## *Compositions Utilizing Fractal Flame Algorithms*

KEVIN NICHOLAS CARLSON

# Compositions Utilizing Fractal Flame Algorithms

## A Ph.D. Compositional Portfolio

**By Kevin Nicholas Carlson**

**Submitted for the Degree of Doctor of Philosophy by Composition**

**Durham Music Department**

**Durham University**

**2021**

# Abstract

This portfolio explores how the iterative and recursive processes employed within fractal flame algorithms can be used to create new and aesthetically pleasing micro and macro sounds from which coherent compositions can be created. A variety of existing electronic compositional procedures, including wave-set substitution and granular synthesis, as well as a number of classical compositional practices, such as hocketing, are deployed to generate a complex and diverse set of compositions. The portfolio shows how marrying these sound manipulating techniques and compositional processes with the sonic events produced by the minimally unexplored field of fractal flame algorithms has allowed me to generate – in the words of Iannis Xenakis – 'sounds that have never existed before'. The portfolio shows the creative potential fractal flame programs have for electronic music generation and how they offer a *terra nova* upon which computer-generated music can lay down solid foundations and expand in new directions to harvest exciting results.

# Table of Contents

Table of Contents

Compositions

(In Chronological Order)

| | |
|---|---|
| *Symphony of Noise* (Final Days): Electronic Stereo | |
| I *Boiling Down* | (05:27) |
| II *Hurricane* | (03:36) |
| III *Armageddon* | (10:00) |
| IV *Null* | (04:01) |
| *Hiccup Hocket*: Chamber Ensemble | (05:23) |
| *Classical*: Electronic Stereo | (07:17) |
| *Julia N*: Electronic Surround 5.1 | (07:38) |
| *Tantrum*: Electronic Stereo | (04:48) |
| *Recursive Writing*: Electronic Stereo | (07:43) |
| *Spots Evolve*: Electronic Stereo | (06:20) |
| *Noise Gate*: Electronic Surround 7.1 | (09:57) |
| *Temple of Shiva*: Electronic Stereo | (06:28) |
| *Atomic Reaction*: Electronic Stereo | (06:44) |
| | Length (87:00) |

# Acknowledgements

The music which I have composed at Durham over the last four years would not have been possible without the help and support of a very large number of people. In particular I wish to thank my supervisors Prof. Nick Collins and Prof. Richard Rjinvos for their patience and support, as well as their encouragement for my explorations in fractal music. I also wish to thank my BA supervisors and lecturers from my time at Cornish College of the Arts Seattle, in particular Dr. Jarrad Powell who first explained to me the role of mathematics in music, and enkindled my love for the music of Indonesia, specifically Gamelan. I also wish to thank Dr Janice Giteck for her kindness and support during my time in Seattle. I am especially grateful for her friendship and gentle encouragement, both at a personal and professional level. Special thanks are also due to Mrs. Karen Nichol at Durham Music Department for her administrative support and unfailing kindness during my Ph.D.

Beyond my academic colleagues I owe a particular debt of gratitude to my family and my close friends of many years who have helped me throughout my life. In particular I wish to express my deep-felt gratitude and heartfelt admiration for my parents, Henry Leroy Carlson and Margaret (Peggy) Carlson, both of whom sadly passed away during the course of my Ph.D. studies and who were instrumental in encouraging my explorations in music, art and mathematics from an early age. I also wish to thank Mr. Louie Swalby for his support, both practical and emotional, these past nine years.

I would also like to express my sincere thanks to Mr. William Crozier for his patient reading of the many drafts of this portfolio and for his support in helping improve my academic writing style. During times of illness, he has been an invaluable comfort acting as my 'scribe' taking down notes and helping collect books from the university library when I have been unable to do so.

As one of the principle inspirations behind my compositional project Benoit Mandelbrot once remarked: ‘A man is known by his heroes’. I owe a particular debt of gratitude to those who have inspired my creative thinking, both within music composition and the science of fractal mathematics, as well as the creative dialogue which is possible between these two fields of study. Principle sources of influence in my efforts to explore the suspended middle which exists between electronic music composition, mathematics, and fractal theory include John Cage, Steve Reich, Harry Partch, Iannis Xenakis, and many more experimental sound aficionados. In particular, my debt to explorers in the field of fractal theory is Benoit Mandelbrot whose influence cannot be overstated. I have found in Mandelbrot’s thought an endless source of inspiration and creative energy. Without question Mandelbrot is the thinker to whom my fascination with fractals owes its origins.

Throughout my academic training, both at undergraduate and postgraduate levels, I have sought to synthesize my love of music with my love of fractals. Doing so has brought me great enjoyment. Moreover, it has served to fuel the same joy which I took in music from my earliest days as a child learning to explore how to play the piano with a particular fascination for the black keys. Put simply: I compose because it is fun. As Karlheinz Stockhausen once remarked: ‘I’m an adventurer. I like invention. I like discovery’.

K. Nicholas Carlson

This thesis is dedicated to my mom
Margaret (Peggy) Carlson who did so much to encourage me both in my music and my life.

And to my dad
Henry Leroy Carlson who first sparked my interest in computer programming.

‘Beautiful, damn hard, increasingly useful.
That’s fractals’

-Benoit Mandelbrot

# Chapter 1
# Introduction

## 1.1) Introduction.

An exciting sphere of scientific research, the discipline of fractal theory, as a subset of the mathematical field of iterative function systems. It is full of fascinating phenomena. In particular, as I hope to show in this portfolio, it has the potential to enrich the field of electronic music composition, opening up new avenues along which electronically generated music can develop and expand into new territory.

This portfolio is a commentary on the ten compositions which I have composed over the last four years using computer generated fractal flame images. Specifically, these iterative and recursive processes generate unique micro and macro sound events. I have used fractal flame programs, in co-operation with standard sound manipulation techniques, such as wave-set substitution and granular synthesis, to generate a variety of complex pieces. Each of my compositions reveals something unique about the contribution of each technique. These iterative function systems of fractal flame algorithms have much to offer to the field of electronic music.

As this portfolio will make clear, my compositions as distinct pieces of work in their own right can be harmonized into a coherent whole standalone structure. This provides the following:

a) Giving them not only a degree of structured unity,

b) Synthesizing them into something akin to a story, possessed of a beginning, middle and end.

Each composition is thus a distinct piece of music within a grander narrative. The 'story' which this portfolio tells is how the application of fractal flame programs to sound generation opens up something akin to a sonic version of the famous visual phenomenon known as the Mandelbrot set.

Magnifying a computer-generated Mandelbrot set allows us to glimpse the seemingly endless visual phenomena created by fractals. These continually reveal the detail hidden within a specific fractal image which simultaneously reflects the pattern of the overall image. By using existing sound manipulation techniques, we are able hear and, in turn, manipulate some of the micro sounds hidden within the sound samples generated by fractal flames. Moreover, by using this technique it is possible to produce sustained pieces of macro sound which are both aesthetically rewarding and conceptually challenging.

## 1.2) Sounds That Have Never Existed Before.

Commenting on the capacity of electronic music to explore new and exciting acoustic phenomena, the famous electronic composer Iannis Xenakis once said that the function of electronically generated music was to create 'sounds that have never existed before'. [1] 'To be a composer' Roads remarked, 'means that one enjoys solving puzzles of pitch, rhythm, sound, colour, phrase, structure, and process, but also questions of taste and feeling. To be an electronic composer, however, requires a particular disposition because of the unique predications of the medium'.[2]

---

[1] Iannis Xenakis, *Formalized Music*: *Thought and Mathematics in Music*, (New York: Pen-dragon Press, 1992), p. vii.
[2] Curtis Roads, *Composing Electronic Music: A New Aesthetic*, (Oxford: Oxford University Press, 2015), p. 1.

My use of fractal flame programmes, and my effort to exploit their iterative and recursive dynamics, to produce in Xenakis' words 'sounds that have never existed before', has allowed me to inhabit new compositional territory. Crucially, however, it has also allowed me to exploit in novel ways what Roads terms the 'unique predications' of the medium of electronically generated sound.

Of particular concern in each of my compositions and indeed my research in general has been to show how the sounds garnered from fractal flame algorithms enhance our understanding of the symbiotic relationship between psychology, emotion, and rational enquiry that is involved in the experience of listening to, and constructing, music. The electronic composer, Xenakis tells us that we must seek to explore how the sonic events he or she generates are received within the 'real' world and what, in turn, these sounds evoke within human emotion and the psyche in general. As such, the aesthetic impact of the sounds I generated have been of particular concern when designing and finalizing my pieces. I shall discuss my aesthetic principles in the next chapter (Section 2.5)

## 1.3) "Sonic Art".

The author of several of the programs I utilized is Trevor Wishart. He remarked in his *On Sonic Art* (1996) that claiming the title of being a 'composer' is often difficult when one works in the field of electronic music[3]: those involved in traditional music composition, especially the classical Western tradition, can find it hard to accept the idea that those that generate new sounds by using computer programmes are 'true composers'. This is why Wishart, when seeking to clarify where he saw his own contribution to music generation, preferred to speak

[3] Trevor Wishart, *On Sonic Art,* (Amsterdam: Harwood Academic Publishers, 1996), p. 4.

of his work as being a form of “sonic art” rather than composition in the traditional sense of the word.

I maintain that electronic music ought not simply to be understood as merely a form of artificial sound generation. Still less, it ought not be viewed as merely an ancillary tool for the manipulation of sounds that can be generated from already existing “traditional” musical instruments. Instead, I view computers themselves, and specifically fractal flame algorithms, as akin to real, albeit virtual, musical instruments. As we shall see, these “instruments” are capable of producing their own unique sounds, which can, in turn, like the sounds generated by any other musical instrument, be manipulated to form coherent and aesthetically pleasing pieces of music or sonic art.

Whilst focusing in on the specific micro sounds generated by fractal flames, each of my pieces has been similarly manipulated at the macro level so as to give them a coherent nature, one which not only explores new ground, but is also rewarding at a sonic level. As such, my pieces are not just random sound events, nor mere collections of chaotic noises. Instead, I have designed them to intrigue and elicit an emotional response from the hearer. As will be seen, some of the “stories” told by my compositions are motivated by my broader personal interests and concerns. For instance, *Symphony of Noise* and *Spots Evolve* reflect my concerns about the current ecological crises generated by global warming.

My attention will focus on my compositions themselves, the process by which I have produced them, and the motivations and broader research horizon behind my experimentation with fractal flame programs. At the end of this portfolio, I offer some brief reflection on how I would develop some of the pieces in the future. In the present study, my principal aim is to show how my central hypothesis concerning the viability of utilizing fractal flame algorithms to produce electronically interesting sounds has been successful.

## 1.4) Literary Review.

To understand the research contribution of this portfolio, it is necessary to note the state of contemporary research into fractal inspired and generated music. By no means a unified field of research, the use of fractal mathematics within electro-acoustic is varied and of varying depth and academic quality.

At its most basic level, fractal composition is an iterative process that adds and removes data until an interesting sound is generated. Many contemporary composers have developed their own style of music based on the science of iterative processing. For instance, one need only consider figures like Agostino Di Scipio,[4] Steve Reich,[5] John Cage,[6] and Charles Wuorinen.[7] Moreover, one needs to consider the ground-breaking work of Iannis Xenakis[8]and Charles Ames.[9] A quick glance at the works of some of these composers reveals, a number of the algorithmic processes which they employ can be thought of as "fractal", or as coming close to something resembling "fractal". This is particularly true of Ames's *Cystals* and the detailed self-similarity which he identifies at the micro sound level.[10] Most notably, Wourinen's organ piece

---

[4] Augustino Di Scipio, 'Iterated Nonlinear Functions as a Sound-Generating Engine', *Leonardo* 2001 (34: 3), pp. 249-54.
[5] Cf. Steve Reich, *Writings About Music,* (Nova Scotia: Halifax Press, 1974).
[6] Cf. Kaja Marczewska, 'The Iterative Turn', https://metaspar.se/wp-content/uploads/2_The-Iterative-Turn_Issue-3.pdf. Accessed: 02-04-2019. Originally published as part of *Parse Journal*, pp.13-28.
[7] Cf. Charles Wuorinen, *Simple Composition,* (New York: C. F. Peters, 1979).
[8] Cf. Xenakis, *Formalized Music: Thought and Mathematics in Music.*
[9] Charles Ames, ''*Crystals':* Recursive Structures in Automated Composition' in *Computer Music Journal*, 1982 (6:3), pp. 46-64; *'Stylistic Automata in 'Gradient''* in *Computer Music Journal*, 1983 (7:4), pp. 45-56; 'Automated Composition in Retrospect: 1956-1986' in *Leonardo*, 1987 (20:2) Special Issue: Visual Art, Sound, Music and Technology, pp. 169-185; 'A Catalogue of Statistical Distributions: Techniques for Transforming Random, Determinate and Chaotic Sequences', *Leonardo*, 1991 (25:1), pp. 55-70.
[10] Charles Ames, ''*Crystals':* Recursive Structures in Automated Composition' in *Computer Music Journal*, 1982 (6:3), pp. 46-64;

*Natural Fantasy* (1985) is influenced by Mandelbrot's work on fractals. In his essay *Music and Fractals*, Wourinen highlights the role of self-similar, fractal nesting in his own compositions.[11] Yet, as we will see, the question of whether the work of some of these composers can be classified as being truly fractal is debatable, and even deeply contested.

### 1.4.1) Rolf Wallin and the State of Contemporary Fractal Music.

The contemporary Norwegian composer Rolf Wallin has also done much to highlight the importance of fractal mathematics for music analysis. Wallin has utilized fractal algorithms in a number of his own compositions. As he suggests, fractals are for him "an organizing principle for rhythm and melody".[12] Amongst others, Wallin's most important fractal pieces include his *Onda di ghiaccio* (1989) and chamber works *Stonewave* (1990) and *Ning* (1991), as well as his recent *Whirld* (2018). All of these are classical rather than electroacoustic pieces.

Wallin highlights in his influential article *Fractal Music – Red Herring or Promised Land?* (1989), how fractals have challenged scientists and artists in almost every discipline. Indeed, fractals, as he argues, have forced many researchers to re-evaluate some of their most basic convictions. This is particularly so in the fields of physics, mathematics and probability theory. In doing so, Wallin tells us that fractals have fundamentally enriched our understanding of the natural world. Thus, on the impact of fractals on the sciences, he profoundly writes:

> However, this is just the shiny façade of a revolution that has left the international community of scientists of most disciplines at first totally dumbfounded by seeing

[11] Essay to be found in Michael Frame, et. al. (eds.) *Benoit Mandelbrot: A Life in Many Dimensions* (Singapore: World Scientific Publishing Co, 2015), pp. 501-6.
[12] Cf. rolfwallin.org/about/c_515a041f1e91c00ef89091af/. Accessed: 12/12/2019.

> central parts of their theoretical basis crumble, then completely frantic to investigate to what extent these scientific Columbi eggs can be applicable to their particular field.[13]

Music, as Wallin tells, us is not exempt to the challenge posed by fractal mathematics. As such, Wallin argues that composers should not, indeed cannot, ignore the great potential which fractals have, both in terms of analysing music as well as producing new compositions and indeed new compositional methods. Wallin is of the opinion that fractals have the potential to reinvigorate and help composers move beyond what he labels as the 'apparent stagnation' of certain elements of contemporary electronic music.[14] He further remarks, that despite their huge compositional potential, few composers have taken advantage of fractals and their unique iterative identities.

> So, what about music? Will fractal mathematics come to the rescue in a time of apparent stagnation, this time in the guise of simple mathematical algorithms that yield delicious patterns that can be further processed, either as a succession of musical events or as complex frequency spectra? The attempts to find an answer to this question have barely begun.[15]

During my research and compositional experimentation, I have found examples of several researchers who have explicitly sought to experiment with fractals and their acoustic potential at a sustained and rigorously academic level. Besides Wallin, other principal

---

[13] Cf. rolfwallin.org/articles/c_5165b8ec1e98c045d02b30b3. Accessed: 20/7/2020.
[14] *Ibid*.
[15] *Ibid*.

researchers I have identified are Magnus Eldenius[16], Agostino Di Scipio[17], Richard Voss and John Clarke[18], Michael Gogins,[19] Kenneth and Andreas Hsu[20] and of course Charles Wuorinen[21] and György Ligeti[22]. Also, of particular note is the contemporary Argentinian composer, Horacio Vaggione.[23] I shall discuss Vaggione and Ligeti and their fractal works in detail shortly. Several of these composers are important when it comes to understanding my own compositional method and situating it in context.

Although important in their own right, this list of composers working in the field of fractal music is relatively limited. It also confirms what Wallin's own research has indicated: that compared to other fields within electronic music there appear to be relatively few researchers and composers working on the relationship between fractals and sonic art. Moreover, as Eldenius points out, those that are actively working on fractal music tend to focus on the theory behind it, rather than actually producing fractal music itself.[24] Thus, as Eldenius notes in his *Formalized Composition on the Spectral and Fractal Trails* (1998), "sometimes one gets the impression that the interest in fractals has manifested itself more in articles and work

---

[16] Magnus Eldenius, *Formalized Composition on the Spectral and Fractal Trails,* (Goteborg: Novum Grafiska AB, 1998).
[17] Augustino Di Scipio, 'Iterated Nonlinear Functions as a Sound-Generating Engine', *Leonardo* 2001 (34: 3), pp. 249-54
[18] Richard Voss and John Clarke, '"1/f Noise" in Music and Speech', *Nature: International Journal of Science,* 1975 (258), pp. 317-18.
[19] Cf. Michael-gogins.com. Accessed 12/12/2019.
[20] Kenneth Hsu and Andreas Hsu, 'Fractal Geometry of Music', *Proceedings of the National Academy of Sciences of the United States of America*, 1990 (87:3), pp. 938-941.
[21] Charles Wuorinen, 'Music and Fractals' in Michael Frame, et., al. (eds.) *Benoit Mandelbrot: A Life in Many Dimensions,* (London: World Scientific Publishing Co., 2014), pp. 501-6.
[22] Heinz-Otto Peitgen, 'Continuum, Chaos and Metronomes – A Fractal Friendship' in Louise Duchesneau and Wolfgang Marx (eds.) *Gyorgy Ligeti: Of Foreign Lands and Strange Sounds,* (Rochester NY: Boydell Press, 2011), pp. 87-106.
[23]See section 1.4.2.
[24] Consider for example: Stephen Ornes, 'Science and Culture: Hunting Fractals in the Music of J. S. Bach', *Science and Culture*, 2014 (111: 29), p. 10393.

titles than in actual music".[25] Beyond Wallin, Vaggione and Ligeti are perhaps the two composers who have produced the most significant corpus of fractal inspired compositions in recent decades. As such, their fractal compositions and compositional method are worth discussing in detail.

### 1.4.2) Horacio Vaggione.

The founder of the influential *Centre de Recherche Informatique et Création Musicale* (CICM) in Paris, Horacio Vaggione has produced several important compositions using fractal mathematics, including his famous *Harrison Variations* (2002). Two of Vaggione's fractal compositions are particularly important for this study. This is because, as we will see in chapter three, they shed light on my own compositional methodology and how it evolved during my research. The first is *Fractal A* (1983) which as Curtis Roads notes, is "one of the few pure algorithmic compositions that Vaggione ever realized".[26] The product of direct translation of a fractal algorithm into sound, Vaggione wrote the code for *Fractal A* using the programming language of AWR, which forms a subdivision of the C coding language.[27] Thus, as the quote from Roads indicates, *Fractal A* was produced by Vaggione without any direct compositional creative or aesthetic input on his behalf beyond instigating the translation of his fractal algorithm into sound. It was thus, to coin a phrase, a 'purist' fractal piece. I shall say more on what I mean by the term 'purist' in chapter three.

In his slightly later *Fractal C* (1983-4), Vaggione moved away from the 'purist' or 'non-interventionist' approach employed in *Fractal A* and adopted what Roads terms as a policy of

---

[25] Magnus Eldenius, *Formalized Composition on the Spectral and Fractal Trails,* p. 81.
[26] Curtis Roads, 'The Art of Articulation: The Electroacoustic Music of Horacio Vaggione', *Contemporary Music Review* 2005 (24:4/5), pp. 295-309, at p. 298.
[27] *Ibid.*

'direct intervention'. Taking the fractal model known as the Triadic Cantor Set as his compositional basis, in *Fractal C* Vaggione actively manipulated the sonic output of the algorithm he employed by using selected computer commands. He repeated this manipulation to produce a piece that consisted of both algorithmic and human input.

Roads summarizes *Fractal C*'s synthesis between algorithmic composition and direct intervention as follows:

> Using a DEC VAX-11/780 mainframe computer at IRCAM, the composer stipulated UNIX commands (such as pipes) to enchain a series of musical processes. Another feature of the CARL system used in Fractal C was a 'fast interactive mode' – a set of commands that the computer used to select portions of a sound file and create new files containing only these selected portions. According to the composer, this kind of selection and subdividing technique was from this point on a typical feature of his compositional strategy.[28]

### 1.4.3) György Ligeti.

Next to Vaggione, the Hungarian-Austrian classical composer György Ligeti is undoubtedly one of the most famous modern composers who has sought to incorporate fractal mathematics within his compositions. Primarily a classical composer, but also drawing upon fractal

[28] *Ibid*., p. 299.

mathematics from a different compositional perspective than the electronic one employed by Vaggione, Ligeti's application of fractals is to be seen clearly in his much praised *Études pour piano* Book 1 (1985).

Included in this oeuvre are his *Désordre*, *Cordes à vide* and *Automne à Varsovie*, as well as several others of particular note. As Toros Can notes, these works contain a strongly fractal identity. *Désordre*, for instance, draws inspiration from the self-similar iterative processes involved in the production of Koch's snowflake, one of the earliest expressions of Western fractal imagery.[29] Composer Can also points out that key to understanding the various pieces included in his *Études* is Ligeti's particular indebtedness to the work of Benoit Mandelbrot and his pioneering work on fractal self-similarity in nature. "Mandelbrot's works with fractals" Can remarks "also play a great role in understanding his [Ligeti's] style".[30] Deeply influenced by the self-similarity of fractals, in particular the famous Mandelbrot set, Ligeti sought to mirror at an acoustic level the complex self-recursion at work within fractals.

[29] Toros Can 'The Importance of Ligeti's Piano Etudes in Compositional and Pianistic Aspects: What it is Necessary to Analyse Ligeti Etudes Prior to Learning', *International Journal of Arts and Sciences* 4(3) 2011, pp. 201-7, at p. 202.
[30] ***Ibid.***

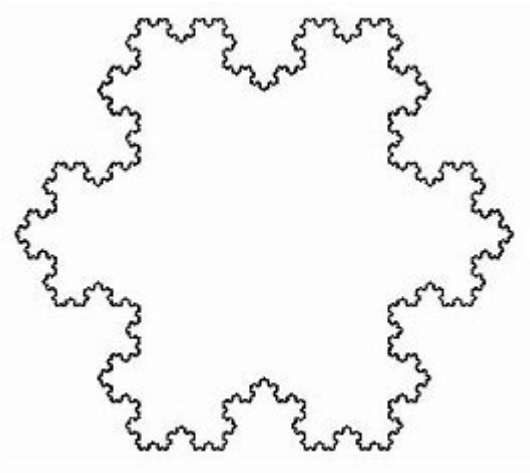


Figure 1

Koch's Snowflake.

The iterative pattern of Koch's Snowflake influenced Ligeti's *Désordre.*

Ligeti commented in the programme note to his 1990 violin concerto that his compositional process had been deeply indebted to Mandelbrot and the self-similar world of the fractal mathematics he had done so much to uncover. He wrote: 'this concept of many-layered polyphony [*in the violin concerto*] is influenced by my preoccupation with geometry, especially fractal geometry and the science of dynamical systems and deterministic chaos'.[31] As Brian Lefresne has shown in his relatively recent study, *The Application of Chaos Theory and Fractal Geometry in the Music of György Ligeti* (2005), fractal inspirations are also to be found in Ligeti's *Atmospheres* (1961), the fourth movement of his *Konzert fur und Orchester* (1985-6) and *Étude pour piano* no. 17 (1998). In these works, Ligeti seeks to mirror the self-similarity of fractal patterns by continually layering chords and notes as the pieces progress according to an iterative identity.

Recently, Ji Won Baik has devoted much attention to exploring the indebtedness of

[31] Quoted in Toros Can. *Ibid*., at p. 202. Italics added.

Ligeti's *Désordre* to fractal self-similarity and chaos theory. As Baik's research has highlighted, in *Désordre,* Ligeti seeks to invert the normal process of fractal geometry and chaos theory regarding chaos and stability.[32] In *Désordre*, the right hand plays the white keys on the piano, whilst the left hand plays the black. As the piece progresses, the rhythms played by the two hands begin to distort. Ligeti inverts the logic of chaos theory by showing how stability does not just arise from chaos, but also has a propensity towards producing it. Under the influence of fractal iteration, stable musical rhythms and rules of toning can quickly descend into disorder and unevenness. As composer Can declares: 'this combination creates the illusion of a different kind of scale of tuning system and gives the disorder sound effect by "deterministic chaos" in style'.[33] Baik's recent study sums up Ligeti's inversion of fractal similarity and chaos theory in *Désordre* as follows:

> His Etude no. 1 *Désordre*, represents fractal and chaos theories. These theories try to find some order in disorder, but instead, Ligeti creates a complicated disorder from the order. At the beginning of *Désordre*, the rhythmic patterns are synchronized; but at the end of the fourth measure, the composer begins to distort the rhythms of the right hand. He accomplishes this by moving one eighth note ahead gradually until the end of the music. This causes an alteration of accent, resulting in a chaotic complexity of rhythm.[34]

[32] Ji Won Baik, *György Ligeti's Piano Études: A Polyrhythmic Study* (PhD Thesis, Florida State University, 2009), p. 26.
[33] Toros Can, 'The Importance of Ligeti's Piano Etudes in Compositional and Pianistic Aspects: What it is Necessary to Analyse Ligeti Etudes Prior to Learning', p. 204.
[34] Ji Won Baik, *György Ligeti's Piano Études: A Polyrhythmic Study*, p. 26.

Ligeti's claim that his works are of a fractal nature has, however, been questioned by Wallin. Wallin argues that despite his preoccupation with self-similarity, Ligeti fails to recognize the true role which chaos theory plays within the fractal universe, in particular how it dictates the seemingly infinite possibilities within fractal processes. Thus, he writes in his 1989 lecture entitled *Fractal Music – Red Herring or Promised Land:*

> But when one investigates Ligeti's supposedly 'fractal' music, for instance his piano *Études* from 1985, one finds that this music could very well be achieved without having heard of the existence of chaos theory or having seen the Peitgen-Richter pictures.[35]

Presumably, Wallin had Ligeti's *Désordre* in mind when making these comments, even though he does not specifically name the piece.

