and *CiK*) as well as in the Movie examples.

Its roots may be found in the equivalent analogue practice of drawing directly onto the film and the optical soundtrack, and Structural/Materialist film. Previous work in the digital realm has been limited. Due to the fast improving capabilities of GPUs and CPUs of laptops, this is a fertile area of study with further scope for exploration. The inaccessibility of experimental sonic art is sometimes attributed to its abstract nature. As a possible solution, the incorporation of audiovisuals can serve a didactic function, enabling more complex and abstract processes to become understandable, whether at control rate as with *CiZ*, or at audio rate as with *CiK*. Thus experimental art can become more accessible without necessarily having to dilute content.

The third contribution is the technique of “self-similar sonification”: the use of data as audio at multiple time-scales.

The Sound examples of the audio rate use of the Lorenz system in *CiS* demonstrate some of the formation of higher-order structures such as timbre and amplitude envelopes possible (as do *CiZ* and *CiK*). These include regular oscillations and percussion-like amplitude envelopes not normally associated with non-standard synthesis in addition to the more typical coloured noise and distortion. They also serve a didactic purpose in conveying features of the underlying system as used in auditory displays. Such possibilities indicate how the use of generative systems at audio rate and its aesthetic potential remain productive areas of study that deserve further study.

The use of dynamical and fractal systems has been generally limited to control rate implementation within academic institutions, with its use at audio rate being less common and consigned to underground electronic music. Both approaches are used simultaneously through SSS for the first time. By the presentation of data at both control and audio rates, SSS is also an attempt at bridging the divide between computer music practice inside and outside academic institutions. The works in the portfolio are successful in both these contexts of electronic music.

The fourth contribution of this research is theoretical, and it is an assessment of the aesthetic and technical implications of emergent behaviour in generative systems within experimental computational art.

Digital technology within which this research was undertaken allows for the development of algorithms through writing software. This enables the creation of generative art based on systems. Emergence, as the term is used by the neo-emergentists and referring to the weak variety, defines an important characteristic of generative systems. Put simply, they are unable to replicate phenomena comparable to human consciousness. Instead, unexpected or surprising results which may otherwise be unthinkable or impossible without the use of such systems become possible due to their level of complexity and unpredictability. This makes them ideal for use in the context of experimental art. In particular, it is an appropriate criteria for assessing noise.

Most studies of computational creativity are based on a naïve understanding of art where it is equated to the ability to imitate human behaviour. Instead, the concepts of the machinic and the cyborg that consider both anthropocentric and non-anthropocentric notions of aesthetics are more appropriate. Within such a framework, rather than attributing artistic outcome to separate human and machine agencies, creative possibilities brought about by their combination are considered. The thesis also provides a re-evaluation of the notion of art-as-it-could-be that references the study of AL. Through the use of generative systems, real-world simulations can be extended, leading perhaps to models not based in reality and the creation of art which may have been unimaginable. Such possibilities are also conducive for the creation of new experimental art. Sonification and visualisation are also conceptualised as a speculative task into the experience of otherwise alien beings beyond our comprehension.

This research involving both theory and practice has touched upon numerous topics of interest, and inevitably, many areas worthy of future study have come to light which have been mentioned.

Developments in technology will bring improvements for many features of the works presented, through increased capacity for audio and visual processing. These could also lead to 3D audio spatialisation and multiple projections and screens, with the use of multiple computers. Alternatively, comparable features may be attained by smaller devices allowing for more mobile setups involving hand-held devices and pocket projectors.

A visual parallel to SSS could be developed. Currently, only one time-scale is used in producing the moving image, whereas up to three may be found in the sound. Combining the visualisation of control rate in *CiZ* and of audio rate in *CiK* would yield a good starting point.

The approaches of SSS and live audiovisualisation could be applied to a wide range of data and processes, perhaps beginning with a re-evaluation of other dynamical systems such as Chua's Circuit to more topical subjects such as Big Data and the vast quantity of information being generated and stored today. These may in turn result in new experimental art that also serves a didactic function in revealing features of the systems upon which they are based.

In recent years, there has been a resurgence in philosophies of materialism, realism and the object as evident in the various branches that were initially grouped together under the umbrella of speculative realism (Bryant, Srnicek, and Harman 2011). There is much further work to be done in exploring aesthetics relevant to the possibilities of experimental and computational art.

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