[35]Cf. rolfwallin.org/articles/c_5165b8ec1e98c045d02b30b3. Accessed: 20/7/2020.

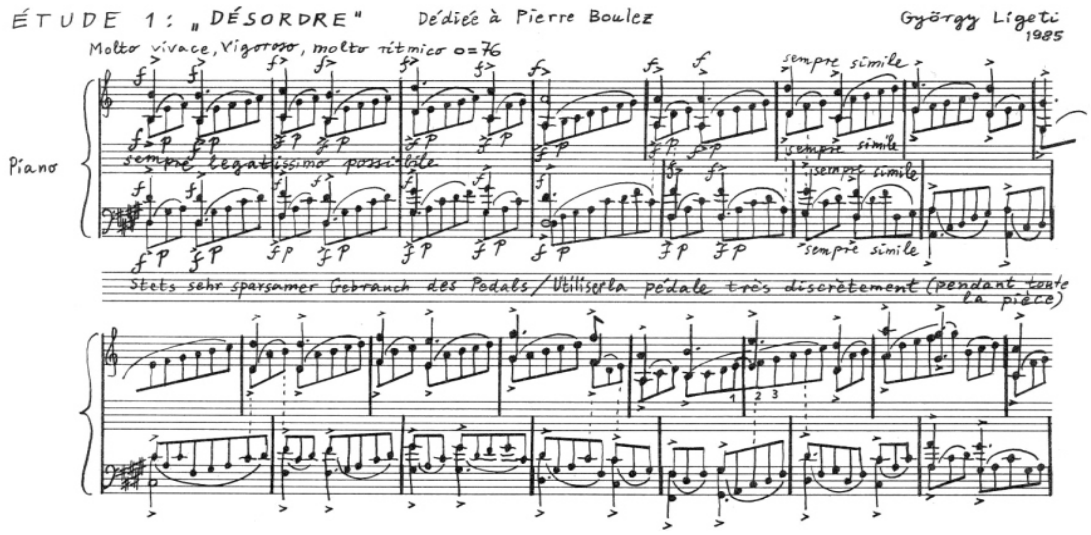



Figure 2

Score extract of revealing something of the self-similar patterns and rhythms employed in parts of Ligeti's *Désordre.*

### 1.4.4) The Limitations of Recent Fractal Music.

Leaving aside the important work of Vaggione, Ligeti and Wallin, it needs to be noted that some of the other composers which I mentioned above have conceded that their engagement with fractals was of a limited nature. For example, Agostino Di Scipio remarked that he had 'no special attractions for fractals and other popular scientific concepts.[36] Instead, he saw only 'potential in these numerical methods as a useful front-end for granular synthesis'.[37] Similarly, it has been argued that whilst figures like Wuorinen engaged with fractals and drew inspiration from them they do not formally and systematically use fractals to compose music that is fractal

[36] Christine Anderson, 'Dynamic Networks of Sonic Interactions: An Interview with Agostino Di Scipio', *Computer Music Journal,* 2005 (29: 3), pp. 11-28, at p. 12.
[37] *Ibid*.

both in origin and design. Michael Segal remarks that Wuorinen 'uses fractal themes in his work very strongly, but he does not compose fractal music as such'.[38]

It is also important to note that several attempts have been made to explore fractal music at a more 'popular' level. Pertinent in this respect is the work of Harlem J. Brothers and Charles B. Madden. However, given that their work tends to be of a more "popular" nature it has been heavily criticized by several sonic researchers on account of its lack of academic rigour. For example, in his review of Madden's *Fractals in Music: Introductory Mathematics for Musical Analysis* (1999, 2007) Bruce Quaglia notes that whilst Madden offers a number of interesting insights into the relationship between fractals and music, his monograph is not only poorly referenced and contains numerous mistakes, but it also fails to systematically explore the compositional significance of fractals and how they have been appropriated by some of the composers which we have already had cause to mention. Quaglia remarks:

> I believe this book offers an interesting but ultimately idiosyncratic view of music history and theory that is often overly generalized and severely underdeveloped…. I am also surprised that a book devoted to mathematics in music and particularly to fractals would omit mention…of composers such as György Ligeti and Charles Wuorinen, composers who have by their own admission been working with fractals for decades as part of their compositional procedures…[39]

In light of the above research into fractal inspired music, it is thus important to note two points.

---

[38] Michael Segal, 'In the Mind of the Fractal King: A Reconstructed Interview on Life and Fractals', *Nautilus*, 2013, http://m. nautil.us/issue/0/the-story-of-nautilus/in-the-mind-of-the-fractal-king. Accessed: 20th/6th/2019.

[39] Bruce Quaglia, 'Review of 'Fractals in Music: Introductory Mathematics for Musical Analysis by Charles Madden', *Computer Music Journal*, 2000 (24: 3), pp. 84-6.

1) On the one hand, there is some precedence for using fractals within sonic art. As I have indicated, by no stretch of the imagination have fractals gone unnoticed by electronic, or indeed classical, composers. It is beyond doubt that there is an existing and steadily growing sphere of electronic music that can be described as “fractal” in one way or another.

2) However, on the other hand, it is also clear there is room for further contribution to the field of fractal music. As indicated above, not only does the depth with which sonic artists have engaged with fractals vary greatly, but to recall Magnus Eldenius’ words, “there remains a tendency within electronic music towards writing about fractal music, rather than actually producing fractal music itself”.

## 1.5) The Research Contributions of this Portfolio.

It is against this background that my research portfolio is to be viewed. In this portfolio I have not simply sought to analyse or outline at a theoretical level the potential which fractals have for sonic art. Rather, I have actively produced sustained compositions from fractal algorithms. I have sought to produce compositions that are not only fractal in origin, but also fractal in design, spirit and overall presentation. As will be seen in most of my compositions, I have used fractal algorithms and images to produce micro sounds from which I then produced a macro sound that resembled the original micro sound at every level of the compositional process.

## 1.6) Argument and Methodology.

Very much like the fractals which it studies, fractal mathematics is a discipline that is expanding at an exponential rate, revealing ever greater detail about our world, both at the micro and macro level. To this extent, fractal theory itself is too broad and uncircumscribed a field of enquiry to form the basis of a limited study such as this current portfolio. As such, to give both precision and coherent structure to my research, my compositional experimentation has focused solely upon how the emerging dimension of fractal theory known as fractal flames, specifically those associated with Scott Draves, can be used to generate acoustic phenomena.[40] I shall say more on the nature of fractal flames in the next chapter.

## 1.7) Hearing the Background Music – The Sources of Inspiration Behind My Compositions.

To understand the music of any composer or sonic artist it is necessary to know something about the styles of music, their influential composers and academic research from which they draw inspiration. Such is the case with my own compositions. As will become clear, my experimentation with generating 'new sounds' using fractal flames has its origins, in part at least within the music of those composers who have influenced my own creative thinking and musical tastes. Several of these composers have worked in fields radically different to the niche of music composition that I have sought to occupy during my research. Simply stated, these are often classical composers.

I have already mentioned the importance of Xenakis on my compositional experiments. However, other important influences include J. S. Bach, Beethoven, Chopin, Schoenberg and

[40] Scott Draves and Erik Reckase, 'The Fractal Flame Algorithm' (2003). Downloaded from https:flam3.com/flame_draves.pdf. Accessed: 10th August 2019.

Stravinsky. Of particular importance is their use of recursive patterns and self-similar melodies, as well as their willingness to break away from standard compositional rules. One need only think of Bach's Toccata and Fugue in D Minor as a powerful example. As we shall see, my composition *Classical* makes direct use of the works of Bach, Beethoven, and Chopin. It subjects extracts from some of their best-known pieces to the iterative processes of fractal flame algorithms so as to produce a unique sound experience.

Four researchers in particular, however, have had a significant influence on my compositional experiments. These are: Harry Partch, Iannis Xenakis, Trevor Wishart and, finally, the mathematician Benoit Mandelbrot. Partch's influence has been at the level of general aesthetic procedures, particularly regarding tonality. The research of Xenakis and Wishart have been absolutely central to my compositional experimentation and are employed repeatedly and systematically in many of my pieces. By contrast, Mandelbrot's influence on my compositional process has been one of a mathematical inspiration.

### 1.7.1) Harry Partch – Unorthodox Sounds.

At the broadest level, my experiments with tonality have been inspired by Harry Partch and his attempt to "shock" western composers out of their somewhat two-dimensional view of tonality.[41] According to Partch, following in the wake of Bach, much of Western music has allowed itself to become trapped within, or at the very least irrevocably wedded to, a purely twelve-tone equal temperament to the exclusion of all other tonal systems. Influenced by his

[41] Perhaps Partch's most influential study is his *Genesis of A Music: An Account of A Creative Work, Its Roots and Its Fulfilment,* (New York: De Capo Press, 1979). See also the following useful studies: S. Andrew Granade, *Harry Partch, Hobo Composer,* (New York: University of Rochester Press, 2014) and Bob Gilmore, *Harry Partch: A Biography,* (Yale: Yale University Press, 1998).

exposure to Eastern music, especially that of Indonesia, Partch sought to open the ears of Western composers to the potential of other tonal systems. He composed with scales dividing the octave into forty-three unequal tones derived from the natural harmonic series. To aid his explorations in tonality, Partch invented, and often built, his own musical instruments, many of which remain unrivalled in their ingenuity, design and beauty.

Although Partch is not an electronic composer and is in some circles labelled as an 'iconoclast' on account of his discussion of 'Western theories of tonality', his critique of what he saw as the self-restrictive limitations of western post-Bach composers is one that has deeply shaped my own views on tonality. Despite my love for Bach and much of post-Bach Western music, Partch was right in seeking to remind Western composers of the rich diversity of other tonal systems. As such, I have sought to bear this in mind during my own compositional experiments.

Moreover, Partch's commitment to generating sounds using specially designed instruments, is one that has resemblances to my own efforts to generate 'sounds that have never existed before'. Whilst Partch may have used hand-made musical instruments to generate new sounds, I have used fractal flame programs, and existing sound manipulation programs such as MetaSynth and PhotoSounder to generate my composition. These have been my unique tools to create 'unorthodox sounds'.

I employ a method of composition and sound generation radically different from the musical techniques and instruments Partch exploited. Indeed, it is hard to think of a more striking dichotomy between the earthy and seemingly primitive nature of some Partch's musical instruments and my chosen genus of computer aided music. My explorations in electronic music have their origins in my indebtedness to Partch's efforts to challenge composers to look beyond the standard instruments used to generate sound.

## 1.7.2) Iannis Xenakis – Granular Synthesis.

Beyond Partch's more general influence on my explorations in tonality, an absolutely central and recurring influence within my compositions has been the concept of granular synthesis pioneered by Iannis Xenakis. In his book *Formalized Music* (1971), Xenakis famously proposed the concept that each sound consists of various 'micro-sounds'. By no means original, Xenakis's belief that sounds consist of individual 'grains' of micro sound finds its origins in the work of the Hungarian physicist Denis Gabor, in particular his influential study *Acoustic Quanta and Theory of Hearing* (1947).

Although hidden from human hearing, Xenakis showed that these micro-sounds can be rendered audible by means of computer programs, extending the sound and isolating its individual constituent elements. These individual elements he labelled 'grains' of sound. Moreover, according to Xenakis, each of these 'grains' can be isolated and exploited for compositional purposes by using computer technology. In Xenakis' thinking, there are thus sounds within sounds:

> All sound, even continuous musical variation, is conceived as an assemblage of a large number of elementary sounds adequately disposed in time. In the attack, body, and decline of a complex sound, thousands of pure sounds appear in a more or less short interval of time'[42]

Xenakis' concept of granular synthesis, and its separation of sound into its constituent elements is clearly summarized by Eric Kuehnl as follows:

---

[42] Quote taken from Curtis Roads, *The Computer Music Tutorial,* (Cambridge MA: MIT, 1996), p. 169.

> The grain is a unit of sonic energy possessing any waveform, and with a typical duration of a few milliseconds, near the threshold of human hearing … it is the continuous control of these small sonic events (which are discerned as one large sonic mass) which gives granular synthesis its power and flexibility.[43]

According to Xenakis, the isolation of individual grains of sound allows for a whole new field of sound experimentation and manipulation to arise. Taking the individual grains of sound within a specific sound sample, and manipulating these micro sounds, either by stretching or by compressing them, offers the electronic composer the tools to produce, and thereby make use of, unique and previously unknown sonic phenomena – phenomena which would be imperceptible to human beings without the assistance of computer technology.

Xenakis' process of granular synthesis has been explored in detail by figures like Curtis Roads, Barry Truax, Agostino Di Scipio and E. R. Miranda. Moreover, it proves central to my own compositional project. Some important compositions which extensively employ granular synthesis include Truax's *Riverrun* (1986), *The Wings of Nike* (1987) and *Tongues of Angels* (1988). As we shall see in many of my compositions, I have used granular synthesis to isolate different individual grains of sound from the sound samples generated through my sonification of fractal flame images. This use of granular synthesis can be seen particularly clear in my compositions *Atomic Reaction*, *Temple of Shiva*, *Symphony of Noise* and *Julia-N*.

The following images illustrate my isolation of individual grains of sound during my generation of an acoustic sample using fractal flame algorithms. These images come from my composition entitled *Atomic Reaction*.

---

[43] Eric Kuehnl, Granular Synthesis (1995) at www.erickuehnl.com./granular-synthesis/. Accessed: 02-04-2019.

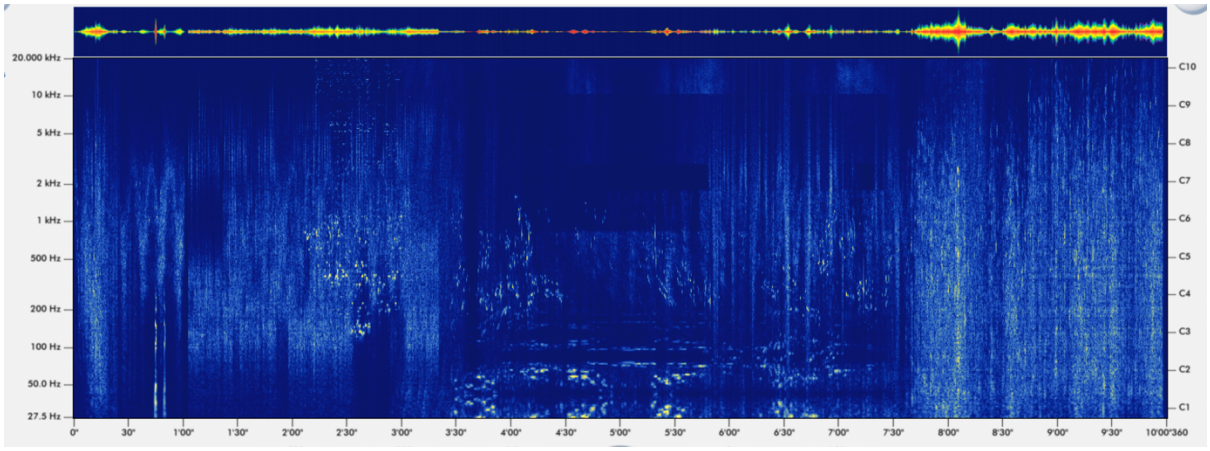



Figure 3

The isolation of sound grains in the production of *Atomic Reaction*.

### 1.7.3) Trevor Wishart – Wave-Set Substitution.

Another important influence on my compositional process has been that of Trevor Wishart's experiments in wave-set substitution, and the various programs which he has pioneered as part of his *Composers' Desktop Project*. Finding expression in his own compositions, most notably his *Tongues of Fire* (1994), Wishart's explorations with wave-sets, in particular his concepts of wave-set repetition, averaging and distortion, have, alongside his practice of wave-set substitution, greatly underpinned much of my explorations in granular synthesis. Of particular influence, are Wishart's *Sound Composition* (2012), *Audible Design* (1994) and of course his *On Sonic Art* (1996).

In his influential *Microsounds*, Curtis Roads defines Wishart's concept of wave-set substitution as one which 'replaces wave-sets by a stipulated waveform of the same amplitude, frequency, and time span as the original wave set'.[44] At its broadest level, wave-sets, Roads

[44] Curtis Roads, *Microsound,* (Cambridge MA: MIT, 2001), p. 207.

states, are a 'family of electronic sound transformations'.[45] Wishart himself, in his appendix to his *Audible Design*, defines a wave-set as: 'the distance from one zero-crossing to a third zero-crossing'.[46] As the diagram below makes clear, each zero crossing is a point at which the whole wave is shrunk so as to replace the wave within each zero crossing point. Wave-set replacement is thus a form of wave-set distortion. Various applications such as SuperCollider and Soundloom have wave-set substitution processes and have in turn been used in many of my compositions.

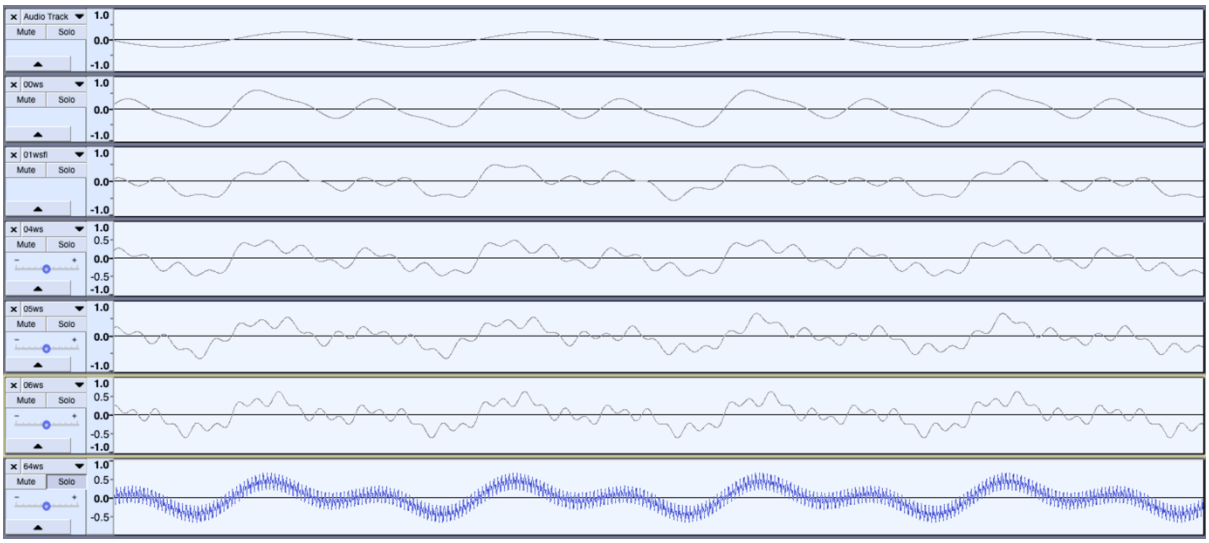



Figure 4

The above is an image reflecting the process of wave-set substitution. The 32nd iteration is a mix of frequencies with the fundamental frequency the loudest. Each iteration lessens the velocity of the sound wave by half. It sounds similar to a roughly distorted sine wave with an exponential overtone series halving in velocity. A further investigation using audio samples for wave-set substitution produces more noise and causes aliasing.

[45] *Ibid.*, p. 205.
[46] Trevor Wishart, *Audible Design: A Plain and Easy Introduction to Practical Sound Composition,* (London: Orpheus The Pantomime, 1994), p. 50.

## 1.7.4) The Fractal King: Benoit Mandelbrot.

Beyond the composers who have influenced the pieces contained within this portfolio, one final influence ought to be mentioned; namely, Benoit Mandelbrot.[47] He is the father of modern-day fractal theory, and it important to discuss the famous Mandelbrot set discovered by this mathematician.

The most complex expression of fractal geometry and imagery, the Mandelbrot set offers something akin to an image of eternity in time. The basic principle of the Mandelbrot set is that of the self-similarity between the image at a macro and micro level such that it looks the same no matter how much it is magnified. Thus, when one looks at one specific part of the Mandelbrot set, one finds not a fragmented or isolated aspect of the set, but rather an image of the fractal as a whole.

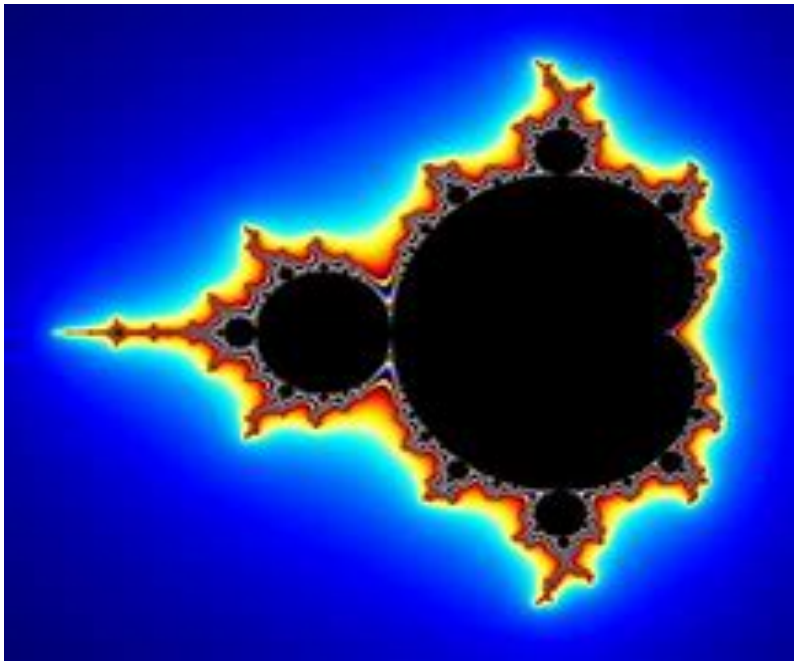


Figure 5

Mandelbrot set.

[47] Perhaps Mandelbrot's most detailed and influential study is his *The Fractal Geometry of Nature*, (New York: W. H. Freeman and Company, 1982).

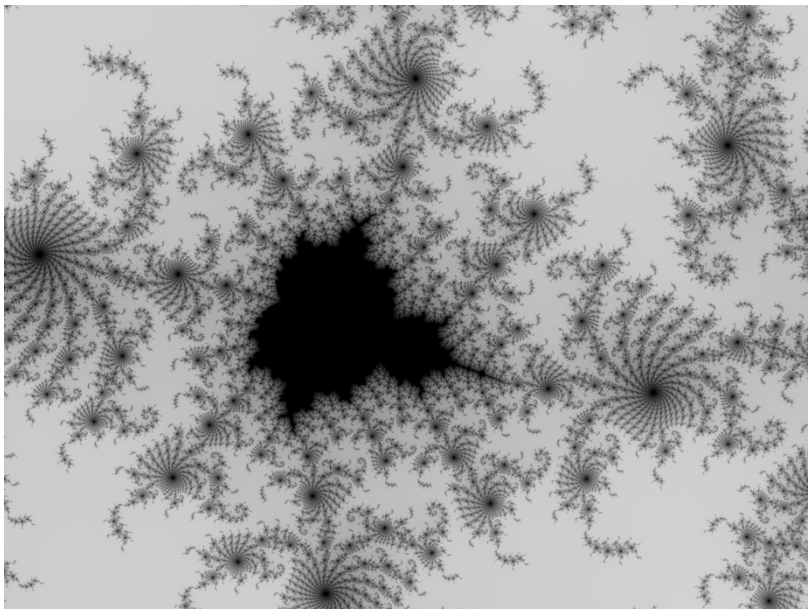


Figure 6

An image of a “minibrot” in the Mandelbrot set.

As we shall see, this self-similarity between the Mandelbrot set at the micro and macro level is something which I have sought to replicate in my own experimentations with fractally generated micro and macro sounds. In the same way that within a Mandelbrot set it is possible to find a ‘vision of eternity in time’, so I have sought to show how, through the iterative patterns of fractal flame programs, it is possible to hear, if I may coin a phrase, something of the 'sound of eternity in time'. In short, my compositions offer something akin to an audible version of a Mandelbrot set.

## 1.8) The Motivations and Aims Underpinning my Compositions.

At its deepest level, the spirit animating my work has thus been a desire to not only explore the interface between electronic music composition and the iterative processes utilized by fractal flames programs, but by doing so, to bring into relief the way iterative algorithmic processes and computer technology can generate ethereal and beautiful sonic art.

Following the enlightenment period, music and science, that is to say, art and logic, have often been portrayed as two mutually exclusive spheres. One is classified as an artistic, creative process free from unnecessary restriction and bland determinism. The other, by contrast, is classified as a logical and prescriptive discipline bounded by set rules. One is viewed as a type of poetry; the other, as a product of rigorous rationality. One is chaotic, the other, stable and structured. This dialectic approach, however, is a relatively modern phenomenon. From the ancient philosophers Pythagoras and Aristotle to the great Renaissance composers, music and science, particularly mathematics, were regarded as fundamentally intertwined. Both were regarded as complementary sciences.[48]

In his Rede lecture of 1959, *The Two Cultures and the Scientific Revolution*, C. P. Snow touched upon the dialectic that has emerged since the scientific revolution between the 'sciences' and the 'humanities', in particular art and music. According to Snow, those working in the sciences and humanities have failed to properly enter into dialogue with one another. Scientists dismiss the contribution of the arts and humanities, whilst the latter see no value in the sciences for their own development. The result is that much of the original creative dialogue between the sciences and the arts so celebrated by scientists and artists until the Renaissance, has become fractured and in many respects non-existent. Snow tells us that 'between the two a gulf of mutual incomprehension' has been generated.[49]

'The non-scientists', he tells us, 'have rooted impression that the scientists are shallowly optimistic, unaware of man's condition', whilst the scientists believe that artists, literary scholars, and in particular musicians, 'are totally lacking in foresight, peculiarly unconcerned

---

[48] Cf. Po-Hung Li 'The Role of Mathematics in the Renaissance Sciences and Arts' *Humanities and Social Sciences Review* 2(2) 2013, pp. 107-111, at p. 109-11.

[49] C. P. Snow, Rede Lecture 1959, *The Two Cultures and the Scientific Revolution*, (Cambridge: CUP, 2012) (E-Book).

with their brother men, in a deep sense anti-intellectual, anxious to restrict both art and thought to the existential moment'.[50] According to Snow, this fissure, which has emerged between the arts and the sciences in post-Enlightenment Western culture, has done much to stagnate the development of both academic spheres, especially those working in the arts and the intellectual credibility of their output. In order for those working in the arts and the sciences to progress and take advantage of the great intellectual potential offered by the other's discipline, Snow tells us they must learn to re-engage with one another.[51]

It is my belief that the scientist-mathematician has much to teach the composer; and the composer, in turn, has much to reveal to the mathematician. A quick review of the work of some composers and sonic researchers already alluded to, confirms that I am not alone in this conviction. For example, Xenakis, as well as Andreas and Kenneth Hsu, and Steven Ornes have done much to reveal the integral link between music and science, in particular the recent advancements in computer technology.[52] In particular, Ornes' recent work has devoted much effort to exploring the mathematical undertones and recursive patterns within Bach's work.[53] Similarly, throughout his career Xenakis did much to pioneer the dialogue between music, mathematics, and computer technology.

---

[50] *Ibid.*
[51] *Ibid*.
[52] Cf. Kenneth Hsu and Andreas Hsu, 'Fractal Geometry of Music', *Proceedings of the National Academy of Sciences of the United States of America*, 1990 (87:3), pp. 938-941. Iannis Xenakis, *Formalized Music: Thought and Mathematics in Music*, (New York: Pendragon Press, 1992).
[53] Stephen Ornes, 'Science and Culture: Hunting Fractals in the Music of J. S. Bach', *Science and Culture*, 2014 (111: 29), p. 10393.

In this portfolio my motivation has been to follow this example of exploring the interface between music and science. Working within the field of electronic composition, I have attempted to show, both at a theoretical and at a practical level, the compositional potential while using the application of mathematical formulas. By employing fractal flame algorithms, I have explored and demonstrated the interface between music and computer technology. As my compositions, like those of Wallin and Vaggione, show, fractal inspired music allows for the relationship between music and science to develop in new and exciting ways; ones in which cutting edge mathematics and compositional techniques can be mutually enriching.

## 1.9) Structure.

The remaining chapters of my portfolio cover the following ground:

(1) First, the specific techniques, especially exploring the fractal flame algorithms, are presented.

(2) Each of my portfolio compositions are analysed in turn, paying particular attention to the methodological processes by which they were produced. This will take up the main body of my commentary.

(3) A short conclusion will highlight how the compositional method outlined could be expanded in the future.

# Chapter 2

# Research Contributions

## 2.1) Introduction: Rendering the Visible Audible.

As a prelude to the discussion of my compositions, this section offers a general overview of the basic principles of the processes by which I generated music using fractal flame images and algorithms.

## 2.2) Fractal Flames – What are They?

At its most basic level, a fractal flame image is a computer-generated visual phenomenon which arises from an algorithm that expresses the iterative processes involved in fractals. These images vary in colour, depth, and brightness, as well as translucency and density. They do so according to the number and complexity of iterations produced by the algorithm as it is performed by a computer. Fractal flame images are the product of a deterministic, often highly complex algorithmic computational process to create colours at X-Y-Z points. These 'grains of colour' are placed at specific points upon the X-Y-Z axes according to the numerical coding employed within the respective algorithm. Fractal flames were originally designed by Scott Draves in 1992 and were made publicly available through his programme *Apothosis*.

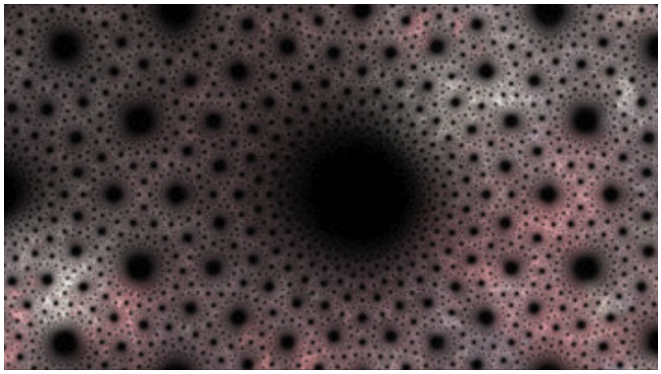


Figure 7

Example of a fractal flame image.

Figure 8

Example of fractal flame image.

Figure 9

Example of fractal flame image.

$$F_i(x, y) = (a_i x + b_i y + c_i, d_i x + e_i y + f_i)$$

$$F_0(x, y) = (\tfrac{x}{2}, \tfrac{y}{2}) \quad F_1(x, y) = (\tfrac{x+1}{2}, \tfrac{y}{2}) \quad F_2(x, y) = (\tfrac{x}{2}, \tfrac{y+1}{2})$$

Figure 10

Example of an open source fractal flame algorithm.

What makes fractal flame images differ, and what is responsible for the highly complex, seemingly endless diversity of fractal flame images even possible, are the variables that are 'seeded' within fractal flame algorithms themselves. These variables may only be very small, but as is perhaps to be expected given the affinity between fractal processes and chaos theory, the result which they have on the image produced is extreme. Variables introduced into a fractal flame algorithm significantly alter the nature of the image which the algorithm produces. This is true not only to the shape and pattern of the fractal flame algorithm but also to its colour and brightness. As I will soon demonstrate, this variability has significant consequences for both the resulting sonic event produced through the sonification of the image produced by the fractal flame algorithm, and how fractal flame algorithms and images themselves can be used within compositional processes.

Further underscoring the affinity between fractal flame algorithms and chaos theory is the fact that most open source algorithms, particularly those which have emerged on the internet in recent years, are seeded with a plethora of random, and thus entirely unpredictable, variables. This meant that when employing such algorithms within my compositional experiments I often had no way of knowing what the sonic output of the algorithm and its derivative image would sound like prior to its sonification. Fractal flame algorithms and images

are *nothing* like classical sheet music. The capacity to 'sight-read' them is beyond the scope of human intelligence. They can only be processed using computers. On several occasions I designed my own project coding which allowed me to have direct control over the auditory events produced by the algorithms. Even then, I could not predict the sound that would be produced because of the complexity of iterations carried out by those algorithms.

## 2.3) Translating Colour into Sound.

Taking a specific fractal flame algorithm as my starting point, the basic process by which I translated the mathematical and purely visual art of a fractal flame image into an auditory phenomenon can be summarised in the following stages. To illustrate this process, I will use examples from some of the compositions included in this portfolio, focusing in particular though on *Spots Evolve*.

However, before proceeding it is important to note the following: as will be explained shortly, during my research my compositional methodology underwent an important development. I moved from a 'purist' or 'non-interventionist' approach in my early pieces to an 'interventionist' one in my later works. The process described in stages 1-2 pertain to my early 'purist' or 'non-interventionist programme period, whereas stages 3-5 reflect the compositional processes found in my later 'interventionist' pieces. I will explain these terms and the nature of my early 'purism' and later 'interventionism' in more detail shortly.

**(1)** Taking a suitable fractal flame generator (I employed several such generators in my compositional experiments) the first phase of my compositional process was to produce a standard fractal flame image by selecting and running either a) an

open source – i.e., freely available – fractal algorithm from the internet; or b) a code which I myself had generated within a fractal flame generator.

$(x, y)$= a random point in the bi-unit square
iterate {
    $i$ = a random integer from 0 to $n - 1$ inclusive
    $(x, y) = F_i(x, y)$
    plot$(x, y)$ except during the first 20 iterations
}

Figure 11

This is an example of part of the open source fractal flame algorithm which I used in the production of *Spots Evolve*.

Figure 12

This image shows one stage of the fractal flame images which I used in the production of *Spots Evolve.*

**(2)** Once the fractal flame image had been generated from the selected algorithm, I translated it into an audio file. This was done using spectral synthesizer programs, such as MetaSynth. The result was the sonification of the fractal

flame image. The output of this sonification process often lasted only a few seconds and its individual sound grains were far too compressed for the ear to hear. As such, so as to bring its individuals grains of sound into relief and to produce a sonic event that lasted several minutes, I stretched the sound sample. As we will see later, during my very earliest compositional experiments this was as far as my compositional method went.

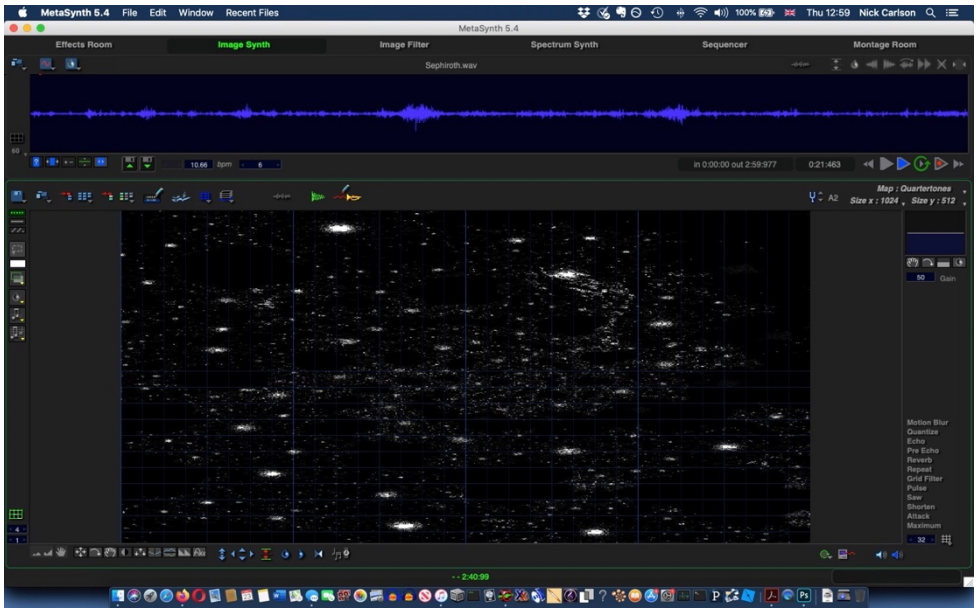



Figure 13

This image shows the transference of one of the early fractal flame iterations utilized in *Spots Evolve* into an audio file using MetaSynth.

**(3)** Once translated into an audio file, the manipulation of this sound sample at a micro sound level could begin. As my commentary on my individual pieces will illustrate, my most common way of manipulating the sound sample was to subject it, or select parts of it, to iterative stretching or contraction by

employing Trevor Wishart's process of wave-set substitution. The result was that the individual grains of sound contained in the sound sample were extended, thereby meaning that they were brought into relief and rendered more readily accessible for individual manipulation. At an audio level, the result of stretching the sound sample was that the pitch of the individual grains of sound it contained was lowered.

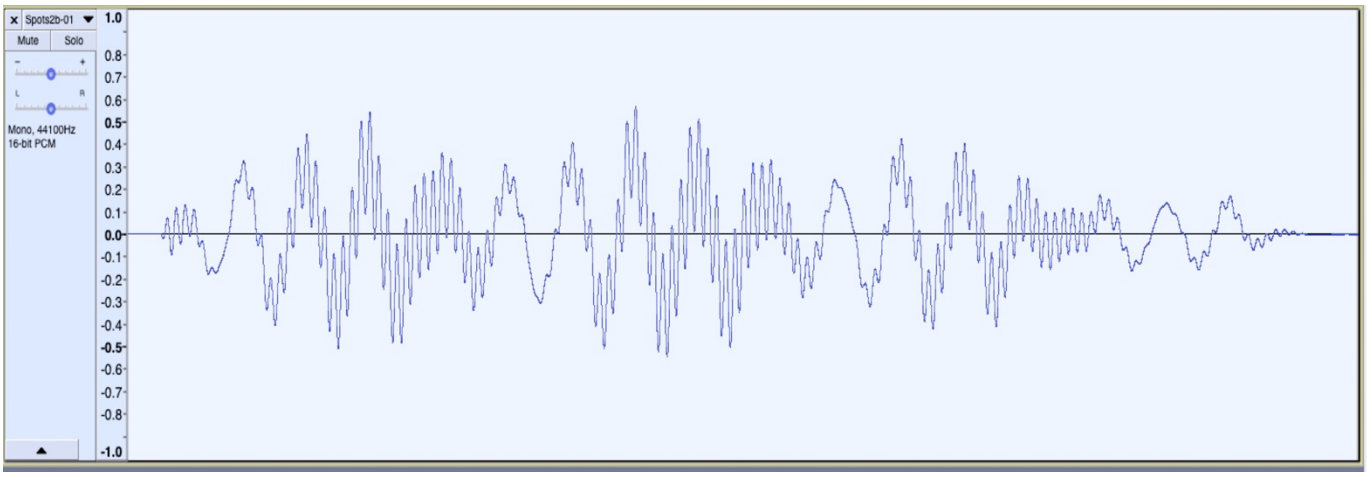



Figure 14

This is an image of wave-set substitution being used on one iteration of *Spots Evolve*.

**(4)** The extension of the sound sample and the revealing of the various grains of sound it contained allowed for several forms of creative manipulation to be applied to it, both in terms of the overall sample and its constituent grains of sound. The most common form of sonic manipulation I utilized was to isolate individual grains of sound and to stretch these and then to overlay them over either the whole of the sound sample or parts of it. In most of my later

compositions, in particular *Spots Evolve, Temple of Shiva*, and *Atomic Reaction, m*y stretching and iterative overlaying of the sonic output was done in such a way so as to reflect the original identity of the seminal micro sound. In other words, each time I overlaid the output of the stretching of the sound sample I made sure that the output was faithful to the original identity and parameters of the first iteration produced by the sonification of the fractal flame image. The purpose of doing so, as we will see in my commentary, was to ensure the final macro-sound was as faithful to the identity of the original micro-sound and that the unique fractal identity of the piece was coherently replicated at each stage of its production, thus ensuring its fractal origins. The complexities of this process will be discussed in detail in the next chapter when we look at some of my individual pieces, in particular *Temple of Shiva* and *Atomic Reaction.*

**(5)** Once I had completed this phase, my attention would turn to manipulating the resulting output of the previous processes at a macro sound level. Here again often through a process of iterative stretching and contracting, I would shape the piece at a macro level for aesthetic purposes and completion (see section 2.5 below for an explanation of the aesthetic principles I sought to follow). As is the case in so many of my later compositions, this process of manipulating the macro sound was often achieved by altering the fractal flame image prior to its sonification, and indeed post its first sonification in some cases prior to its then being subject to a process of sonification again. By manipulating the image, by decreasing or increasing its luminosity or by altering its colour, I was able to alter the sound output of the image produced when it was run through

a spectral synthesizer. As will be clearly seen when we look at *Spots Evolve*, altering the brightness or colour of specific parts of a fractal flame image changed the volume and pitch of the image when it was translated into audio format. The repeated manipulation of the fractal flame images formed an integral part of my compositional process, either through recursive overlaying or simple alteration of their brightness, prior to sonification. The following figures illustrates my manipulation of the brightness of the fractal flame image used to produce *Spots Evolve*.

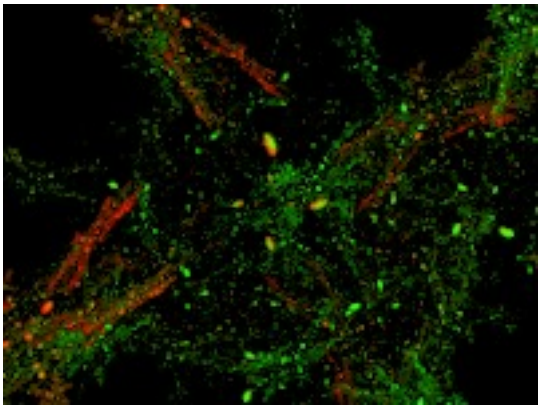


Figure 15

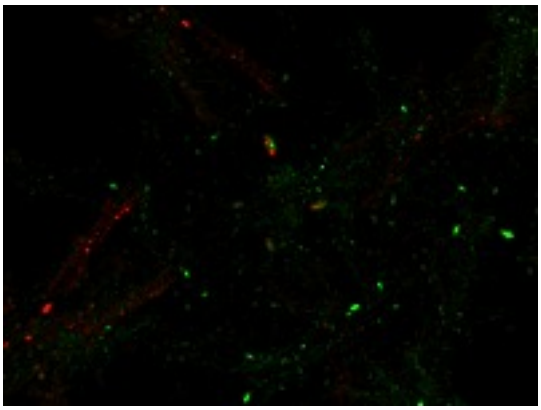


Figure 16

Figures 15-16 illustrate how I manipulated the fractal flame image responsible for *Spots Evolve* in Photoshop. I made the spots more visible and distinct in the image by removing some of the less luminous grains of colour, thereby bringing the denser clusters of colour grains forming the spots themselves into relief. The purpose of doing this, was to allow for the sound output of the individual spots to be more distinct and to avoid the production of pink and brown noise.

I shall say much more on the stages described above when discussing my individual pieces in the next chapter.

## 2.4) Key Compositional Concepts and Points of Clarification.

To understand the processes by which I composed most of the pieces contained within this portfolio a number of important points need to be made.

### 2.4.1) Manipulating Luminosity and Colour to Change Sonic Output.

First, I should like to explore in greater detail what was indicated above concerning how I manipulated the sonic output of fractal flame images by altering their luminosity and colour.

As will be seen, there is a unique correspondence between the fractal flame image itself (i.e., its colour, luminosity, depth, and density) and the volume, pitch, speed and number of voices in the sound which it produces. The result of course is that any change to the fractal flame image will affect the sound sample it produces. Also important in this respect, is the identification of specific voices with specific colours. Correspondingly, each colour within the fractal flames I utilized were identified with specific voices. The result was that I was able to manipulate the sonic output of the image by manipulating the colours within the image itself. I did this by either increasing or decreasing the vibrancy of specific colours, or even by merging

colours into one another. As is to be expected, the number of voices and colour within each of my pieces varied. As we will see, in *Julia N* there were a total sixteen different colours corresponding to sixteen different colours, whilst in *Spots Evolve* there were only eight.

The purpose of identifying certain colours with certain voices was to produce a polyphonic rendition of the fractal flame image. To use the analogy of more classical types of music, the result would be something like one colour corresponding to a soprano voice, another to an alto, and yet another, to a bass. Thus, colour in effect, represents a visual expression of a particular voice within a fractal flame inspired composition. The following images shows how I allotted different colours within a fractal flame image to different voices.

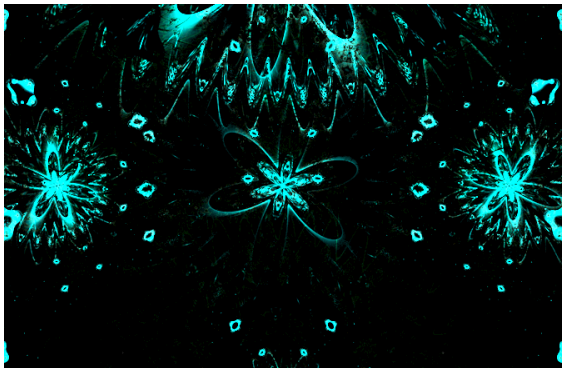
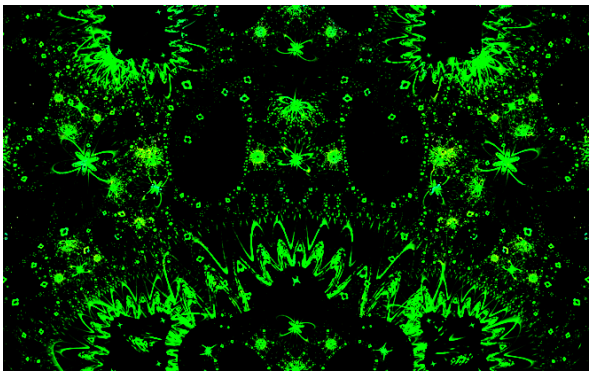


Figure 17



Figures 18

Selection of images of the fractal flame used in the production of *Julia N*. These show how I allotted different colours to different voices within the same fractal flame image.

## 2.4.2) The Dependence of the Luminosity and Colour of a Fractal Flame Image upon the Data of the Algorithm.

It needs to be noted that within fractal flames there exist very specific connections between colour and luminosity on the one hand, and the fractal data itself on the other hand. At the risk of oversimplification, this relationship can be summarised as follows:

**a)** As the fractal flame algorithm is processed, it maps individual grains of colour onto sets of X-Y-Z axes. As it does so, it gradually builds up a 3D image with each grain of colour illustrating a specific point on the axes upon which the algorithm(s) generate a response.

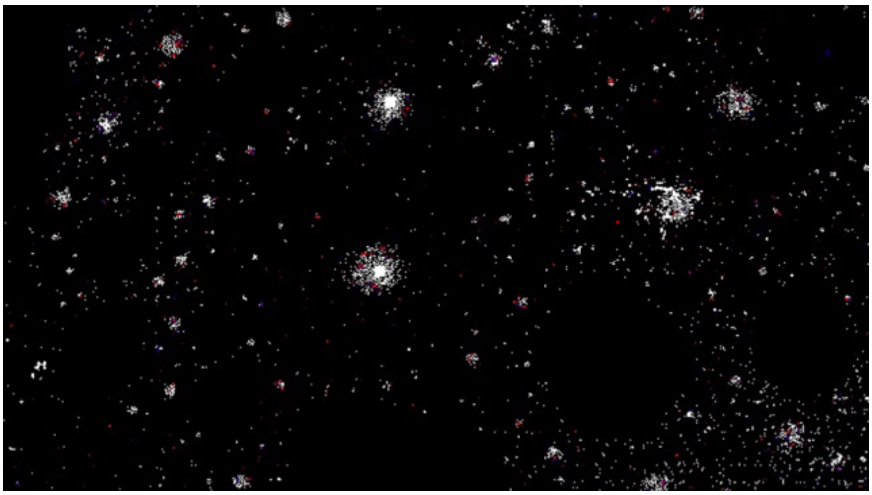


Figure 19

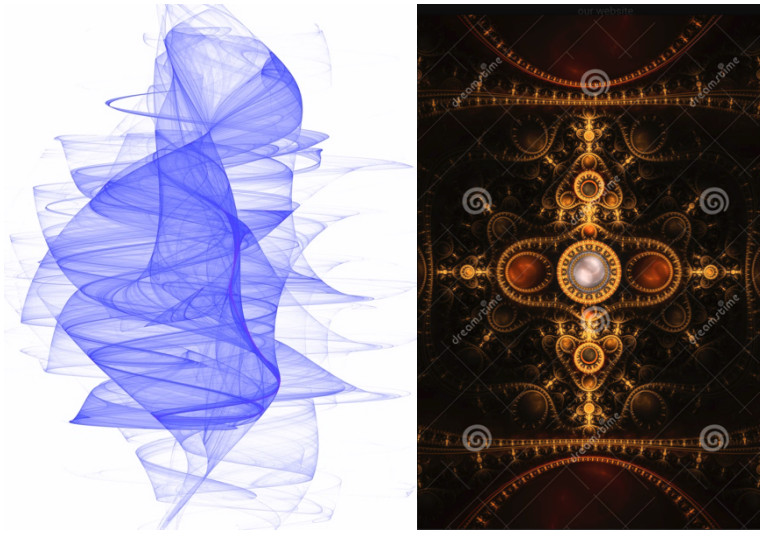
Grains of colour being mapped onto X-Y-Z axes. Here we see a predominance of white grains with the beginnings of red grains of sound beginning to appear towards the central bright white spot.

**b)** Depending on the intensity of the clusters of grains of colour generated by the algorithm(s), the image produced often appears to gravitate towards certain points on the X-Y-Z axes. This gravitation towards these random points on the X-Y-Z axes is produced by the phenomena known as 'attractors' and 'repellents'. These are well-known features involved in the production of fractal flame images. The presence of these 'attractors' and 'repellents' is dictated by the variables contained within the algorithm used to produce the fractal flame image. The presence of 'attractors' and 'repellents' means that the images produced often take on a decidedly ethereal, highly 3D nature. Moreover, they often possess a highly irregular shape and pattern.

Figure 20

A fractal flame showing how strange 'attractors' and 'repellents' give rise to very irregular shapes. Here we see how the grains of colour within the image gravitate toward certain points, whilst other areas are devoid of colour.

**c)** Depending on the fractal flame algorithm used, some fractal flame images also possess a high degree of self-similarity not just at the micro level, but also at the macro level. The following images which I generated illustrate how some fractal flame images are obviously self-similar whilst others are less so.



**Figures 21 and 22**
Self-similar fractal flame mages.

**d)** Those areas at which the algorithm registers a particularly positive response on the axes produce clusters of individual grains of colour. As would be expected, the greater the number of grains, the denser and more visible the colour cluster becomes. Similarly, the more the individual grains of colour cluster around specific points upon the axes, the brighter the luminosity of that particular part of the image is rendered. This can be seen in the following image.

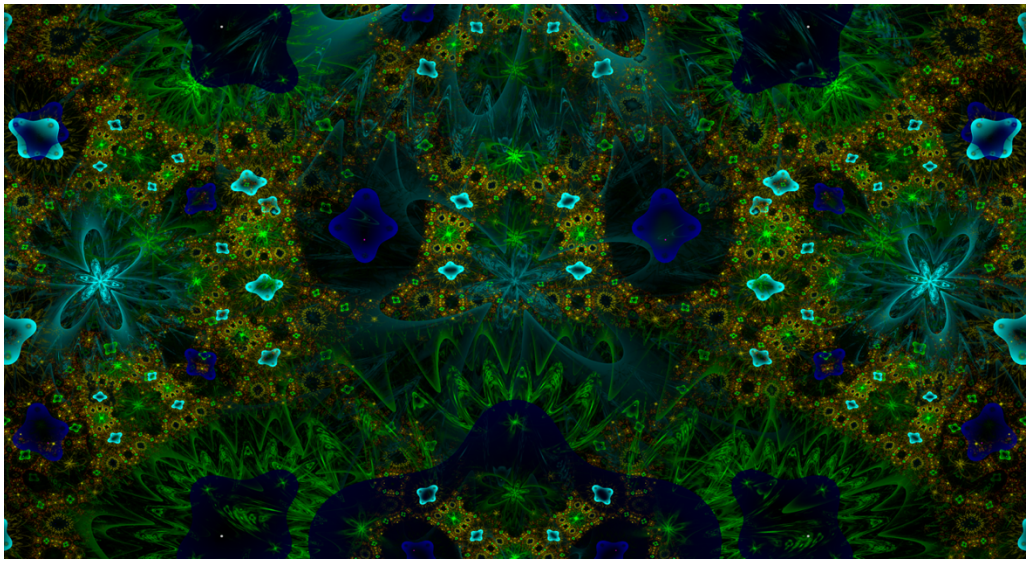


Figure 23

Here we see the varying degrees of luminosity within a fractal flame image. As we shall see, the voices associated with the more luminous colours produced louder sounds, whilst those associated with less luminous colours produced quieter sounds.

## 2.4.3) The Importance of Sine Waves.

One of the points which must be explained is why I used sine waves as the basis for each of my electronic pieces. When using Supercollider to generate fractal flame images, it is possible to have the audio output of a fractal flame image presented in either MIDI or in sine waves. The reason why I chose sine waves for the micro sounds used in my compositional experiments is that they can be more readily subjected to fractalization. That is, these sine waves allow the iterative processes which I have described above without the production of white noise or the fragmentation of the original micro sound into smaller non-self-similar grains of sound.

If the original micro sound was not put into sine waves, then this would have prohibited any serious attempt to subject it to the process of iterative stretching and over layering in such a way that it remained faithful to the identity of the original micro sound. Put simply, sine

waves suited my compositional method, particularly in my later 'interventionist' compositions. Specifically, they allowed for the coherence of the original fractal flame sound sample to be more readily preserved and retain its integrity as it was successively expanded and overlaid. As we will see, the importance of this is particularly clear in several of my compositions, most notably *Atomic Reaction* and *Temple of Shiva*.

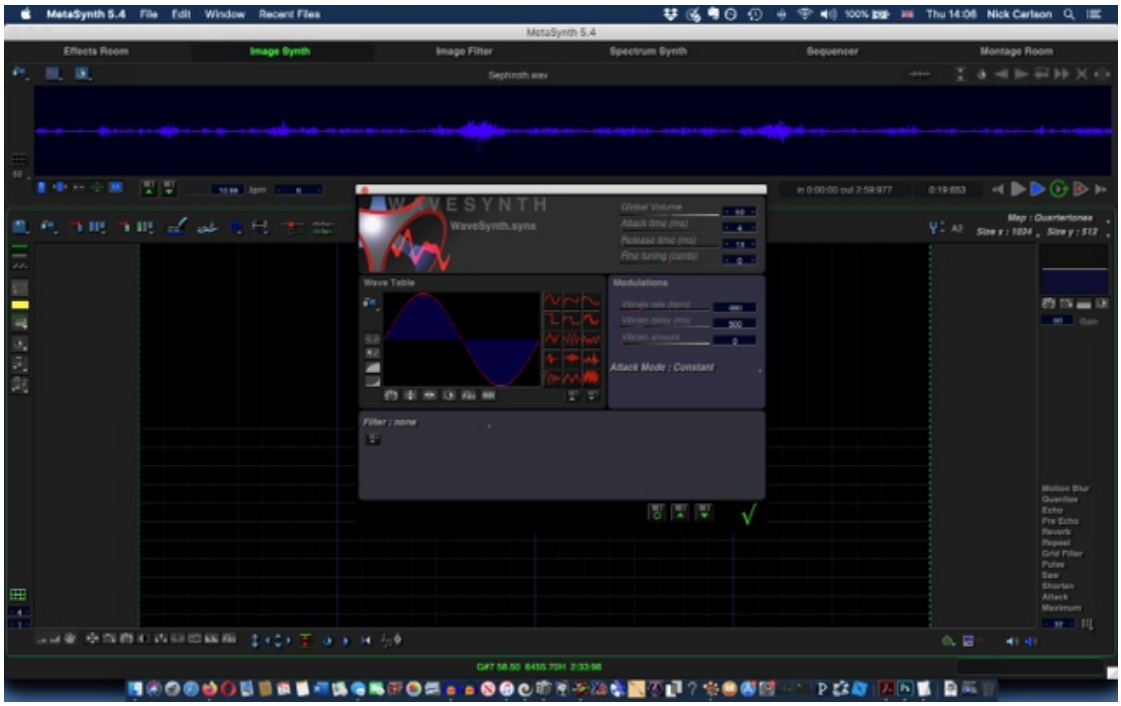



Figure 24

Using sine waves in MetaSynth during the production of *Spots Evolve*.

## 2.5) Aesthetic Manipulation.

It is important to note what is meant by the refining of my pieces for “aesthetic purposes”.

As is self-evident, any aesthetic manipulation, be it in the visual or the musical arts, possesses a highly subjective basis. What one listener may find unpalatable; another may find acceptable. Similarly, aesthetic principles are dictated by the response which the composer

seeks to elicit. If the composer seeks to shock, discomfort or expose the listener to dissonant sounds, then they may use jarring or piercing pitches. Similarly, if they wish to sooth the listener or to evoke a sense of calm, they may use soft tones or repetitive rhythms.

At an aesthetic level, I have sought in my compositions, to elicit both fascination and intrigue. Likewise, I have sought to show how fractal flame generated music can produce macro sounds which are pleasant to the ear whilst also possessing a discernible rhythm, pattern and story. As such, when editing my pieces for aesthetic purposes, both in their final macro sound and the stages used to reach this sound, my primary goal was to remove sounds which were either: a) too piercing for the human ear, b) too quiet, c) lacking in any discernible pattern or rhythm or d) too complex. These complex sounds were those that, consisted of too many grains of sound in too short a time frame for the listener to properly discern them or appreciate their sonic value. Sounds of this sort did not suit my aesthetic goal.

As I have already alluded to, one particularly important aesthetic principle which I sought to follow, particularly in my mature 'interventionist' compositions, was preserving the fractal identity of the original micro sound sample in the macro sound. The purpose of pursuing this agenda was that the final macro sound was as faithful as possible, both in its final form and the various iterative steps used to produce it and to the original sonic output of the fractal flame image and algorithm from which it derived. It is for this reason that in pieces such as *Atomic Reaction*, *Spots Evolve*, and *Tantrum* that I continually removed any sonic elements that arose during their production which risked distorting their macro sound from its original micro exemplar.

As indicated in the last chapter, the aesthetic manipulation involved in my compositions involved a number of processes. For example, they included altering the luminosity of the fractal flame image prior to its sonification, the stretching of sounds through wave-set

substitution so as to lower Hertz and the use of gating, etc. I will say more about these processes in a later commentary.

So as to produce pieces of music compliant with my aesthetic aims it is also important to note that I used various bottom-ending techniques in several of my 'interventionist' pieces, including the use of a sub-woofer. The use of a sub-woofer is perhaps most notable in my composition *Julia N*. The purpose was to render some of the lowest sounds audible to the human ear and place them within the range of 20 Hertz to 25 Kilohertz. As alluded to earlier, some of the sounds produced by my pieces were too low for the human ear to hear. These sounds had to be brought within the range of human audio perception to be appreciated. It is thus to be noted that to appreciate my compositions they are best listened to with the use of a sub-woofer. This allows the listener to not only hear, but also to "feel" the sounds produced by my music.

## 2.6) The Unique Nature of Fractal Flame Sonification.

The sonification of images, or indeed any other form of data, is nothing new within electronic composition. Many composers have used this process to produce compositions. One need only think of the work of Charles Dodge during the 1970's, in particular his *Earth's Magnetic Field* (1970). Similarly, the sonification of images has been explored at length in a recent study by David Worrell.[54] If the sonification of images is nothing new, then an important question arises: What is the significance and compositional value of the sonification of fractal flame images; and how, in turn, does it differ from the sonification of other images?

[54] Cf. Worrel's recent study *Sonification Design: From Data to Intelligible Sound Fields* (Chicago: Springer, 2019).

The answer to this question is a complex one. Several points, however, stand out as pertinent:

1) First, unlike other images, be they artificial, natural, or a combination of the two, fractal flame images are unique in terms of their origins and design. Unlike other visual phenomena, they are the product of complex, specially designed fractal algorithmic computations. They are the product of complex computer-generated fractal processes which are designed to produce images of a high degree of self-similarity, both at the macro and micro level. This is clearly not the case in images of natural phenomena. Similarly, the production of fractal flame images is substantially different to that used in other computer-generated art and imagery as it has its origins within fractal algorithms. This is clearly not the case in ordinary Computer-Generated Imagery (CGI).

2) Second, fractal flame images have a complexity, depth and self-similarity which cannot be easily replicated in nature or indeed in art. Thus, for example, the famous Julia set, very much like the Mandelbrot set, can only be produced using complex fractal algorithms that only a computer can process. This means that fractal flame images – unlike other fractals or iterative designs produced by hand, such as the Sierpinski Triangle, the Koch Snowflake, or even the drawings of M. C. Escher – cannot be produced in any other way except by the unique algorithms used to generate them. Fractal flame images, in short, are of a truly unique fractal genre.

3) Third, as a consequence of the above, when fractal flame images are subject to the process of sonification, they produce sonic events that are not reproducible from non-

fractal flame images. In other words, the complexity and high degree of self-similarity of fractal flame images means that when they are subjected to sonification they offer a range of unique grains of sound that cannot be easily replicated from non-fractal flame images.

4) Fourth, the fractal quality of the sounds produced by fractal flame images differs from those produced by other fractal algorithms, for example, those employed in the fractal compositions of Vaggione. The fractal algorithms employed in Vaggione's compositions are less complex than those used to generate fractal flame images and as a result of this, the quality of the fractal sounds that fractal flame images produce are far more intricate and detailed.

However, another important point presents itself at this stage. If we take Mandelbrot's claim that fractals and self-similarity permeate the natural order thoroughy, then could it not be argued that almost all images and natural phenomena possess, at some level at least, an underlying fractal identity? As Mandelbrot observes, the classic example of natural fractal phenomena include trees, ferns and lightening. These, as close observation reveals, all contain a high degree of self-similarity, both at the micro and macro level. This raises an important point: if all images, natural and artificial, can claim some fractal identity, even if only slight, what (beyond the points made above) separates the sounds produced through the sonification of fractal flame images from the 'fractal' sounds produced from other images of natural fractals, say trees or ferns? The answer to this question is as follows:

- Natural and artificial images tend to be of varying fractal quality. Thus, for example, if a picture of a tree were to be subjected to sonification, then parts of the picture (i.e., the tree itself) would produce a sound that could be legitimately classified fractal, at least in part, whereas other parts of the image would not (i.e., the sky in the background). Images of natural phenomena would thus not (except without significant digital manipulation to remove non-fractal parts of the image) produce sounds that are 100% fractal. They would mix fractal and non-fractal elements together.

- By contrast, fractal flame images have no such limitations. For each part of the image, constituted as it is from the same fractal flame algorithm, it not only is 100% fractal, but it possesses a high degree of self-similarity that is distributed evenly throughout the image, both at the micro and macro level. This means that the sonic output of the image possesses a highly stable and coherent fractal identity, one which can be subjected to iterative processes without losing its original fractal quality if only part of the image is focused upon, and risk incorporating non fractal data – or less coherent fractal data – and thereby diluting the fractal identity of the sound itself and the macro sound which it can be used to produce.

# Chapter 3
# Commentary

## 3.1) Introduction.

Now that I have outlined the basic compositional method which I utilized in the production of the pieces contained in this portfolio our attention turns to offering a commentary on my individual pieces themselves. I have produced ten compositions based on my experimentation over the last four years. Each of these compositions are distinct pieces of music in their own right. Moreover each piece seeks to illustrate my compositional process using fractal flames by expressing something unique about how the latter can be used to generate new acoustic phenomena. Before we proceed to discuss my compositions, a number of important points must be made. The first concerns how my compositional method evolved during my PhD research; the second, how this evolutionary process relates to the fractal processes used by other fractal composers.

## 3.2) The Evolution of My Compositional Method.

Each of my compositions will be discussed according to the chronological order in which they were produced. The reason for this, as I alluded to in the previous chapter, is that my compositional methodology developed and expanded during my research and, as a result, so did the nature of fractal generated music which I produced. This evolution is reflected in the compositions contained within this portfolio. It offers a selection of both my early and my mature PhD works. Not all of the compositions which I produced during my PhD studies are

contained in this portfolio, however a full list of these compositions I produced is to be found in the appendix.

### 3.2.1) 'Purism' and 'Interventionism'

As I alluded to in the first chapter, during the course of my compositional experiments I transitioned from what may be termed a 'purist' or 'non-interventionist' approach towards fractal flame music. This is when I simply translated the fractal flame images which I had generated into sound without employing any sound manipulation techniques (i.e., gating, wave set substitution), to an 'interventionist' approach. As the overview of my compositional method in chapter two showed this 'interventionist' approach involved both subjecting the sonic output of the fractal flame images to various sound manipulation techniques, and changing the sound output of the fractal flame images by manipulating the images themselves in terms of their colour, luminosity, etc.

### 3.2.2) The Nature of My Early 'Purism'

It is important to clarify what exactly is meant by the term 'purist'. Whilst my early compositions were 'purist' in the sense that they arose from the direct sonification of a fractal flame image and employed no post-sonification editing using sound manipulation techniques, they nonetheless involved some creative input on my part. Thus, as we will see in my discussion of *Symphony of Noise*, I selected the fractal flame images from which they are derived, and in some cases, I introduced variables into the algorithms generating these images to alter their sonic output. Similarly, once these images had been subject to sonification I extended the length of the audio file. This was necessary because the sound sample produced by the sonification of the image often lasted only a few seconds, or in some cases less than a second.

The result was that the many thousands of grains of sound which were contained within it were played at an extremely rapid pace and were thus indistinguishable to the human ear. To this extent, they were not suitable for my purposes.

The consequence of lengthening the audio file was that it resulted in lowering the frequencies of the grains of sound it contained. This stretching of the audio file to bring into relief the various grains of sound which it contains was the only alteration to the audio sample which I employed in my early 'purist' compositions post-sonification.

Thus, to be clear, when describing my early compositions as 'purist', I mean that these early compositions, unlike my later interventionist compositions, involved no manipulation of the sonic output of fractal flame images using either sound manipulation techniques, such as wave-set substitution, gating, or granular synthesis or, the manipulation of the sonic output by changing and altering the colour and luminosity of the fractal flame image itself. I shall offer an evaluation of the degree to which my early compositions can be described as 'purist' in the conclusion of this portfolio.

### 3.2.3) The Purpose of My Early 'Purist' Approach.

The reason I adopted this purist approach in my early compositional experiments is that I wished to test the limitations, qualities and variations of the sonic events produced by the direct and unadulterated sonification of fractal flame images. I felt that this was a necessary step during my first stage of research as it would help me to grasp the compositional potential of fractal algorithms on their own, i.e., without aesthetic editing.

The direct sonification of fractal flame images produced some interesting results which shaped my later compositional method. For example, I found that each image generated a

unique set of sounds, and that even the slightest variation to the image or the algorithm from which it was generated could result in a very different audio output. This can be clearly seen in my piece *Symphony of Noise.* The four movements it contains all arise from the same algorithm repeated but seeded with different variables. Moreover, these early “experiments” did much to highlight the close relationship between the luminosity and colour of a fractal flame image and the quality of the sonic output it generated. As chapter two explained, this link between the luminosity, colour and the sonic output was to prove critical in my later “interventionist” compositions.

### 3.2.4) The Limitations of My Early Purist Approach.

Despite these important results, my early 'purist' experiments also revealed that there are limitations to trying to generate sonic events by simply subjecting fractal flame images to sonification. The direct transference of these images into sound could result in unpleasant sounds or sounds that lacked a wide diversity of pitches or sense of rhythm. In some cases, the results produced were simply indistinguishable noise. Whilst in other cases, the sounds produced were too piercing or too low to actually hear. An example of one of my early compositions which I deemed unpalatable is that of *Sephiroth*. This piece contained various examples of sounds that are far too piercing and unpleasant to the ear. As a result, I decided to not include it in my portfolio. For the benefit of the reader, however, I have attached a short sound sample from *Sephiroth* which illustrates the piercing sounds it contains. This will serve to illustrate some of the failings associated with my early purist approach.

### 3.2.5) My Shift Towards an 'Interventionist' Approach.

The desire to avoid producing non-pleasing sounds was an important factor in why I chose to move away from a 'purist' approach towards a more 'interventionist' one. Given that the guiding aesthetic principle (see section 2.5 Aesthetic Manipulation) behind my compositional experiments was to reveal the acoustic potential of fractal flame images and algorithms I felt that the production of unpalatable sounds was something that I should seek to avoid. I also chose to move to an 'interventionist' approach in my later works as I wished to explore a number of important avenues of research. The most important included:

a) How fractal flame generated music could be successfully subjected to the sound manipulation techniques used by many contemporary electronic composers, e.g., gating, granular synthesis, wave-set substitution, gating.

b) How sound manipulation techniques could be used to enrich the complexity of the iterative patterns at work within the sounds produced by the fractal flame images. This was done through the successive overlaying of sound samples; a particularly clear example of this objective is to be found in *Atomic Reaction*.

c) If it was possible to produce a macro sound utilizing the creative input of existing sound manipulation techniques that remained faithful, at every step of its production, to the parameters, identity and sound pattern of original fractal flame micro sound from which it derived. As will be seen, this ambition formed the basis of several of my later compositions, in particular *Spots Evolve*, *Temple of Shiva* and *Atomic Reaction*.

d) How the creation of fractal music using fractal flame algorithms could be enhanced by human creative input and how, in turn, human creativity could find expression within fractal flame music. This, in turn, reflects my early comments made in chapter one about my belief in the importance of human creativity in the dialogue between science and music.

## 3.3) How this Evolution Relates to the Work of Other Fractal Composers.

To offer some perspective on the evolution at work within my compositions, it is worth situating it in relation to the work of some of the fractal composers whom we touched upon in chapter one. Particularly instructive is how my own compositional development relates to the methodologies employed by Horacio Vaggione and György Ligeti.

### 3.3.1) Convergent Evolution: Horacio Vaggione and my Fractal Flame Music.

As chapter one explained, in his first piece of fractal music, *Fractal A*, Vaggione adopted a decidedly 'purist' approach. He directly translated fractal mathematical data into sound without human intervention post sonification.[55] By contrast, in his slightly later *Fractal C* Vaggione abandoned this 'purist method in favour of an 'interventionist' one. Thus, in *Fractal C,* he actively manipulated the sound output of his fractal mathematical data and did so to suit his own aesthetic judgements. Vaggione accomplished this manipulation primarily through altering the fractal equations which he used and, more often, by editing the sonic output of these equations, synthesizing extracts of the sound outputs together to produce a final macro

[55] Cf. Curtis Roads, 'The Art of Articulation: The Electroacoustic Music of Horacio Vaggione', at p. 298.

sound. Commenting on Vaggione's later fractal work, Curtis Roads summarizes Vaggione's 'interventionist' approach as follows:

> The interaction between formal algorithmic control and direct intervention is a hallmark of Vaggione's compositional strategy. Specifically, he combines both algorithmic procedures and purely manual, interactive operations, the latter realized on the products of the first. [56]

Although I only became aware of Vaggione's work relatively late in my compositional experiments and can thus claim no direct indebtedness to the evolution at work within his thought, it is clear that his shift from a 'non-interventionist' approach to an 'interventionist' one prefigures something of my own compositional journey. To this extent, it is clear that my own movement from a 'purist' to an 'interventionist' approach, has some precedence within the field of fractal composition. Moreover, it offers an interesting example that composers working within a similar field can adopt similar methodologies not by deliberate design but rather by a process of convergent evolution and pure chance.

Crucially, however, my 'interventionist' compositional methodology differs significantly from Vaggione's. As we saw in the previous chapter, it involves the manipulation of fractal flame images in terms of their colour, depth and luminosity, whereas Vaggione's method does not. Instead, as I alluded to above, Vaggione, in *Fractal C,* merely synthesized extracts of the sonic output of different algorithms so as to produce a coherent piece of music. There was thus nothing of the complex interaction between sound and colour, as well as recursive

[56] *Ibid*., p. 297.

overlaying and stretching, which my compositions employ in Vaggione's 'interventionist' fractal pieces. To this extent, his 'interventionist' method was much simpler than my own.

### 3.3.2) Organic Development: György Ligeti and My Fractal Interventionist Method.

In many respects, my later 'interventionist' approach is more in tune with Ligeti's desire to allow fractals to shape his compositions according to their iterations and the self-similar patterns they produce. In his works, in particular *Désordre*, Ligeti seeks to allow the fractal sources he employs to 'evolve', as he puts it, in an 'organic' manner.[57] As I touched on in chapter one, Ligeti allows the small fractal iterations he includes in his pieces to grow unhindered, producing both greater degrees of self-similarity and, in some cases, dissidence, until the whole piece has been 'fractalized'. The result is that, as his pieces progress, the small fractal identities with which they were seeded come to determine the macro nature of the piece. As alluded to in chapter one, this is particularly clear in *Désordre*.

This idea of allowing small fractal sounds to multiply as a composition progresses until the final macro sound possesses a fractal identity is something which resembles the methodology employed in my later 'interventionist' compositions. As I alluded to in chapter two, in my 'interventionist' compositions, I allowed the original micro fractal flame sound samples I employed, to actively shape and determine the various layers of sound that were produced from them through iterative overlaying and stretching. The micro sound, in effect, functioned as the "seed" providing the fractal DNA from which the composition itself grew and

[57] Cf. Toros Can, 'The Importance of Ligeti's Piano Études in Compositional and Pianistic Aspects: What it is Necessary to Analyse Ligeti Etudes Prior to Learning', p. 204.

derived its macro sound fractal identity. Or stated another way: at each level of recursive overlaying, the micro sound naturally expanded, until it fully flowered in the final macro sound. I find the following quote from Ligeti to be a particularly helpful summary of the spirit which I sought to employ in my later compositions:

> I do not use direct mathematical translation into my music, like Xenakis. The influence is poetic: fractals are the most complex ornaments ever, in all the arts…they provide exactly what I want to discuss in my own music, a kind of organic development.

## 3.4) Commentary on My Pieces.

We now turn to considering each of the pieces of music contained in this portfolio. We begin by considering an example of a composition from my early 'purist' stage, namely, *Symphony of Noise*.

### 3.4.1) *Symphony of Noise*

I *Boiling Down* (05:27)

II *Hurricane* (03:36)

III *Armageddon* (10:00)

IV *Null* (04:01)

As an illustration of my early 'purist compositions, I have chosen to include one of my very earliest 'purist' pieces in this portfolio: *Symphony of Noise*. This is a four-movement work containing a variety of compositions all stemming from the same fractal flame algorithm, albeit modified in terms of its variables for each of the compositions. Like my other early works, the pieces incorporated within *Symphony of Noise* arose from the direct sonification of a fractal flame image without any aesthetic manipulation or iterative overlaying of the audio file post-sonification. To this extent, like my other early compositions, the pieces in *Symphony of Noise* can be said to be “pure-bred” fractal flame compositions. They are direct and as far as possible, unadulterated products of fractal flame images.

As alluded to earlier, I chose to adopt this 'purist' approach at the very beginning of my compositional experimentation because I wanted to test the richness and diversity of sonic events that can be generated by relying solely on the sonification of fractal flame images. On the whole, the results of my experimentations were satisfying. As can be heard in *Symphony of Noise,* a rich diversity of sounds was generated when a direct usage of fractal flame algorithms was employed. As also noted above, sometimes the direct sonification of fractal flame images produced unpalatable results, including white noise (cf. the audio file *Sephiroth* in appendix). I have called the four movements within the piece *Boiling Down*, *Hurricane*, *Armageddon* and *Null*. I chose these dramatic titles because the story which I have sought to tell in this symphony is one of impending disaster.

In part, the “apocalyptic” undertones of the four movements of *Symphony of Noise* have been motivated by my interest in environmental concerns, in particular the current global crisis concerning global warming. In selecting which of the ‘pure’ fractal flame compositions I produced during my early compositional experimentations (of which there were many) I deliberately looked for those pieces which sounded the most dramatic, chaotic and emotionally

unsettling. The four movements included in *Symphony of Noise* were the ones which I felt best fulfilled these requirements. To my mind, each movement betrays something of the chaotic and disruptive effects which man-made global warming has had, and indeed will have, on global weather patterns.

These movements consisted of some of the most satisfactory 'purist' pieces that I produced during my doctoral research. My goal with the movements in *Symphony of Noise* was to explore how much scope there was for generating sound events by solely relying on fractal flame algorithms. In restricting my experimentation to rendering sounds derived directly from fractal flame algorithms, my aim at this very early stage of my compositional experimentation was to articulate as much as possible, the data within a fractal flame algorithm at an auditory level. In generating the different movements, I used the same fractal flame algorithm each time. However, I varied the input data into the fractal flame algorithm so that the sound output would be different. Often the data directly fed into the algorithm only varied a small amount.

$(x, y)$= a random point in the bi-unit square
iterate {
    $i$ = a random integer from 0 to $n - 1$ inclusive
    $(x, y) = F_i(x, y)$
    plot$(x, y)$ except during the first 20 iterations
}

Figure 25

An extract of the open-source algorithm which I used in the production of *Symphony of Noise*.

Sometimes the variations I introduced were infinitesimally small. Indeed, they were so small in some cases that one could be forgiven for overlooking them. Yet, as the piece reveals, the result of these small variations was a notably different sound produced by the fractal flame algorithm, something akin to the famous 'butterfly effect'. This meant that it was possible to produce a wide, and seemingly endless, selection of sound events from a single fractal flame algorithm with relatively little effort on my part. Only the slightest variation of input data fed into the algorithm resulted in very different acoustic phenomena to the ones which the algorithm produced prior to its modification.

The original fractal flame algorithm responsible for generating each of the movements within *Symphony of Noise* was processed in SuperCollider. The algorithm was an open source one. I took aspects of the fractal flame algorithm, that is to say its output, and united these to certain sound elements, i.e., different levels of pitch, volume and panning. At this point, I tried to transfer the algorithm output to Sibelius. However, this programme proved insufficient for my purposes. This is because it could not interpret the data of the fractal flame algorithm to a high enough quality, thereby preventing a reasonable transference of the algorithm output into sound. As such, I decided to put the algorithm's data into picture form and transfer it into a spectral analysis program.

In this case, I used PhotoSounder. This programme then reinterpreted the fractal flame image into sound, thereby rendering it from a visual phenomenon into an auditory one. However, the sound produced by PhotoSounder was extremely short, lasting only about thirty seconds. Obviously, this was insufficient for my purposes. As such, I transferred the sound sample into MetaSynth where the sample is used to "play the image". Once in MetaSynth, I began to manipulate the sample by extending it, i.e., by stretching it over longer and longer periods of time. The result was that the piece not only increased in time length, and thereby

wavelength, but its various pitches were also lowered. I continued to experiment with the samples until an aesthetically pleasing sound was produced; one which I felt matched the story I wished to tell in *Symphony of Noise*.

Given that each of the movements within *Symphony of Noise* arose from the same fractal flame algorithm, albeit modified in the case of each movement, the four movements within this piece are closely related to one another and share a common ancestry. So as to reflect the environmental concerns of the symphony as a whole, one could be forgiven for saying that each piece represents an 'evolutionary' development of the movement which immediately preceded it. As the movements reveal, however, this evolution is not always a gradual and slow one. Indeed, in some cases the evolution of the sounds in the different movements is quite stark, thereby serving to underscore how by modifying just a small element of a fractal flame algorithm I could generate notably differing sound events.

In this respect, I feel that the movements reflect a specific strand of Darwinian evolutionary theory; namely, the theory of 'punctuated equilibrium' articulated by Stephen Jay Gould.[58] According to Gould, at certain points in natural history, often at times of great environmental stress, evolution has occurred rapidly and drastically, at least when compared to the slow process by which it normally unfolds. In Gould's thinking these 'leaps' in the evolutionary process and the great environmental stresses which give rise to them, often occur when the climate is altered by only a small amount. Thus, in the same way that small variations in climate can have a drastic effect on evolution, I have sought to show how slight variations in the complex algorithms generating fractal flame sounds can result in radically different sonic phenomena. To this extent, the evolution at work within the movements of *Symphony of Noise,*

[58] Cf. Stephen Jay Gould, *Punctuated Equilibrium* (Cambridge MA, Harvard University Press, 2007).

and indeed all fractal flame music, is one of “punctuated equilibrium’”, i.e., it is short, sharp and fast.

Albeit a somewhat unusual title, I have entitled the piece *Symphony of Noise* because it incorporates all the basic properties of noise as understood within modern electronic composition (i.e., white, pink, brownian). These different forms of noise can be heard throughout the piece with varying degrees of clarity, dominance and timing.

Those who have heard the piece have found the title *Symphony of Noise* to be a particularly apt one. Not only does it embody a complex range of noises, but it also utilizes them in such a way that these noises retain an inherent aesthetic quality which makes them palatable to the ear, both that of the trained electronic musician as well as the non-expert. Commenting on the piece, several listeners observed that as the movements unfolded, the tension and drama of the piece increased. This building up of tension, it was noted, reflected the story of impending chaos which the piece seeks to tell with regards to the various ecological and climate related crises occurring in the world.

Now that I have given an example of how I produced my early ‘purist’ music let us turn to consider my interventionist pieces and how a process of development can be traced throughout them.

### 3.4.2) *Hiccup Hocket* and *Classical.*

During the very earliest stages of my interventionist compositional phase, I experimented with the production of pieces of classical music that either derived from fractal flame algorithms; or incorporated the recursive patterns of fractal flame algorithms in their production. To this end,

I produced two pieces which we will now consider: *Hiccup Hocket* and *Classical*. Although this experimentation with classical music was only a short-lived one, the results were both positive and served to highlight the compositional potential of fractal flame images and algorithms for classical as opposed to electronic music.

### 3.4.2.1) Hiccup *Hocket* (05:23).

A piece with a rich and complex series of iterative patterns, as well as a significant diversity of pitches, *Hiccup Hocket* is a chamber ensemble piece consisting of four instrumental voices: flute, clarinet in B flat, violin and violoncello. Produced during the summer of 2013, *Hiccup Hocket* is a piece that is heavily indebted to my earlier studies in classical music in Seattle and is the sole instrumental work in this portfolio.

Perhaps the most acoustically varied and rhythmically dynamic of my compositions, I wrote this piece as a means of exploring how my experimentation with fractal flames could be brought into dialogue with the ancient practice of 'hocketing' in musical compositions, i.e., the technique of alternating the various notes, pitches and chords produced by various instruments or voices within a melody. This is done within two-to-four individual "voices" following their own unique musical notation so that as one voice sounds, the others rest. The result is a musical 'hocket'. The pattern of a hocket thus resembles something like interlocking sequence of letters. Each letter can only be represented in the space left open by another:

A – A – A – A – A – A

– B – B – B – B – B –

Figure 26

The following extract of sheet music from *Hiccup Hocket* illustrates the principle of hocketing particularly well.

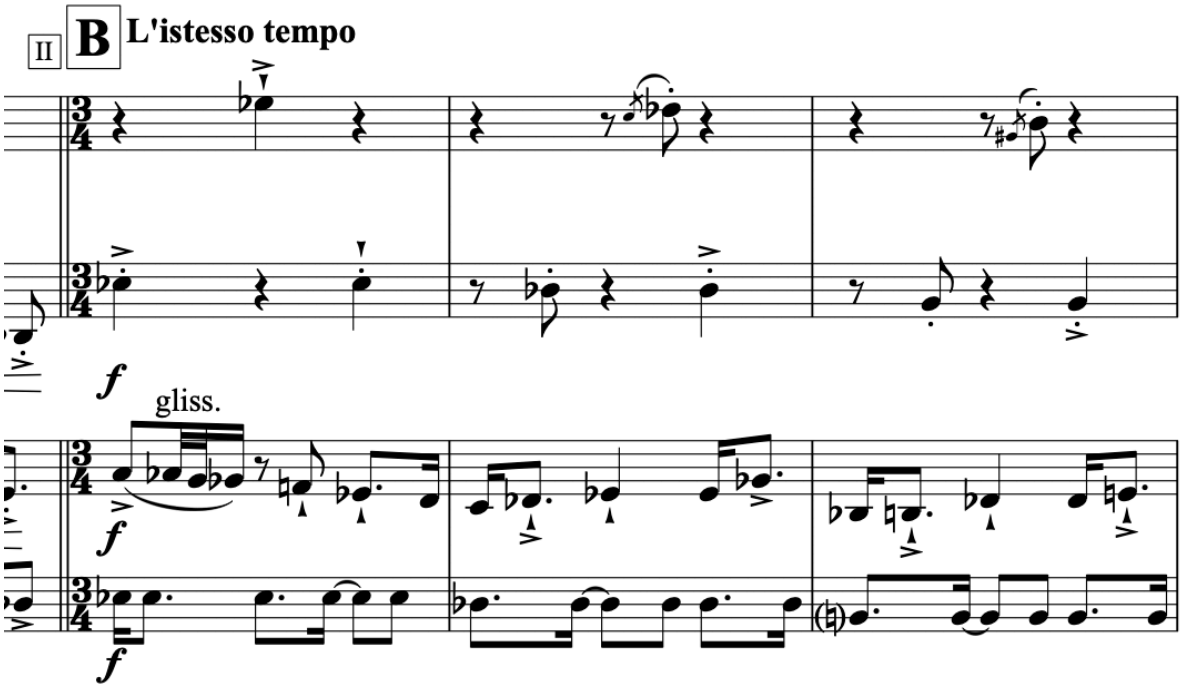



Figure 27

As *Hiccup Hocket* reveals, the practice of hocketing and its allowance for interlocking musical patterns to revolve around one another without clashing, provides a particularly rich arena in which separate musical voices, following their own fractal generated iterative patterns, can be said to enter a more classical arena of music composition.

Although many of the techniques involved in the composition of *Hiccup Hocket* differ from my other compositions, *Hiccup Hocket* nonetheless derives from a fractal flame algorithm. However, given that the processes involved in the algorithmic generation of the fractal data output utilized in *Hiccup Hocket* are similar to those described elsewhere in this portfolio, they need not be discussed in any detail here. However, a couple of points ought to be noted.

- First, *Hiccup Hocket* has its origins within a linear version of an open source fractal flame algorithm, one in which time was not included, that is to say, time is not a variable in the algorithm.

- Second, like some of my other compositions, such as *Atomic Reaction*, the output of the algorithm employed was recursively overlaid by a process of stretching and contraction, and this followed a multi-layered process similar, albeit less complex, to the one employed in *Atomic Reaction*.

- Third, I identified each of the voices (that is to say, the four instruments mentioned above) with a specific colour of the fractal flame image used and manipulated them in the way I described in chapter two.

*Hiccup Hocket* took about one month to compose. It was written whilst I was researching how various combinations of traditional ensemble instruments, particularly those used within quartets, could be used as a potential arena for my fractal flame compositional process. Although it differs from my other pieces in that it does not employ sound modification systems, such as wave-set substitution and granular synthesis, it is nonetheless a piece with which I am especially satisfied, particularly in terms of what it shows about how electronically generated fractal sound patterns can be brought into fruitful dialogue with more classical models of musical composition, in this case a chamber ensemble.

The four instruments within the piece were chosen because they provided the most interesting, and acoustically diverse, combination of voices and the most aesthetically pleasing results.

I had this piece performed by the Ensemble Seven Bridges in Durham. Those playing the instruments commented that they found the piece very interesting and rewarding. As one of the instrumentalists noted, the complexity of interlocking rhythms achieved by the hocketing effect allowed the quartet of instruments to "dance around one another" in such a way that the expert timing of the instrumentalists and the particular sound duration of the notes played by each instrument were pushed to the extreme.

The general reaction from the instrumentalists was one of appreciation and interest in its underlying compositional process. One of them commented on how the seemingly "chaotic" pattern of the piece gave it a certain instability, yet crucially, for all this "instability" and "unpredictability" it "held together" in a successful and rhythmically engaging way. I found this comment to be a satisfying one as it highlighted how the final product resembled something of the chaotic pattern of the fractal process from which the piece has its origins.

The score of *Hiccup Hocket* is attached to this portfolio as an appendix.

### 3.4.2.2) *Classical*: Electronic Stereo (07:17).

Perhaps the piece which has produced the most aesthetically satisfying results, acceptable both to those favouring more classical styles of music as well as those working in the field of computer-generated sonic art, the next composition within my portfolio, *Classical,* is a fractal manipulated piece of music derived from the works of Bach, Beethoven and Chopin. As with *Hiccup Hocket*, my motivation in producing this piece was to explore how the decidedly modern

phenomenon of fractal music (specifically, the iterative algorithms of fractals) can be brought into dialogue with traditional classic music to show how these two seemingly diverse spheres of music, with notably different compositional methods, and in some respects notably different cultural and intellectual milieus, can result in an aesthetically beautiful piece of music. That is, one that is pleasing to the ear and possessed of a discernible rhythm.

*Classical* was produced following *Hiccup Hocket* and seeks to build upon some of the key themes and ideas which inspired the latter. One of my primary motivations for producing *Classical* is that I wanted to "invert" the fractal composition process which I employed in *Hiccup Hocket. I*n *Classical* I sought to construct a classical piece of music with a fractal basis,i.e., which had its origins within a fractal algorithm. In *Classical*, by contrast, I started with existing pieces of classical music, and proceeded to turn them in fractal pieces of work. To put it in a simplistic term, where in *Hiccup Hocket* fractals inspired and produced the music, in *Classical,* it was the music that produced the fractals.

*Classical* is a medium length piece which has a unique energy and distinct playfulness of its own. As several of its listeners have noted, *Classical* does sound notably different to the classical compositions from which it derives. Yet, at the same time, it remains faithful to the spirit and character which animated these classical pieces. One of the people with whom I shared this piece, noted: "It's Bach and yet not Bach, Beethoven and yet not Beethoven".

For some time prior to my doctoral studies, I was particularly interested in the self-similar melodies employed within classical composition, in particular the recursive use of melodic patterns by Bach in many of his fugues, especially his Toccata and Fugue in D Minor. The following image reveals the use of recursive melodies by Bach.

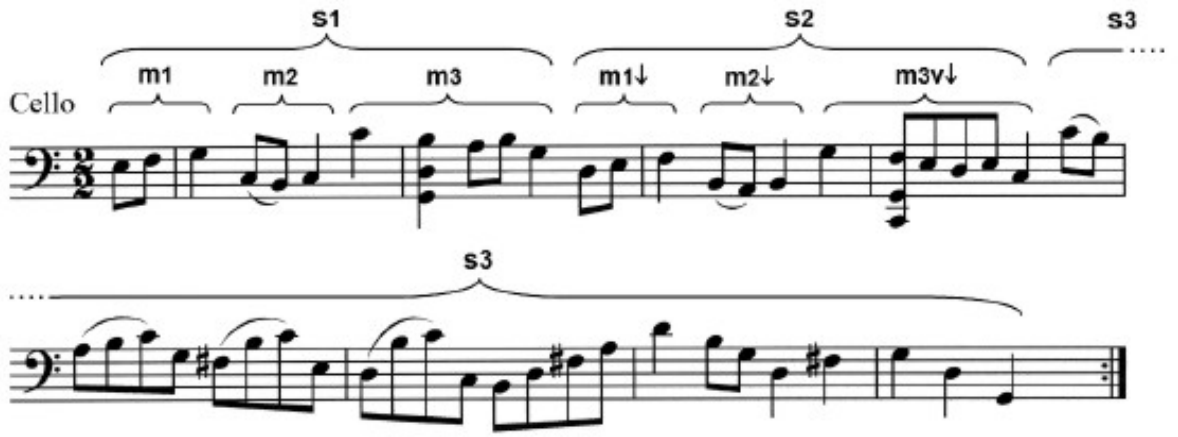



Figure 28

An example of Bach's use of recursive melodies in his cello suites.

What first stimulated my interest in the algorithmic potential of Bach's music for computer generated music, is that many have seen in Bach's compositions distinctly mathematical undertones. Moreover, given that several composers working in the field of fractal music (primarily Kenneth and Andreas Hsu) have argued that the music of Bach can be said to have a decidedly fractal nature, I was especially keen to include within my portfolio a piece of music which sought to marry Bach's work, and that of other classical composers known for their use of self-similar melodies, with the science of fractals.

On a more personal note, my love for the music of Bach and Beethoven, especially the self-similar patterns of some of their greatest works, meant that I wished to generate a piece of fractal flame music which both drew upon the work of these composers and allowed them to find expression within a compositional medium that has not been fully explored. As *Classical* demonstrates, the result is a particularly dynamic and harmonically stimulating piece of music.

An important part of my objective when composing *Classical* was to allow the work of Bach, Beethoven and Chopin to be actively expressed within a fractal generated sonic event. The purpose of doing this was to move beyond the realm of the mere speculative theory, as

was pioneered by researchers such as Kenneth and Andreas Hsu in the field of “real composition”. In *Classical* I have sought to show something of how the great music of the last four centuries not only has an underlying fractal basis, but also how it can be rendered into a new and aesthetically pleasing form by subjecting it to fractal iteration.

In selecting the short samples of classical pieces with which I experimented, I deliberately chose those pieces of music by Bach, Beethoven and Chopin, which are readily familiar not only to music experts, but also to the general public. My intention was to try to unsettle the way the listener approaches these very familiar pieces of music by revealing how, at an unrealized level, they contain within themselves a hidden, equally beautiful music, which can only be unleashed by means of fractals. In short, in *Classical* I have tried to show how fractals have the capacity to not only enhance our understanding of the beauty of the music of Bach, Beethoven and Chopin, but also reveal the ‘secret’ music which lies beneath the surface of familiar classical music. In this sense, I have sought to unsettle the familiar by making it decidedly unfamiliar.

Following my experimentation with producing pieces of classical music that possessed a fractal flame basis, I returned to the production of electro-acoustic pieces. The following pieces which I will now proceed to discuss are those which illustrate most clearly the wide variety of 'interventionist' techniques which I employed in my later compositional experiments. As we will see, these “interventions” consisted of a complex variety of sound manipulation techniques coupled with human creativity, both at a visual and auditory level.

### 3.4.3) *Julia N*: Electronic Surround 5.1 (07:38).

I wish to begin this part of the commentary by discussing my piece *Julia N*. This piece, perhaps more so than any other included in my portfolio, represents the clearest expression of my efforts to show how fractal flame programs can translate fractals, in this case the famous Julia set, into sound. It is a particularly useful example for us to consider at this point as it helps to remind us of the broader methodological hypothesis of this portfolio.

As one of the first electro-acoustic 'interventionist' pieces which I produced, the various processes by which *Julia N* was composed closely matches those described in chapter two. Following the production of the fractal flame images used in *Julia N*, I subjected these to the various stages of iterative stretching and overlaying, using colour to separate the various voices within the images (see figures 30-32 below). As in several of my later compositions, I manipulated the sound output of the images by altering the luminosity of the colours and by a process of iterative overlaying of the images themselves. Wave-set substitution proved an integral part of the manipulation of the sound output of this process.

The piece is entitled *Julia-N* because of the fractal flame algorithms which I used to generate it. These allowed for the easy replication of the famous Julia set, and its underlying complex iterative identities, at a digital level. The open source algorithms which I used in the production of *Julia N* represent a most authentic expression of a Julia set within a fractal flame program. During my research I found that many such algorithms exist. However, for purposes of efficiency I chose the ones that were the most succinct and easy to work with. Next to the famous Mandelbrot set, the Julia set represents one of the most important and well-known expressions of fractal geometry and imagery. For this reason, I decided to use the Julia set fractal flame algorithms for at least one of my compositions.

Before analysing *Julia-N* it is important to state why I chose to use a fractal flame expression of the Julia set rather than the more well-known Mandelbrot set. Put simply, no successful fractal flame algorithm for the Mandelbrot set has ever been developed. The complexity of the iterative processes involved in the production of the Mandelbrot set is so great that it cannot be translated into a fractal flame image. As a result of this, it has proved impossible to produce a fractal flame piece of music directly generated from the famous Mandelbrot set. This has been the most disappointing aspect of my compositional experiments. Given my fascination with Mandelbrot's work, I would have very much liked to produce a composition generated from his most famous discovery.

Part of the reason why I chose to include *Julia N* in my portfolio is that it differs from the other 'interventionist' pieces in one important respect. As we will come to see, whilst my other 'interventionist' compositions, such as *Atomic Reaction* and *Temple of Shiva*, employ similar sound manipulation techniques to those used *Julia N*, they nonetheless differ from it in one important respect. They derive from the use of a single fractal frame algorithm. *Julia N*, by contrast, uses a plethora of fractal flame algorithms and images, which, are revealed by the images below. I combined them with a colour coordinated sound system adopted for sixteen separate voices. I also deliberately chose to employ a multitude of fractal flame algorithms and images in the production of *Julia-N,* as I wanted to explore the opportunities that this method provided for the production of a final a complex fractal macro sound.

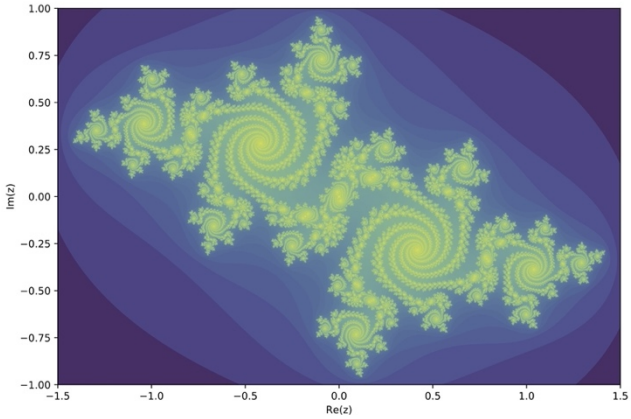



Figure 29

This is one of the first Julia set fractal flame images which I generated. I extracted elements of this image and combined it with extracts of other Julia set fractal images so as to produce the collage of Julia set fractal flame images used in the composition of *Julia N*.

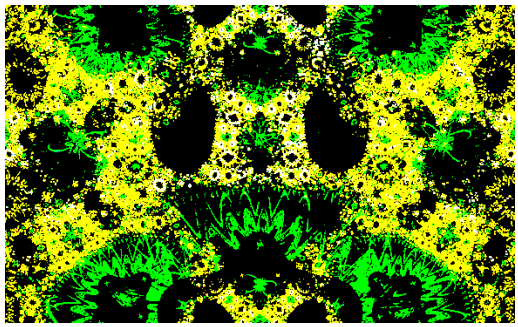


Figure 30

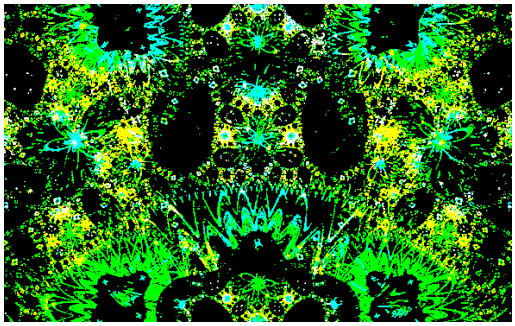


Figure 31

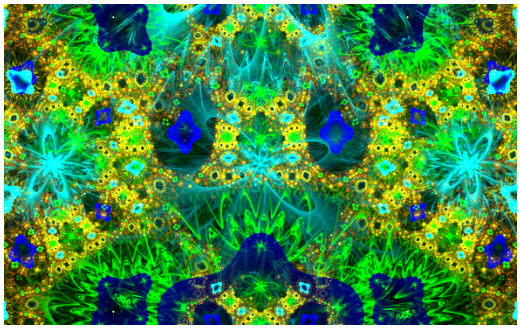


Figure 32

Figures 30-32 illustrate how I produced a colour coordinated system corresponding to sixteeen vocies in *Julia N*. They also show how I manipulated the colours employed in the fractal flame image used and how the fractal flame image itself became more complex as it underwent iterative overlaying.

One of my more acoustically complex pieces, and perhaps the one with the most variety of new sound events, *Julia-N* has received a positive reception. One hearer of the piece noted how, despite its overtly electronic nature, there was nonetheless a striking resemblance to natural auditory phenomena, including, amongst other things, whale song.

The original length of the piece meant that, in order for it to be included in this portfolio, I had to select only a short extract from it. For aesthetic reasons, the first five minutes of the piece were chosen. This contains the most dynamic and readily auditable sounds of the piece

as a whole. Due to the iterative process of the fractal flame algorithm used in the production of *Julia N*, the longer the algorithm was allowed to run, the more complex and more "crowded" the soundscape it generated became.

Thus, like the Julia set from which the fractal flame algorithm used in the production of *Julia-N* takes its name, it starts off relatively simple, but its constant iteration gradually renders it more and more complex. The result was that by the middle of the piece, the distinct sounds originally perceptible at the beginning of *Julia-N* began to converge and melt into one relatively unified sound phenomenon. Despite its beauty, this unified sound event proved too complex for detailed analysis in a short commentary such as this.

It strikes me as significant that as the number of iterations increased within the fractal flame algorithm, and the complexity of the sound produced also increased, there was a convergence at the macro level which produced a steady and relatively stable acoustic event. From my perspective, the parallels with chaos theory are particularly striking here.

The central tenet of chaos theory is that no matter how complex a system may be (whether it be biological, digital, or human) and no matter how many unpredictable variables it may contain, it will eventually converge around a point of stability.[59] This point of stability will bestow some kind of order upon the system. At the same time, the system will remain fragile enough that even the slightest change will alter its nature completely. Yet ultimately it will not prevent it from returning to some form of stability again. Something along these lines appears to have been at work in *Julia-N*. From a process of ever-increasing complexity and self-recursion,

---

[59] A substantial yet accessible account of Chaos Theory is to be found in James Gleick's *Chaos: Making a New Science*, (New York: Viking Books, 1987).

there arose, not chaos and disjointed noise, but rather a distinctly ethereal piece, one radically oriented towards a convergence in peace and not chaos.

Whilst the use of a plurality of fractal flame algorithms and images in the production of *Julia N* resulted in the production of an acoustically varied, though aesthetically pleasing, piece of fractal flame music, the use of several algorithms and images meant that the production of *Julia N* was both complex and time-consuming. As such, following the completion of *Julia N,* I decided to restrict myself to using a single fractal flame algorithm in the production of my subsequent pieces. The first of these single source algorithm pieces I wish to consider is *Tantrum*.

### 3.4.4) *Tantrum* (04: 48).

A fun piece to produce, and one which did much to highlight the interplay between sound and visual data within music generated using fractal flame algorithms, *Tantrum* arose from a fractal flame image which I generated using an open source algorithm. Perhaps the best way to describe the image from which *Tantrum* arose is that it resembled a three-dimensional portrait of multiple 'bubbles', varying in shade, depth and diameter (see figure 33 below). A grayscale image, with no colour, the effect produced in the fractal flame image looked something similar to thousands of little bubbles in carbonated water. The image struck me as having particular depth and intensity, resembling something akin to modern art.

One of my favourite images from the large selection of fractal flame images that I generated during my compositional experiments, was the bubble image. I selected it as the basis for a compositional project because I thought its striking complexity, yet notably simple basis, (i.e., the fact that it consists of the same shape repeated over and over again at different sizes and shading intensity), would produce a unique sound event from which I could generate

an interesting composition. Moreover, the sound sample generated by the bubble fractal flame image, struck me as having more room for greater sound manipulation by means of wave-set substitution and repeated overlaying of the image.

Figure 33

Grayscale image of bubbles used in the composition of *Tantrum*.

The piece was generated using the following process. Once I had produced the fractal flame image, it was transferred to a sound spectrum program, thereby turning it into an audio file. Once within the selected sound spectrum programme, which in this case was MetaSynth, the piece was layered over parts of itself. That is, according to a harmonic spectrum, I layered the image as a whole over certain 'bubbles' which it contained. It should also be noted that the image was manipulated using Photoshop prior to its transference and subsequent manipulation within Metasynth.

Using MetaSynth, I selected certain bubbles upon which I layered a duplicate image of the picture as a whole. By layering the bubbles over themselves and shrinking them I transposed the harmonics. This would make the selected bubble sound like a chord. When layered over itself, the image would be about fifty-percent darker. On average I layered the bubbles over themselves until they became so dark that when translated into sound their pitch began to fall. Thus, the visibility of the bubbles in the fractal flame image reflected their audibility. The darker a bubble was made, the less perceptible to our hearing it became. Similarly, the lighter a bubble became by my manipulation, the louder and more dominant its sound became. On the whole however, I did not make the bubbles lighter; as if taken too far, this made the sounds corresponding to the bubbles unacceptably loud and unpalatable. Moreover, had many of the bubbles been rendered lighter there would have been too many sounds at work within the piece, thereby spoiling its harmony.

The composition is entitled *Tantrum* because of the almost destructive quality of the sound event itself. In this piece I have sought to create something akin to the release of pent-up frustration. Several people commented that the piece varied greatly in mood and sound, with a number noting it had an elusive, almost fractured quality to it. This struck me as particularly satisfying given that the piece, like all of my compositions, has a fractal origin.

Moreover, this interpretation fitted well with my intention to give the composition a bursting effect and to reflect its origins within the bubble fractal flame image from which it arose. In the future I may expand *Tantrum* by adding more variability to the texture of the sounds. I may also implement within it some of the ideas I used in several of the compositions which I produced after it, most notably *Atomic Reaction*.

Upon my completion of *Tantrum*, I decided to produce a fractal flame composition that I modified from standard fractal flame open source algorithms. Previously, I used generic algorithms in the production of *Tantrum, Julia N* and my earlier 'purist' compositions. I attempted several such projects, all of which I have listed in the appendix attached to this portfolio. However, the piece that I found the most satisfactory, and the most interesting to produce, both in terms of designing its algorithm and in producing final sonic event, is the one which I wish to consider next: *Recursive Writing*.

### 3.4.5) *Recursive Writing* (08:16).

*Recursive Writing* is a fractal flame algorithm put into sound and manipulated using Trevor Wishart's principle of wave-set substitution. Perhaps one of the most acoustically interesting of my pieces, *Recursive Writing* arose from my experimentation with stretching sound waves and lowering pitches. Like several of my other pieces, it made particular use of my prior experience in computer programming, especially elementary coding. This piece, especially at its inception at an algorithmic level, involved significant background preparation and planning. As noted above, the code which produced the the original fractal flame sound samples for *Recursive Writing* had to be refined a number of times to produce the desired pitch and MIDI attributes within the resulting fractal flame sound.

I especially enjoyed producing *Recursive Writing* because it allowed me to work in close relation with a number of colleagues working in the field of computer programming, This opportunity allowed me to critically engage with, and learn from the knowledge of other programmers, especially my supervisor and fellow Ph.D. Students. It also allowed me to build upon my existing knowledge of coding practice, and how I can utilize these particular skills in my future compositional projects using fractal flame algorithms. The following is a sample from the coding I produced for *Recursive Writing*:

```
{(xv = (a[0] * x) + (a[1] * y) + (a[2]);
                yv = (a[3] * x) + (a[4]
* y) + (a[5]);
                vRadius = sqrt((xv * xv)
+ (yv * yv));
                x = xv / (vRadius *
vRadius;);
                y = yv / (vRadius *
vRadius))},
           {(xv = (a[6] * x) + (a[7] *
y) + (a[8]);
                yv = (a[9] * x) + (a[10]
* y) + (a[11]);
                vRadius = sqrt((xv * xv)
+ (yv * yv));
                x = xv / (vRadius *
vRadius);
                y = yv / (vRadius *
vRadius))}].choose.value;
```

Figure 34

The underlying code for the production of the piece was multi-layered and complex due to its recursive and iterative processes. It required considerable involvement and time investment, especially in transferring the sound output from one programme to another and the subsequent iterations. Broadly speaking, the following stages were involved in the production of *Recursive Writing*.

First, a fractal flame image was produced, and its output data was imported into Sibelius. Once within Sibelius, the second stage of production involved the transformation of the fractal flame data into an audio file. Third, the file was transferred to an audio spectral synthesizer, in this case MetaSynth. Here the file was then exported into a new audio file in which it could be manipulated using wave-set substitution. At this point, I stretched the sound waves, thus lowering them by an octave. This resulted in the piece being much longer than I desired, roughly thirty minutes in length.

As a result, I selected those extracts from this extended piece which sounded the most aesthetically pleasing, and which were also most appropriate for the limited time frame allowed within a doctoral commentary. The sections which I extracted were then input into a Digital Audio Workshop (DAW). Subsequently, I enhanced the sound data using acoustic reverb and other environmental enhancements to create more natural sounds. The piece was then smoothed and rendered into its final form by adjusting its minor elements. Again, parts of it were selected for removal to reduce the piece to the desired time frame.

The story I have sought to tell in this piece is one of metamorphosis. That is to say, how, through repeated transitions and successive iterations, the original sounds generated by my fractal flame code could be manipulated by stretching and pitch alteration. The purpose of doing so was to transform the original sound, which was relatively uninspiring, into a richer and more diverse one. This “evolution” can be heard as the piece progresses. It starts out with very

little pitch manipulation, and thereby has a somewhat monotone, localized sound range. However, by the end of the piece, the pitch is far richer as a result of my manipulation of the original sound through wave-set substitution and my recursive stretching of the sound wave itself.

Throughout the piece, I have sought to show how my use of wave-set substitution, especially by lowering the octaves through repeated sound wave stretching, allowed me to push the boundaries of the original sound itself. By doing so I transformed it into something different, but crucially at the same time it remained faithful to its original identity.

Throughout the piece, I try to show how the original sounds became 'fractured' through my repeated manipulation, yet still remain "unbroken", i.e., it maintained a thread of cohesive unity with the original sound sample. When composing this piece, my interests in the concept of metamorphosis, were, in part at least, inspired by my appreciation of the work of M. C. Escher and its treatment in Douglas Hofstadter's *Gödel, Escher, Bach: An Eternal Golden Braid*.[60] I was particularly struck by how every-day objects undergo a process of transformation in Escher's paintings, yet their underlying nature remains the same, or at least coherent.

[60] Douglas Hofstadter, *Gödel, Escher, Bach: An Eternal Golden Braid* (New York: Basic Books, 1979).

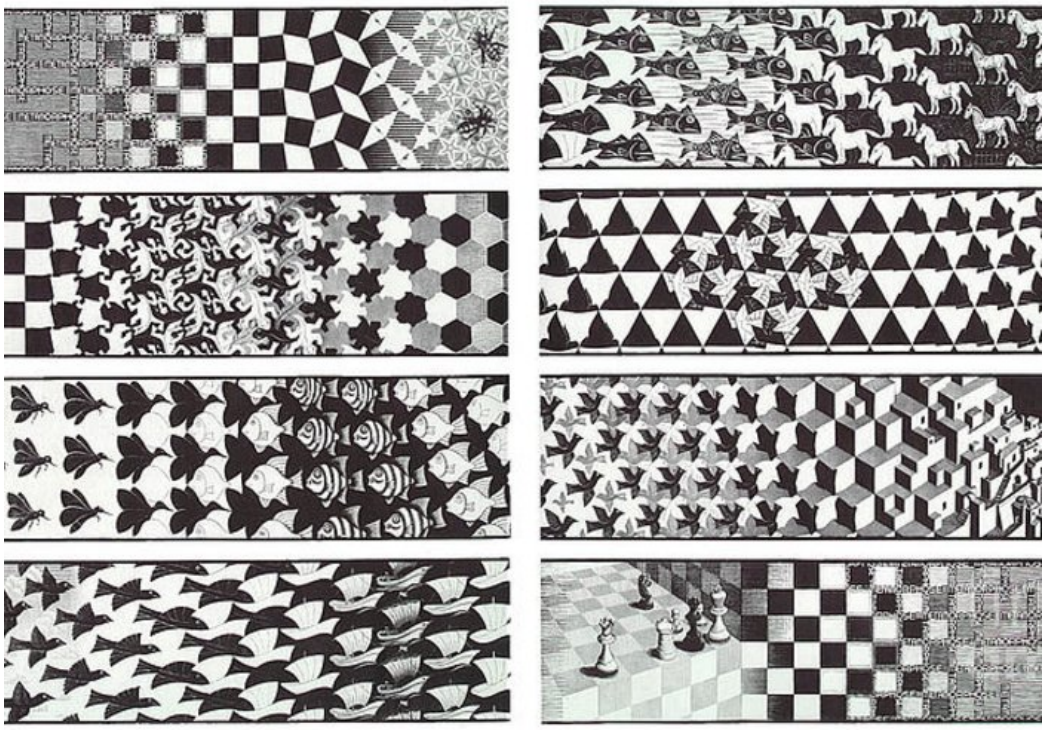


Figure 35

Images of representing the process of transformation and metamorphosis in M. C. Escher's paintings.

My use of sound wave stretching by repeated manipulation through wave-set substitution has produced a sound which is not only haunting, and in some respects slightly unsettling, but also alien. As one listener stated: *Recursive Writing* has an "otherworldly' nature". By contrast, it was noted by some, that many of the environmental factors which I introduced into the piece had the effect of making the sounds seem to have something akin to a metallic quality. Indeed, parts of the piece sound like bells with their complex underlying tonality and pitches.

Whilst it was rewarding to produce a fractal flame composition that I refined from other fractal flame algorithm code, the amount of time and process that it involved was overwhelming. I decided to return to using open source algorithms in the compositions I produced after *Recursive Writing*. An important factor in this decision was also the fact that the

sonic events which I produced using my own fractal flame algorithms and those derived from the internet were of an equal quality.

### 3.4.6) *Spots Evolve* [6:20].

Produced shortly after my experiments with designing my own fractal flame algorithms, *Spots Evolve* seeks to illustrate how a specific fractal flame image, and the sound events it generates, can be said to 'evolve' and diverge significantly by introducing only the slightest variations into the original fractal flame algorithm. The open source algorithm employed for this piece generated a fractal flame image which resembled a collage of spots, each of varying size, luminosity, colour and visual depth (see figure 36 below). As with my other composition, *Tantrum* employed translucent bubble images rather than opaque spots. However, within *Spots Evolve,* the luminosity and colour of the different spots in the fractal flame image served to dictate the various levels of pitch and volume which the fractal flame image produced once it was translated into a spectral synthesizer. I will say more on how I varied the luminosity of the spots within the different fractal flame images employed in the composition of this piece shortly.

The piece arose from my experiments with successive fractal flame images by taking the original algorithm and introducing minor variations into it, thus causing the algorithm to generate notably different fractal flame images. Each time I introduced algorithmic variations, the image produced varied from its predecessors in that the spacing, size, luminosity and visual depth of the spots that it contained, were significantly different. Once each image had been translated into an audio file and the sounds which they contained were adjusted to the correct size I began the process of composing the primary piece.

$(x, y)$= a random point in the bi-unit square
iterate {
    $i$ = a random integer from 0 to $n - 1$ inclusive
    $(x, y) = F_i(x, y)$
    plot$(x, y)$ except during the first 20 iterations
}

Figure 36

Extract of open source algorithm used to generate the fractal images in *Spots Evolve*

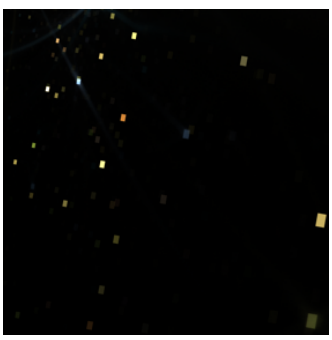
Stated briefly, I began composing *Spots Evolve* by placing the various fractal flame images I had generated at specific points on a digital linear timeline, so that each image was read by the computer according to a determined sequence chosen by me. In effect, these images served as the 'pictorial sheet music' for *Spots Evolve*. Thus, at its most basic level, the piece was composed by my ordering of the different fractal flame images which served to generate the individual parts of the melody. Once I had finalized the desired sequence of various fractal flame images to be processed by the computer, I began the process of composing the primary piece at a macro sound level.

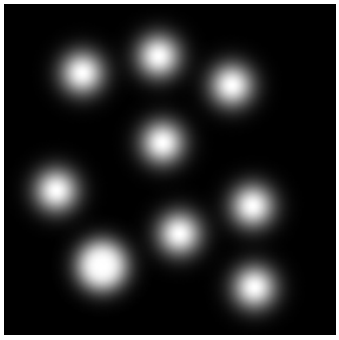
This was done by subjecting the images, once they had been rendered audible by means of a spectral synthesizer, to various sound manipulation techniques. This was the case with many of the compositions included in this portfolio. In particular, Trevor Wishart's process of wave-set substitution and the process of stretching sound waves which it employs, was used. As was the case in my other compositions which utilize wave-set substitution, this stretching of the sound waves not only brought into relief the particular grains of sound produced by the fractal flame image, but it also had the effect of lowering the pitch of these sounds. However, it was my repeated manipulation of the luminosity of the dots within each fractal flame image

which was the central process by which I manipulated the sounds. In short, it can be said that I composed *Spots Evolve* by using visual data and feedback from the various fractal flame images.

Taking each image in turn, I altered some of the spots contained therein by changing them in terms of their size, luminosity and shape. The result was that when the fractal flame images were viewed successively on a linear timeline, and according to the specific time allotted to each image within the movement of the piece itself, it was possible to observe how the spots, and the sounds they correlated to, changed. As the piece progresses, some spots increased or decreased in terms of their luminosity. By contrast, other spots grew in size whilst others shrunk to the point where they eventually disappeared. Similarly, as these spots either disappeared or became more visible, so the sounds they corresponded to either disappeared, i.e., became fainter, or became more dominant.

This gradual unfolding of how the spots evolved over time is illustrated by the images below. At an auditory level, this evolution of the spots in terms of their size, density and luminosity dictates the nature of the sounds which they produce, and not just in terms of volume. Those spots which grew in size and increased in their luminosity produced louder pitches and stronger sounds, whereas those spots that faded away or reduced in size generated sounds with lower pitches.





Figures 37 and 38

Images used in *Spots Evolve*. These reflect the different degrees of luminosity articulated during its composition.

Of special note is the role which colour played within the manipulation of the sounds produced by the spots of the fractal flame images. I used different colours to separate the different voices within the piece, thereby allowing me greater precision to manipulate them. That is, I identified green and red with different voices. By manipulating the intensity and brightness of these colours, I was able to manipulate the volume and pitch of the voices to which they corresponded. I increased the brightness of one colour at particular points within the fractal flame image to increase the volume of the voice with which it was identified, whilst at other times, I decreased the brightness of the other colour to affect a decrease in the volume of the voice to which it corresponded. Therefore, to a certain extent, it can be said that I composed *Spots Evolve* using colour.

As the piece progresses, the colour as well as the luminosity of the spots within the fractal flame image change. Moreover, as they do so, the volume of the voices to which they correspond also change. Within *Spots Evolve* there was a direct link between how the fractal flame image itself evolves over a linear timeframe and how the melody of *Spots Evolve* itself progresses.

This interplay of different voices and their interlocking with one another according to the colour of the spots which produced them can perhaps be thought of as my “painting” of sound using colour. In *Spots Evolve* colour and sound became interchangeable. I manipulated the colours within the fractal flame image, and by doing so I manipulated the sound event which it produced. Colour, in effect, became another example of how, when using fractal flame algorithms, images, with their varying intensities of brightness, hue and colour, serve as a form of ‘pictorial sheet music’.

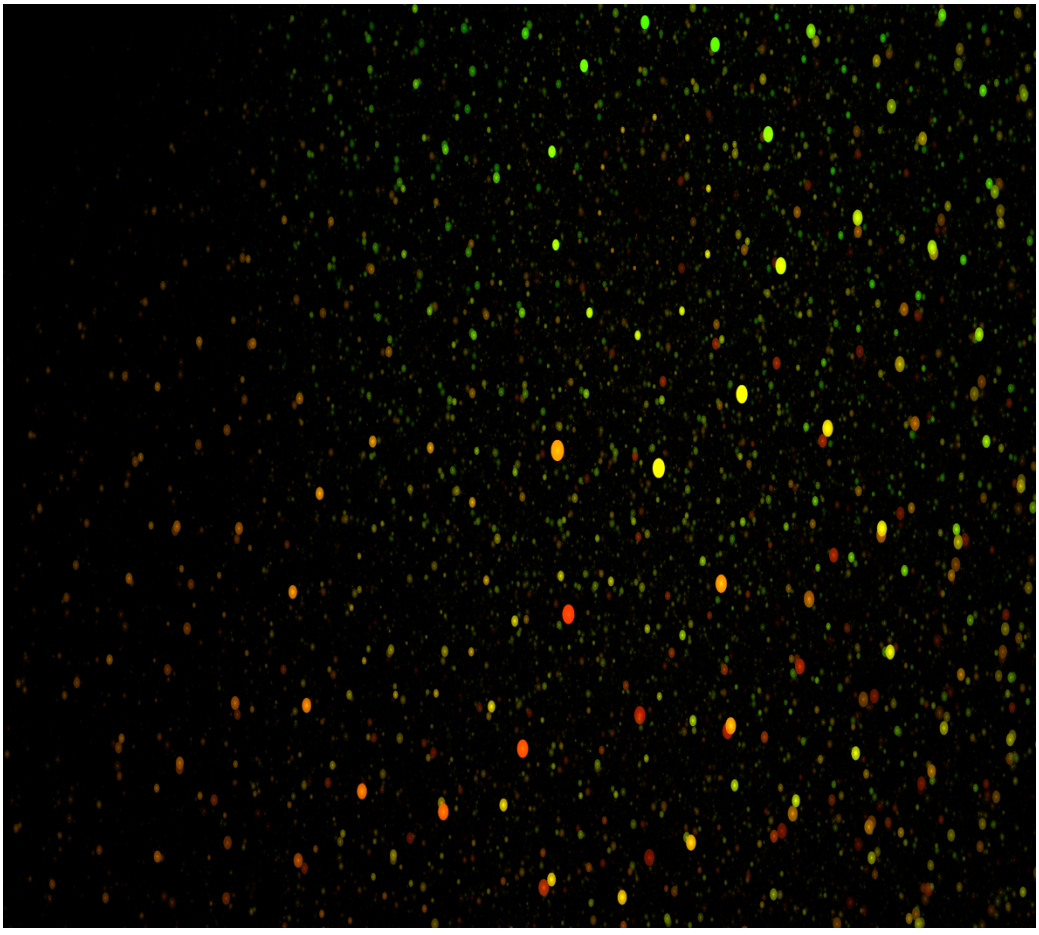


Figure 39

Larger Image of the coloured spots in *Spots Evolve*.

One of the factors I encountered during my 'interventionist' compositional experiments was the generation of unwanted sounds. In particular, these often arose through the iterative overlaying and stretching of the original micro sound sample from which the composition derived. Often these sounds were unpleasant to the ear, i.e., piercing, or risked the production of undistinguishable noise if they were incorporated along with the original sound sample during the next phase of iteration. Following my completion of *Spots Evolve*, I decided to experiment with gating. Gating is the practice of removing undesirable pitches or Hertz ranges within a piece, such that the desired voices may be heard more clearly. Whilst I used gating in several of my 'interventionist' pieces not included in this portfolio, I decided to produce a fractal flame composition that made extensive use of the practice of gating. To this end I produced the next composition that I wish to consider: *Noise Gate*.

### 3.4.7) *Noise Gate*: Electronic Surround 7.1 (09:57).

*Noise Gate* represents an attempt to take a 'natural'' sound, i.e., a single note from a traditional musical instrument (in this case a flute), and to subject it to a process of repeated stretching and digital manipulation. The motivation behind my repeated stretching of the original note, and the various sound samples this gave rise to, was not only to lower the hertz range over time, but also to reveal the wide variety of hidden grains of sound which lie beneath the original sample note. My goal in this piece was to explore how sound manipulation techniques can be applied to natural sound samples to generate new sounds within a digital framework. I wanted to integrate real acoustic samples, which of course have natural acoustic attributions, into my compositional portfolio, rather than rely solely on digitally generated sound samples.

Thus, like *Hiccup Hocket*, *Noise Gate* does not have its origins within a fractal flame algorithm; nor, strictly speaking, does it derive from any fractal inspired sound or algorithmic process, at least at its point of origin. Having said this, its composition made extensive use of the various iterative sound manipulation processes which I have used in my other fractal inspired pieces. For this reason, it fits well with my experimentations with fractal flames. It shows how the iterative sound manipulation techniques which I employ in my other compositions, particularly in pieces like *Tantrum* and *Atomic Reaction*, possess a truly universal applicability, i.e., they can be applied with equal success to both natural as well as digitally authored sound events. Furthermore, as we have noted in the previous chapter, the iterative qualities of these sound manipulation processes give them a certain fractal quality, especially in terms of their ability to reveal in ever greater detail the depth of hidden grains of sound in each sound sample.

Thus, whilst *Noise Gate* may not, strictly speaking, be fractal in terms of its original sound sample, it can nonetheless be described as truly fractal on account of the iterative processes to which I subjected it. It is thus, to coin a phrase, “fractal by nurture, if not by nature”. I have explained this phrase to those who have listened to the piece, and they noted, somewhat to my surprise, that it was hard to tell the difference between those compositions which arose from digitally generated sound samples, i.e., from my generation of fractal flame images, and *Noise Gate* which has its origins within a purely natural sound. I found this to be an especially fascinating insight, as it reveals how the decidedly fractal qualities of the iterative sound manipulation techniques, which I employ in my compositional experiments, can generate sounds that present as if they are derived from fractal flame algorithms, yet are wholly natural in origin

The process by which I composed *Noise Gate* can be summarized as follows.

(1) First, I experimented with a wide variety of traditional instruments, to find ones which not only offered the least variation in a single note, but which also provided the most stable wavelength. Having experimented with various instruments, such as violin, guitar and piano, I found that the flute and secondarily the organ, produced the purest sample note. It produced notes with relatively little variation in wave signal, i.e., the notes produced by a flute had the closest approximation to a plain sine signal.

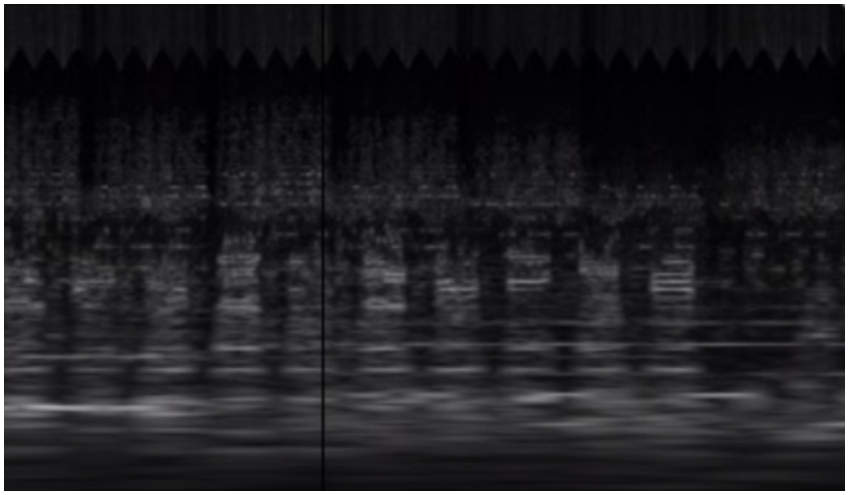


Figure 40

Original axiom for *Noise Gate*.

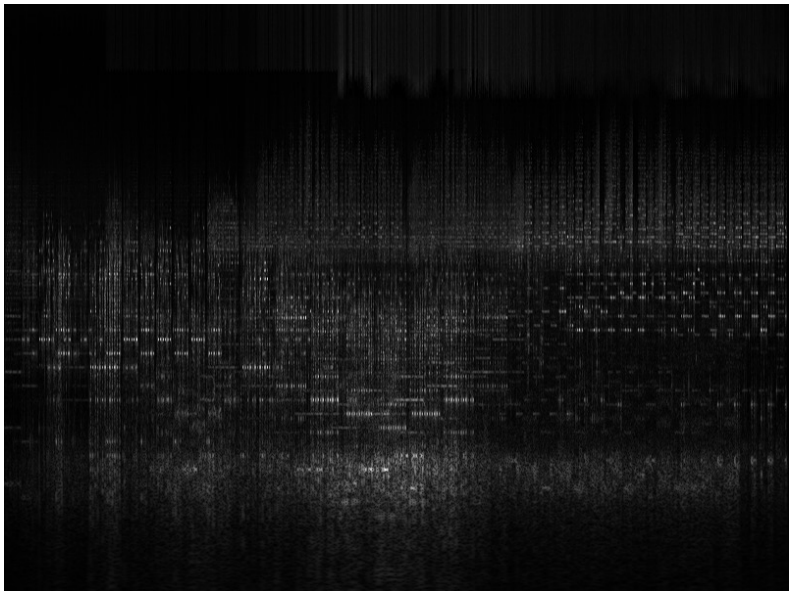


Figure 41

Axiom for Noise Gate (right speaker)

(2) For this piece I decided that the flute is my instrument of choice, and I proceeded to transpose the chosen note from the flute to about fifty Hertz. This not only lowered the sound by around an octave, but it also revealed the hidden grains of micro sound which it contained. I took this modified sound sample and subjected it to Trevor Wishart's process of wave-set substitution. After completion, I adjusted the sound sample for volume and gated it to take away unwanted pitches or Hertz ranges. This was done for two reasons. First, Wishart's programme of wave-set substitution introduces a wide variety of new pitches into the manipulated sound sample, thereby altering the nature of the original sample. Second, if these newly introduced pitches are not removed, they eventually degrade the piece into White Noise. This would obviously prove counterproductive to my original intentions, that is, the production of a recognizable melody.

(3) After gating, I repeated the whole process of stretching.\, using wave-set substitution a number of times. In total the process was repeated six times. I tried to change each gate that I used for aesthetic purposes (cf. section 2.5), with special concern for the coherence of the final macro sound. My aim was to create a variety of different octaves from which I could generate an interesting melody. I created this melody in the same way that I generated *Hiccup Hocket*, by using Sibelius. Once completed, I took the samples that I had generated and exported them into a DAW, specifically Logic Pro. Next, I created a MIDI file from Sibelius and imported it into Logic Pro to play the sound samples that I generated. Finally, I adjusted the piece for aesthetic purposes, removing pitches that were either piercing or too dominant.

On account of the complexity of sound manipulation techniques employed in its composition, *Noise Gate* took an especially long time to produce. Indeed, out of all the pieces included in this portfolio, *Noise Gate* is the one on which I spent the most time and energy. It is the one which required the most attention to detail as well as the most acoustic experimentation. This was especially challenging during its early stages, as I tried to find an instrument to produce a homogeneous, self-contained note with little variation. As the above description of its compositional processes indicate, each of the stages involved in its production, especially the removal of undesirable pitches using gating, had to be done very carefully.

Otherwise, the iteratively generated sound samples would not have remained faithful to the original sound sample which, as I have already noted, is one of the guiding principles of the compositions that I have sought to produce. To this extent, *Noise Gate* can be classified as one of my most 'interventionist pieces. It is the one that required the most human intervention in order guarantee its self-similar identity at both the micro and macro sound.

### 3.4.8) *Temple of Shiva* (06:28).

A piece with a decidedly ethereal, otherworldly nature, and one which I feel has almost metaphysical and quasi-religious undertones, *Temple of Shiva* is a medium length composition. I produced the original sound sample using a fractal flame image that I generated from an open source code and processed using multiple sound inputs. The idea behind the piece was for the original fractal flame image to find as much expression as possible at both the micro and macro dimensions of the composition. In addition, I used the original fractal flame image as the blueprint for the piece at all levels, both micro and macro, with the intent of translating as much as possible of the fractal flame image into sound. The original fractal flame image from which this piece derived, dictates the overall nature of the piece at a macro sound level, that is to say how it unfolds as a coherent synthesis of sound, i.e., its speed and variations in pitch and tonality. It also dictates the individual grains of micro sound which it contains and the order in which these are placed within the piece. How I achieved this goal will become apparent when I examine the various stages of sound manipulation and repeated overlaying which I employed whilst composing the piece.

I found the *Temple of Shiva* both interesting to produce and particularly satisfying at an aesthetic level. I have included this piece in my portfolio for two reasons.

(1) First, it illustrates the rich diversity of sonic phenomena which can be generated using fractal flame images. As I stated earlier, I can never fully predict what kind of sounds will emerge, and what quality they will have from a fractal flame image, until I have translated the image into an audio file and begun to manipulate the sound using a process of iterative overlaying, shortening and stretching. This makes the sound generated by each fractal flame image not only unpredictable, but also, and perhaps most importantly of all, highly unique. Given the unique complexity of each fractal flame image, no sound events, both at a micro and micro level, produced by fractal flames are ever the same. Resembling something akin to an auditory fingerprint, each fractal flame image produces sounds that are particular to it alone. In the case of *Temple of Shiva*, I was able to use the original sound sample to generate a piece that seemed notably different from my other compositions.

(2) Second, I have included *Temple of Shiva* in my portfolio because the process by which it was produced, illustrates the plasticity, both of fractal flame images and the grains of sound, which they give rise to. It also serves to underscore the various sound manipulation techniques I have used in my previous 'interventionist' compositions. As will be shown, by exploiting the malleability of the iterative process of overlaying sound samples, for example, where exactly within the composition these sound samples could be overlaid and at what depth, I was able to compose *Temple of Shiva* by working with fragments of sound in the same way one would do so with visual materials in a collage.

The process by which I composed *Temple of Shiva* was a complex one. To this extent, like *Noise Gate*, it can be classified as a highly 'interventionist' piece. It involved much overlaying of the original sound produced by the fractal flame image once it had undergone a process of repeated stretching and shrinking. As with all my compositions, the first stage of the compositional process involved the generation of a fractal flame image using a particular open source code. In this case I did not do much to alter the code selected. Once the image had been generated using a fractal flame generator, I manipulated it to bring it into sharper relief by changing the contrast.

Following this, samples from the image were abstracted and placed into a sound synthesizer to translate the data from the image into an auditory phenomenon, thereby translating the fractal flame image into a specific sound. Subsequently, I selected samples of this sound and matched these to specific dots or markers within the original fractal flame image itself. The result is that certain parts of the image became associated with certain sounds, and as the computer scrolls through the image it “plays” the relevant sounds. The original fractal flame image in effect comes to resemble something akin to sheet music. As the computer reads the image, it allocates certain sounds to certain parts of the image and plays these according to the timing dictated by the image.

This identification of certain sounds with specific markers or dots within the original fractal flame image is only the first stage of the compositional process.

Once the computer had played the sound sample generated by fractal flame, the sample was manipulated by shortening it and laying it over the image by allocating this new sample to specific dots within the original fractal flame image. The piece was then played again, this time with the two samples voicing themselves together, albeit at different speeds and pitches. The new sound sample produced by this bifurcation of the voices was then

manipulated and layered over parts of the original sound piece according to specific dots within the fractal flame image, thereby giving the resulting piece three layers of sound.

This process of iterative shrinking and over layering was carried out three times. Each time the resulting sound was shortened, I reduced it on average between one-hundred to two-hundred Hertz within the spectral plane. On average, the sample was reduced about 200% before it was layered over the original piece and the subsequent layers of sound which I had generated from it. The result of this stretching of the samples and their being overlaid over their shorter predecessors was the production of an echoing effect as well as a crackling sound.

With regards to how I mapped the different layers of sound onto the original fractal flame image, it is important to note that whist the overlaying of the various sound samples was done, I adjusted the contrast and luminosity of specific points within the fractal flame image itself. More often than not, the luminosity of the image was strengthened to highlight the various points of clustering within the image and the various dots which were to be found here. The purpose of this, was to bring into relief the individual grains of sound which were to be found in these clusters, and avoid the production of white noise when the computer translated the image into an auditory event.

Had this increase of luminosity not been carried out, the computer, when translating the image into sound, would have produced an indistinguishable noise with no recognizable sound grains and no scope for aesthetic adjustment. This is so because the cluster of dots within the image would have registered not as individual grains of sound, but rather as a single sound event. This is a good example of how, within the art of generating sonic events using fractal flame images, the process of manipulating the visual quality of the fractal flame images themselves is integral to the quality and nature of the sounds which they produce.

The mode by which I organized the fragmented samples of sound to produce the composition can be thought of as something resembling a three-dimension auditory jigsaw puzzle. Rather than simply placing the sounds randomly over the layers of sound which preceded them, I placed samples at specific points within the composition to give variations in depth. The result is that as the composition unfolds, there is a variety of different sound events occurring at differing points, often with different samples of sound being played at the same time.

The selection of where and when samples were to be laid over one another was done in part on an aesthetic basis. However, by and large, it was done to reflect the nature of the original fractal flame image itself. Where there were points of particular intensity in the image, I over-layered as many sound samples as possible. Accordingly, the intensity of sounds within the piece reflects the intensity of luminosity and depth at work within the original fractal flame image.

It should now be clear that the fractal flame image upon which *Temple of Shiva* is based not only shaped nature and structure at a micro sound level, but as well at a macro sound level. *Temple of Shiva* is quite literally a translation of the original fractal flame image (to the highest degree possible) into a sonic event. It was created in an 'interventionist' mode rather than using the 'purist' approach of my early compositions. It is in effect, the reincarnation, to reference the Hindu god selected for this title, of the original fractal flame image from a visual phenomenon into an auditory one. In it, the light and colour of the fractal flame image are reborn into pitch, tempo, and volume.

### 3.4.9) *Atomic Reaction*: Electro Stereo (6:44).

Following my completion of *Temple of Shiva*, I decided to end my 'interventionist' phase of compositional experiments, and indeed my PhD studies as a whole. However, I did subsequently produce a piece of fractal flame sonic art that incorporated most of the processes, skills, and sound manipulation techniques that I had employed during my PhD. To this end, I produced *Atomic Reaction*.

*Atomic Reaction* is one of the most complex pieces to produce, and the piece with which I am most satisfied. This piece illustrates most clearly the sonic potential of fractal flame algorithms when brought into dialogue with existing sound manipulation techniques. It is a multi-layered and particularly complex piece, with many underlying complexities of pitch, tonality and iteration. *Atomic Reaction* is the piece which allowed me the most freedom and space to explore how the electronic sounds generated by fractal flame algorithms can be rendered malleable by using a plethora of sound manipulation techniques, such as wave-set substitution and granular synthesis, as well as repeated stretching and overlaying.

As the accompanying recording reveals, *Atomic Reaction* pushes the boundaries of both tolerable frequencies and the complexities of sound that can be produced using wave-set substitution. I have chosen to call this piece *Atomic Reaction* because in it I have sought to show how a small sound sample, originally only a few milliseconds long, and seemingly insignificant in itself, can be said to ‘explode’ within a large space of time once it has been manipulated and experimented upon using a granular synthesizer. The result is a piece which has many reverberations and subsequent smaller explosions.

A precedent for generating a sustained piece of music from a single sound sample is to be found in Trevor Wishart’s *Imago* (2002). Famously, Wishart generated a twenty-five-minute composition from a clink of two whisky glasses. However, *Atomic Reaction* differs from

Wishart's *Imago* in two important ways. First, unlike *Imago*, *Atomic Reaction* is composed in such a way that there is a self-similarity between the original micro sound and the final macro sound. As will be explained, the micro sound sample from which the composition derives dictates both the iterative processes by which the macro sound is composed and the final macro sound itself. This is not the case in Wishart's *Imago*. Second, the micro sound sample I used was a digital one produced by a fractal algorithm. By contrast, Wishart's sound sample was a natural, non-algorithmic one.

Given the self-similarity between its micro and macro sounds, *Atomic Reaction* is a good example of how sonic identities can function like fractal patterns, revealing ever greater detail whilst remaining faithful to the likeness of the original sound sample. Moreover, as can be heard from the accompanying recording, *Atomic Reaction* has a particularly explosive quality, with many smaller 'explosions' of sound stemming from the original sound as it was subjected to repeated stretching and over-layering. As we shall see, the sonic output of the fractal algorithm and image contains a multiplicity of different constituent sounds, and these, in turn, give rise to a plethora of smaller sonic events, each of which has the potential to generate further sonic phenomena.

There is something of a chain reaction of sonic events at work within *Atomic Reaction*. The more the sound was stretched using wave-set substitution, the more the individual grains of sound it contained came into focus at an auditory level. To this extent, it is perhaps helpful to think of *Atomic Reaction* as being something akin to an auditory fireworks display. Except, unlike in a real fireworks display, the same fireworks are simultaneously used over and over again, albeit exploded at different sizes, pitches, and tonality. Moreover, each explosion gives birth to subsequent smaller explosions.

The production of *Atomic Reaction* incorporated most, if not all, of the digital sound manipulation processes employed in the previous 'interventionist' pieces discussed, i.e., wave-set substitution, granular synthesis and the repeated over-layering of sonic events. *Atomic Reaction* is in many respects the culmination of my portfolio. The piece embodies most clearly the compositional agenda and methodology that I have sought to employ in my doctoral research. *Atomic Reaction* represents the compositional horizon against which my other pieces are to be measured.

*Atomic Reaction* essentially consists of a bass sound recursively mixed, stretched, contracted and layered over itself numerous times until the desired aesthetic result was achieved. It stems from an original grain of sound originally only a few milliseconds long, that being rendered plastic enough by its subjection to sound manipulation techniques, have moulded and manipulated it into a coherent piece lasting nearly seven minutes. *Atomic Reaction* is thus a clear example of how the process of focusing in on the particular micro sounds produced by fractal flame algorithms, in this case one particular grain of bass sound, can result in an interesting macro sound. The process of manipulation at the level of macro sounds, in *Atomic Reaction* was a particularly complex and intricate one. At the risk of oversimplification, however, it was produced using the following four stage process.

Stage 1: The preparation of micro sound samples.

- This first stage primarily involved the conversion of the fractal flame image I generated into sound and the reversal of this process (i.e., turning the sound sample back into an image) once it had been iteratively manipulated. The following three steps were involved in this process. Not only were each of these integral to the

production of *Atomic Reaction* at its seminal micro sound level, but they also recurred at various points during its composition.

a) First, the fractal flame image which I had generated using an open source algorithm was translated into sound. This was done by importing it into Metasynth.

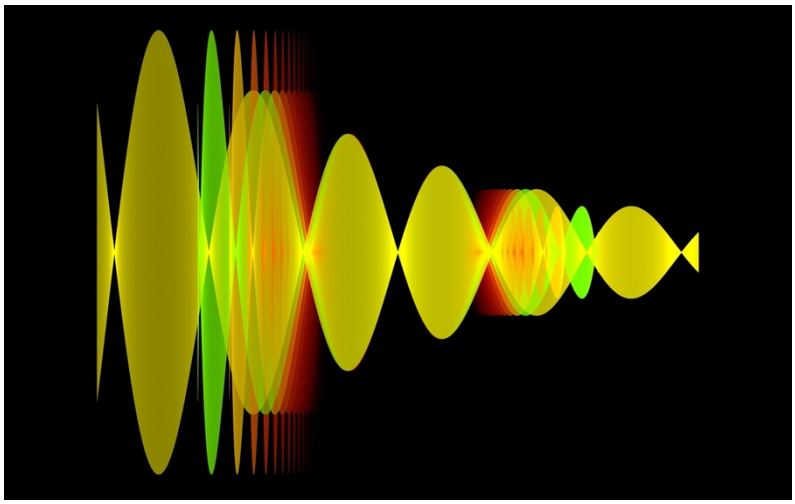


Figure 42

This is the first axiom in *Atomic Reaction* – i.e., the translation of the fractal flame image into sound using Metasynth.

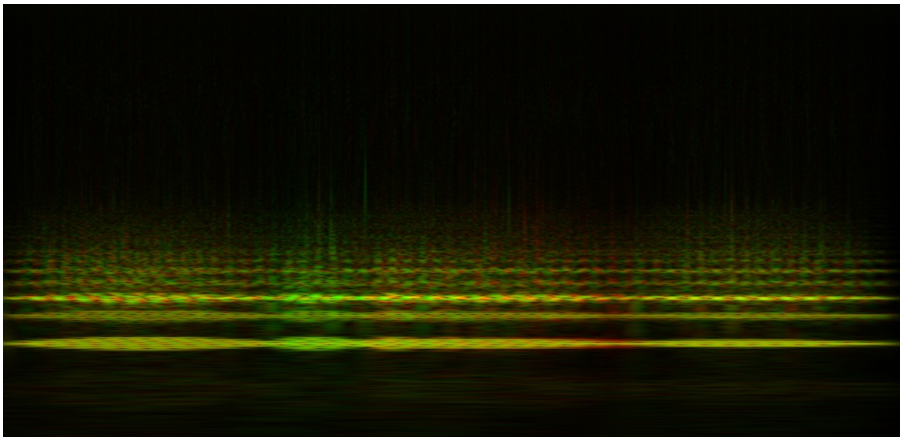


Figure 43

The original spectral image of *Atomic Reaction*.

b) Next, the sound sample was edited for aesthetic purposes so as to remove unpalatable pitches and to bring the various subsonic sounds it contained to the level of human perception.

c) Finally, I took the sample and translated it into a spectral image using Metasynth. The result is a picture which represents the sound as image over time. The image was then edited through a process of dimming and brightening certain parts of it to manipulate the sound output it would produce once it was translated back into sound.

- Once the above threefold process was completed, I again subjected that sound sample to the same 3 stage process. In total this cyclical process was repeated five times.

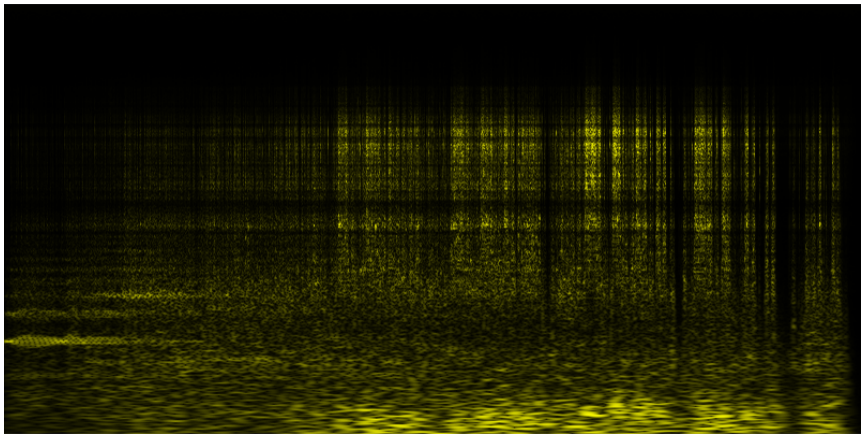


Figure 44

Spectral image in Metasynth after five iterations of the processes described in stages a, b and c.

Stage 2: The manipulation of the sound samples resulting from stage 1 to form the template of the composition itself.

- Taking the resulting sound samples from stage 1, I proceeded to manipulate them using a DAW. Here I organized the micro sound samples to produce the macro outline of the composition itself, i.e., I used them to form the 'skeleton' upon which the composition itself would be based. Thus, this stage of the compositional process involved using the micro sound samples to design the macro sound which formed the foundation for *Atomic Reaction.*

Stage 3: The production of new templates for the macro sound.

- To begin the process of designing the macro sound I took the resulting outputs of stages 1 and 2 and subjected them to the three phases outlined in stage 1, i.e., stages a, b and, c. This process created a larger micro level sound.

- This process was then repeated, i.e., the subjection of the output to stages a, b, c in stage 1) five times.

- The output of this iterative process was subjected to the procedures involved in stage 2. That is to say, I created another template for the macro sound by using the micro sound samples produced from the process just described above.

- This process was repeated again five times and produced five new templates which were used to map the macro sound.

Stage 4: the generation of the macro sound

- Taking the five templates which, I produced in stage 3, I mapped out another sample.

- Once completed, this sample was subjected to the three phases involved in stage 1 (stages a, b and c).

- I then took each of the fifteen variations and created the nearly completed piece by mapping them out the same way as every other process.

- Finally, I edited the piece for aesthetic purposes.

I have found this piece to be one of the most intriguing of my doctoral compositions, both in terms of the compositional process involved and the end product itself. This is because *Atomic Reaction* allowed me to explore with precision and rigorous experimentation how micro sounds can be stretched, contracted and mixed whilst being layered over themselves. This gave the same sound a three-dimensionality which it could not achieve by itself. It is particularly satisfying that this piece has allowed me to explore the interface between micro and macro sounds and demonstrate the potentiality of iterative stretching of macro and micro sounds to produce, in Xenakis's word, "sounds that have never existed before", and finally to push the boundaries of frequency and tonality.

The response I have sought to elicit with this piece, has been to expose the listener to the seemingly endless complexity and intricate diversity which can be experienced by exploring how micro sounds can be stretched and recursively layered over themselves so as to produce an interesting macro sound. In doing so, I have attempted to intrigue the listener and reveal to them the hidden sounds and sonic art which can be found in a simple sound sample.

# Chapter 4
# Conclusion

## 4.1) General Remarks.

Now that I have outlined the compositional processes by which I generated my pieces of music and discussed each of these pieces in turn, all that remains to do is to draw together the threads of research, arguments and creative inspiration which have run throughout this portfolio. The purpose of doing so, however, is not simply to bring this portfolio to a close, nor simply to summarize the research contributions which this study has made. Instead, its aim is to sketch out how in the future I hope to further develop some of the compositional processes that I have outlined in the preceding chapters. In particular, I wish to touch upon some of the ideas that I have for how some of my compositions could be enhanced at a performance level, as well as how it may be possible for me to simplify some of the compositional process which several of my pieces employ.

Before I do this, it is important to:

a) Offer a critical assessment of where the aesthetic of my compositions lies in relation to the 'purist' and 'interventionist' approach which I outlined above and in earlier chapters.

b) Highlight a number of the important conclusions raised by this portfolio concerning the use of fractal flame algorithms to generate sonic art. Particularly

pertinent here, are some of the advantages and limitations of the compositional methodology I have employed in my research.

## 4.2) Situating My Aesthetic in Relation to the 'Purist' and 'Interventionist' Approach.

As seen during my compositional research, I moved from a 'purist' approach in my early compositions, such as *Symphony of Noise,* to an 'interventionist' one in my later compositions. In light of this evolution, two questions may be asked:

1) To what extent may my early and late compositions be described as truly 'purist' and 'interventionist'?

2) Do all my 'interventionist' compositions employ the same degree of intervention or are some more 'interventionist' than others?

With regards to the first question, I believe that my early compositions can be described as 'purist' to the extent that they arose from the direct sonification of a fractal flame image. As we have seen, they involved no sound manipulation post-sonification, except the necessary stretching of the sound sample to bring into relief the individual grains of sound which it contained. However, as seen in *Symphony of Noise,* there was nonetheless some creative input on my behalf in terms of selecting and adapting the fractal flame algorithm prior to its sonification and, the selection of the pieces to include in the four movements.

Further supporting the description of my early works as 'purist', is the fact that this label is applied to Vaggione's early fractal compositions which, like my own early compositions, involved no creative manipulation post sonification of the fractal data.[61]

In response to the second question, it is clear from the mature pieces which I discussed in chapter three, that they did indeed vary in the degree of 'interventionism' which they employed, thus meaning that some are more 'interventionist' than others. This is because:

a) I utilized a variety of different sound manipulation techniques in my later compositions. Moreover, each of the techniques which I employed in my later compositions varied in terms of the degree of input which they required on my behalf. Thus, for example, the process of gating employed in *Noise Gate* or the designing of the fractal flame algorithm used to generate *Recursive Writing* was far more labour intensive than say the manipulation of luminosity and colour employed in the generation of *Spots Evolve* or *Tantrum*.

b) The degree to which I manipulated the fractal flame images or algorithms, and the number of times this was done, varied in my compositions. For example, the manipulation and overlaying of the fractal flame images employed in *Spots Evolve* was much more restricted than the degree to which this iterative process was utilized in *Atomic Reaction*. At this level, *Atomic Reaction* could be legitimately described as more 'interventionist' than *Spots Evolve.*

[61] *Supra*.

In summary, it is clear that the 'interventionist' approach which I employed in my later compositions was not of a homogeneous nature.

## 4.3) Advantages and Limitations of Fractal Flame Music.

My transition from a 'purist' to an 'interventionist' approach points towards an important truth about using fractal flame algorithms and images within sonic art. At an aesthetic level, generating sonic events from fractal flames has both strengths and weaknesses. For example, we have seen, whilst adopting a purist approach can produce complex and intriguing results, it can also produce unpalatable sounds. *Sephiroth* offers an example of this failing. The process of simply subjecting fractal flame images to sonification without human intervention post sonification was thus mixed and by no means consistent. By contrast, we have seen that adopting an 'interventionist' approach allows for the removal of any unpleasant sounds and the production of complex aesthetically pleasing macro sounds. Similarly, an 'interventionist' approach allows for the creative interface between algorithms, fractal flames and human creativity to be explored in many rich and diverse ways. However, as we have seen, the production process of some of my 'interventionist' pieces was a long, often complex and highly repetitive one, and this could potentially be seen as something of a limitation. Nonetheless, I would point out that such complexity and repetition cohere well with the self-similar nature of fractals themselves, in particular their high degree of mathematical and artistic complexity.

## 4.4) Looking to the Future.

In the coming years I hope to further develop several of the compositional methods which I have pursued during my PhD. This portfolio is thus not simply the culmination of my explorations in fractal flame music. Instead, it represents the “springboard” from which I hope

to move into further research concerning the acoustic potential of fractal flames, and indeed fractals in general. In particular, I should like to develop the following pieces accordingly:

1) *Symphony of Noise*: I would like to make a virtual soundscape environment for this composition in which I could explore all the different aspects of the sounds involved in it in a three-dimensional environment. Ideally, I would use multiple computers for this and connect them to a large set of speakers in many rooms, so as to produce a "living" sound environment, either virtual or live. This sound environment would be one in which the listener could actively "walk" through the four movements, thereby experiencing the progression of the symphony as they move into different rooms.

2) *Recursive Writing*. In the future I would like to simplify the process whereby this piece was produced, thereby aiding not only its replication, but also the easy production of pieces similar to it. I would especially like to design a computer programme or code which would allow me to sidestep the various states of production undergone in the generation of *Recursive Writing,* i.e., the time-consuming process of transposing the sound from one programme to another. My aim would be to generate an efficient programme which could produce sounds directly from the fractal flame coding itself, thereby further underscoring the capacity of fractal flame programs to produce electronic music. I would also like to ensure that any future programs I design have the capacity for human interface manipulation. This would allow for easy aesthetic editing and the removal of unwanted sounds.

## 4.5 Summary of the Research Contributions of My Portfolio.

The research contributions of this portfolio are twofold:

1) I have shown that the much-neglected acoustic potential of fractal flame programs ought to be brought to the attention of those working in the field of electronic music composition. As chapters one and two explained, fractal flames are a resource which no serious electronic composer or contemporary researcher has sought to engage with before.

2) I have shown how the sonic events produced by fractal flame images can be successfully harmonized with existing modes of sound manipulation techniques employed by electronic composers, i.e., granular synthesis, wave-set substitution.

## 4.6) Final Remarks.

I hope that in this portfolio I have succeeded in generating in Xenakis' words, 'sounds that have never existed before' and fulfilled something of what Xenakis himself believed to be the goal of all good electronic composition, namely, 'to fascinate, to exhilarate and to intrigue the listener'. When composing electronic music, Xenakis tells us that the work of the sonic artist must have the following effect on the listener:

> The listener must be gripped and whether he likes it or not, drawn into the flight path of the sounds without special training being necessary. The sensual shock

must be just as forceful as when one hears a clap of thunder or looks into a bottomless pit.[62]

[62] Xenakis quoted in Jennifer Shryane, *Blixa Bargeld and Ein Sturzende Neubaten: German Experimental Music* (London: Routledge, 2016). E-book.

# Bibliography

Anderson, Christine, 'Dynamic Networks of Sonic Interactions: An Interview with Agostino Di Scipio', *Computer Music Journal,* 2005 (29: 3), pp. 11-28.

Ames, Charles, ''Crystals': Recursive Structures in Automated Composition', *Computer Music Journal,* 1982 (6:3), pp. 46-64.

- 'Stylistic Automata in 'Gradient'', *Computer Music Journal*, 1983 (7:4), pp. 45-56.
- 'Automated Composition in Retrospect: 1956-1986', *Leonardo,* 1987 (20:2). Special Issue: Visual Art, Sound, Music and Technology, pp. 169-185.
- 'Statistics and Compositional Balance', *Perspectives of New Music,* 1990 (28:1), pp. 80-111.
- 'A Catalogue of Statistical Distributions: Techniques for Transforming Random, Determinate and Chaotic Sequences', *Leonardo*, 1991 (25:1), pp. 55-70.

Can, Toros, 'The Importance of Ligeti's Piano Etudes in Compositional and Pianistic Aspects: What it is Necessary to Analyse Ligeti Etudes Prior to Learning' *International Journal of Arts and Sciences* 4 (3) 2011, pp.201-7

Di Scipio, Agostino, 'Iterated Nonlinear Functions as a Sound-Generating Engine', *Leonardo*, 2001 (34: 3), pp. 249-54.

Draves, Scott and Reckase, Erik, 'The Fractal Flame Algorithm' (2003). Downloaded from https:flam3.com/flame_draves.pdf. Accessed: 10th August 2019.

Eldenius, Magnus, *Formalized Composition on the Spectral and Fractal Trails,* (Goteborg: Novum Grafiska AB, 1998).

Gilmore, Bob, *Harry Partch: A Biography,* (Yale: Yale University Press, 1998).

Gleick, James, *Chaos: Making a New Science*, (New York: Viking Books, 1987).

Gould, Stephen, J., *Punctuated Equilibrium,* (Cambridge MA: Harvard University Press, 2007).

Granade, S. Andrew, *Harry Partch, Hobo Composer,* (Rochester NY: University of Rochester Press, 2014).

Hofstadter, Douglas, *Gödel, Escher, Bach: An Eternal Golden Braid,* (New York: Basic Books 1979).

Hsu, Kenneth and Andreas, 'Fractal Geometry of Music', *Proceedings of the National Academy of Sciences of the United States of America*, 1990 (87:3), pp. 938-941.

Kuehnl, Eric, 'Granular Synthesis' (1995) at www.erickuehnl.com./granular -synthesis/. Accessed: 02-04-2019.

Lambert, Phillip, *The Music of Charles Ives,* (Composers of the Twentieth Century Series) (Yale: Yale University Press, 2009).

Mandelbrot, Benoit, *The Fractal Geometry of Nature*, (New York: W. H. Freedman and Company, 1982).

Marczewska, Kaja, 'The Iterative Turn', https://metaspar.se/wp-content/uploads/2_The-Iterative-Turn_Issue-3.pdf. Accessed: 02-04-2019, 2019. Originally published as part of *Parse Journal*, pp.13-28.

Ornes, Stephen, 'Science and Culture: Hunting Fractals in the Music of J. S. Bach', *Science and Culture*, 2014 (111: 29), p. 10393.

Partch, Harry, *Genesis of a Music: An Account of A Creative Work, Its Roots and Its Fulfilment,* (London: De Capo Press, 1979).

Paynter, John, et.al. (eds.), *Companion to Musical Thought*, vol., 2, (London: Routledge, 1992).

Peitgen, Heinz-Otto, 'Continuum, Chaos and Metronomes – A Fractal Friendship' in Louise Duchesneau and Wolfgang Marx (eds.) *Gyorgy Ligeti: Of Foreign Lands and Strange Sounds,* (Rochester NY: Boydell Press, 2011), pp. 87-106.

Po-Hung, Li 'The Role of Mathematics in the Renaissance Sciences and Arts' *Humanities and Social Sciences Review* 2(2) 2013, pp. 107-111.

Quaglia, Bruce, 'Review of 'Fractals in Music: Introductory Mathematics for Musical Analysis by Charles Madden', *Computer Music Journal*, 2000 (24: 3), pp. 84-6.

Reich, Steve *Writings About Music,* (Nova Scotia: Halifax Press, 1974).

Roads, Curtis, *Composing Electronic Music: A New Aesthetic*, (Oxford: Oxford University Press, 2015).

- 'The Art of Articulation: The Electroacoustic Music of Horacio Vaggione', *Contemporary Music Review* 2005 (24:4/5), pp. 295-309.
- *The Computer Music Tutorial,* (Cambridge MA: MIT, 1996).

Segal, Michael, 'In the Mind of the Fractal King: A Reconstructed Interview on Life and Fractals', *Nautilus*, 2013, http://m. nautil.us/issue/0/the-story-of-nautilus/in-the-mind-of-the-fractal-king. Accessed: 20th/6th/2019.

Shryane, Jennifer, *Blixa Bargeld and Ein Sturzende Neubaten: German Experimental Music,* (London: Routledge, 2016). E-book.

Snow, C. P., Rede Lecture 1959, *The Two Cultures and the Scientific Revolution*, (Cambridge: CUP, 2012).

Swafford, Jan, *Charles Ives: A Life with Music,* (London: W. W. Norton & Company, 1998).

Wishart, Trevor, *Audible Design: A Plain and Easy Introduction to Practical Sound Composition,* (London: Orpheus The Pantomime, 1994).

Wishart, Trevor, *On Sonic Art*, (Amsterdam: Harwood Academic Publishers, 1996).

Wallin, Rolf, Comments on website: rolfwallin.org/about/c_515a041f1e91c00ef89091af/. Accessed 12/12/2019.

Won Baik, Ji, *György Ligeti's Piano Études: A Polyrhythmic Study* (PhD Thesis, Florida State University, 2009).

Worrel, David, *Sonification Design: From Data to Intelligible Sound Fields* (Chicago: Springer, 2019).

Wuorinen, Charles, 'Music and Fractals' in Michael Frame, et., al. (eds.) *Benoit Mandelbrot: A Life in Many Dimensions,* (London: World Scientific Publishing Co., 2014), pp. 501-6.

- *Simple Composition,* (New York: C. F. Peters, 1979).

Xenakis, Iannis, *Formalized Music: Thought and Mathematics in Music*, (New York: Pendragon Press, 1992).

# Appendix 1

SuperCollider Source code for *Recursive Writing*

```
(
	var file,data;
	var px, xv, yv, vRadius;
	var creationfunction;
	var fftsize = 1024;
	var complex, cosTable;
	var array;

	px = 0;//previous x
	x = rand2(1.0);
	y = rand2(1.0);

	a = Array.rand(12,-1.0,1.0);

	creationfunction =	{|numberrequired = 256|
		Array.fill(numberrequired, {
			px = x;
		[{(xv = (a[0] * x) + (a[1] * y) + (a[2]);
			yv = (a[3] * x) + (a[4] * y) + (a[5]);
			xv = (xv + yv) * 0.5;
			yv = (px - yv) * 0.5;
			x = xv; y = yv)},
			{(xv = (a[6] * x) + (a[7] * y) + (a[8]);
				yv = (a[9] * x) + (a[10] * y) + (a[11]);
				xv = (xv + yv) * 0.5;
				yv = (px - yv) * 0.5;
				x = xv; y = yv)},
			{(xv = (a[0] * x) + (a[1] * y) + (a[2]);
				yv = (a[3] * x) + (a[4] * y) + (a[5]);
				vRadius = sqrt((xv * xv) + (yv * yv));
				x = xv / (vRadius * vRadius;);
```

```
                        y = yv / (vRadius * vRadius))},
                {(xv = (a[6] * x) + (a[7] * y) + (a[8]);
                        yv = (a[9] * x) + (a[10] * y) + (a[11]);
                        vRadius = sqrt((xv * xv) + (yv * yv));
                        x = xv / (vRadius * vRadius);
                        y = yv / (vRadius * vRadius))}].choose.value;
        });
};

cosTable = Signal.fftCosTable(fftsize);

//defaults to 44100 sample rate
file = SoundFile.new.headerFormat_('WAV').sampleFormat_('int16').numChannels_(1);

file.openWrite('/Users/nickcarlson/Desktop/writetest2.wav');

array = Array.fill(256, {|i|
        var spectra;

        spectra =
Complex(Signal.newFrom(creationfunction.(fftsize)),Signal.newClear(fftsize));

        (spectra.real.ifft(spectra.imag, cosTable)).real;

}).flatten;



data = Signal.newFrom(array);

file.writeData(data);
file.close
```

# Appendix 2

List of select compositions produced during my PhD which are not included in this portfolio.

*Sephiroth* (2.30)

*Cloud* (2:32).

*Organ Panic* (9:20).

*Bullitio* (5:04).

*Shard* (7:33)

*Manual Turn* (3:34).

*Monster Mash* (2:55).

*Attractor Strange/Strange Attractor* (2:22).

*Metal Water* (3:32).

*Lux incorporata* (4:21).

*Fractal Rainbow* (2:57).

*Paranoid Panic* (4: 45).

*Pulchra est Luna* (7:22).

*Nuclear Nihilism* (2.12).

*Drag-on Dragging* (4:56).

*Selfish Inversion* (6: 46).

*Metaphysics* (7:33).

*Bestia Ascendens* (6:66).

*Black Box* (6:32)

*colour spectrum* (1:12).

*Dante's Despair: Abandon Hope All Ye Who Enter* (8:32).

*Re-winding the Rainbow* (3:01).

*Cataphatic Crash* (2:22).

*Something Wicked* (5:21).

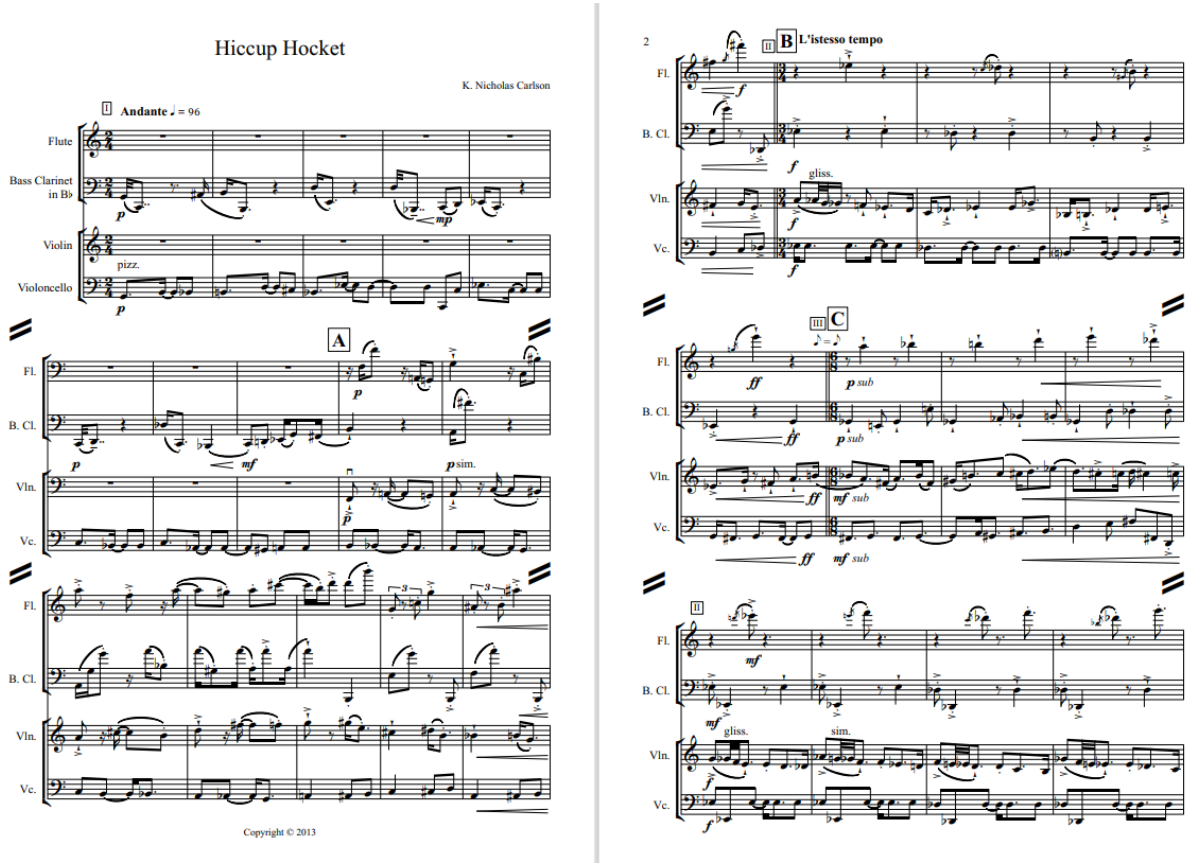
*Rigged Election* (3:11).

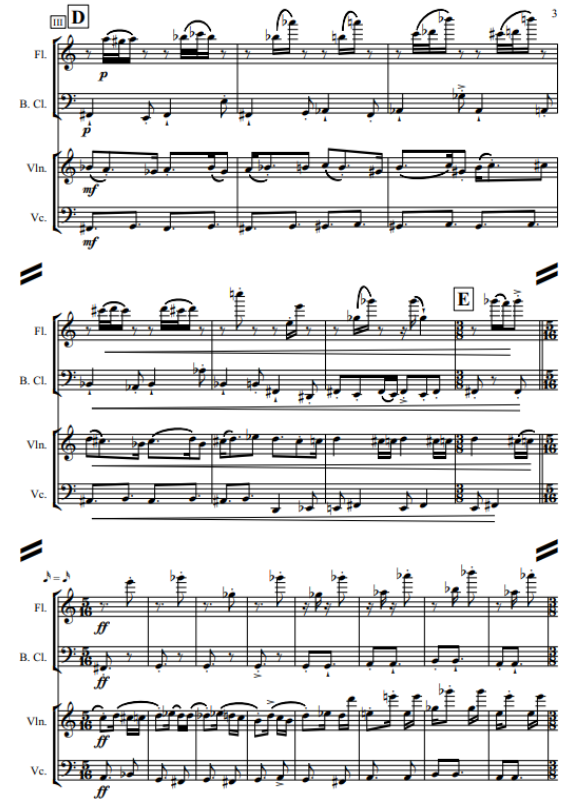
Swerving Desire (7:32).

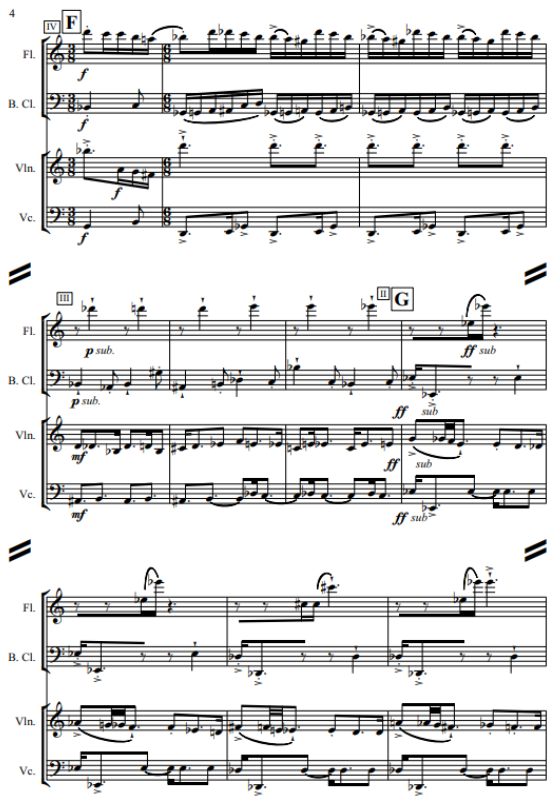
*Kodo Despair* (7:21).

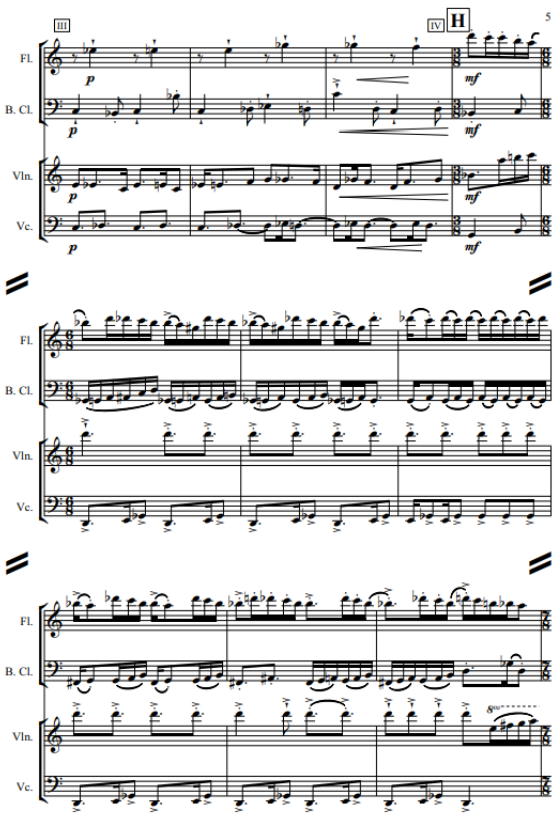
# Appendix 3

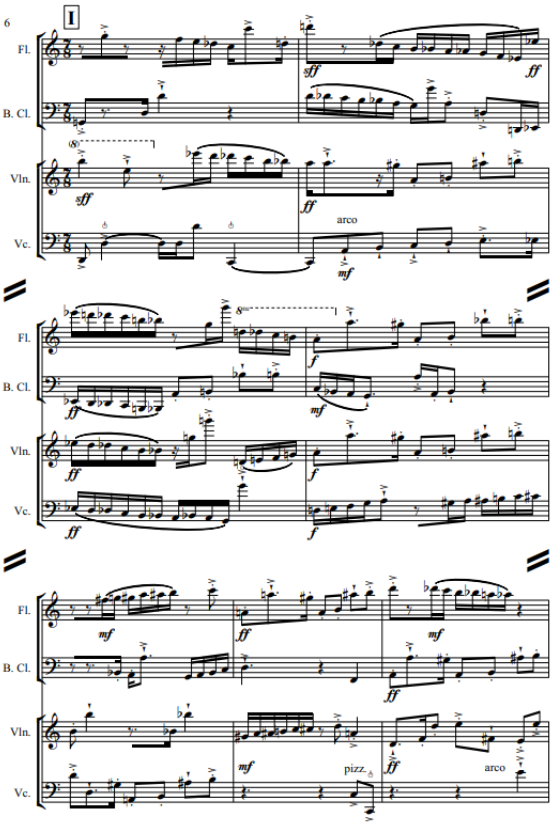
Score of Hiccup Hocket

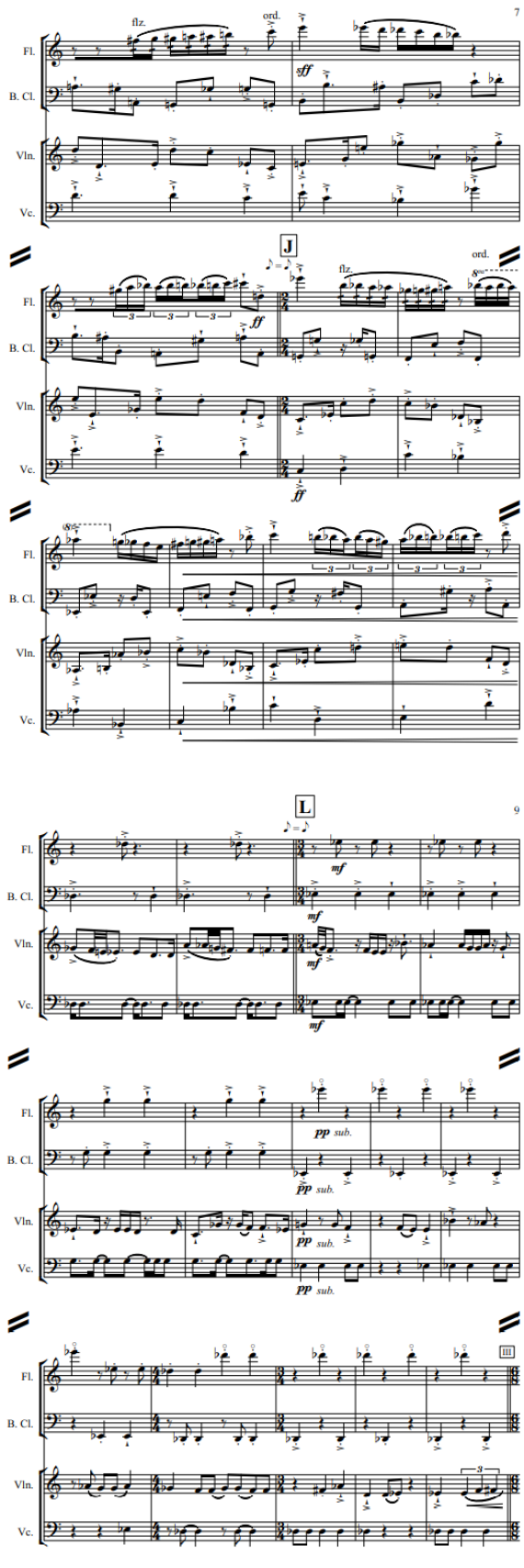


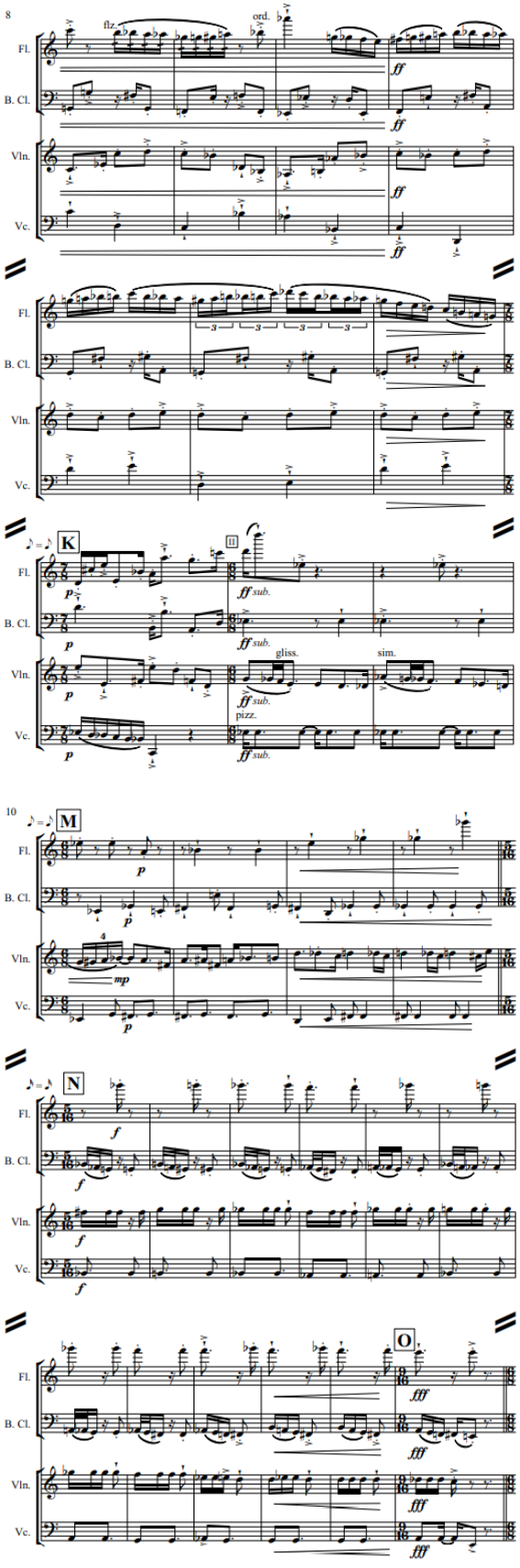

D
E
Fl.
B. Cl.
Vln.
Vc.

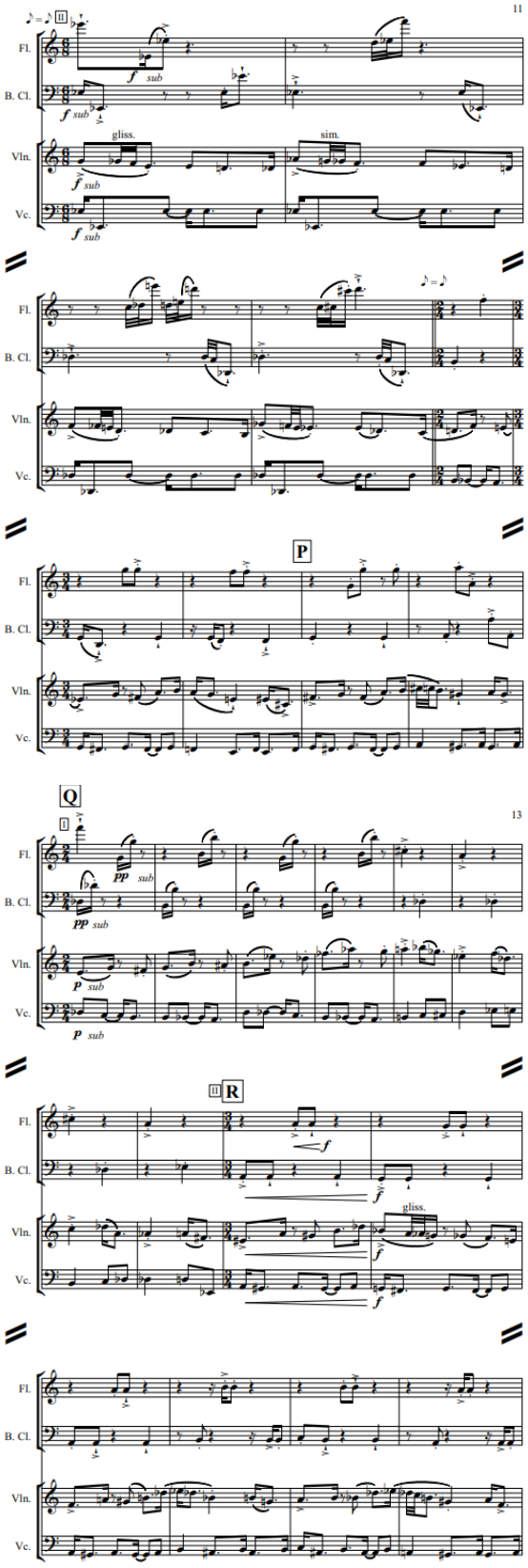

F
G
Fl.
B. Cl.
Vln.
Vc.

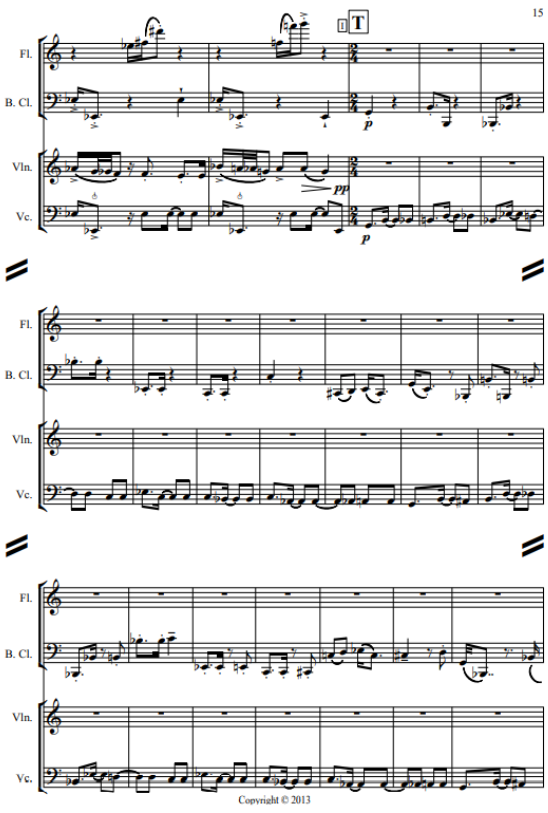

H
Fl.
B. Cl.
Vln.
Vc.

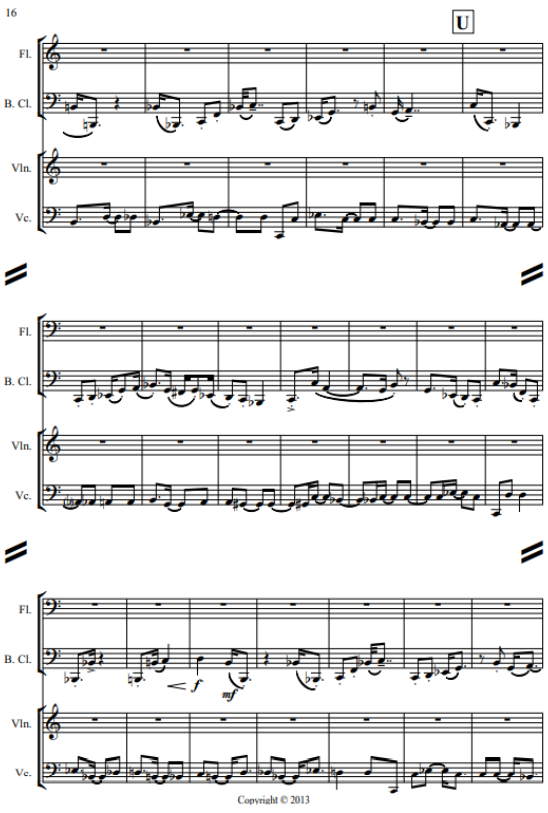

I
arco
pizz.
arco
Fl.
B. Cl.
Vln.
Vc.

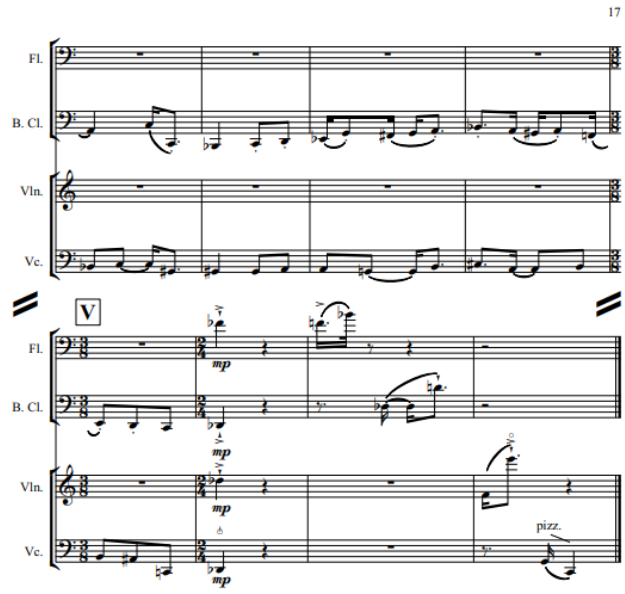

7
flz.
ord.
Fl.
B. Cl.
Vln.
Vc.
sff
J
ff
8
L
mf
9
pp sub.
III


8
flz.
ord.
Fl.
B. Cl.
Vln.
Vc.
ff
K
II
ff sub.
gliss.
sim.
pizz.
10
M
N
O
fff


11
Fl.
B. Cl.
Vln.
Vc.
gliss.
sim.
P
Q
R
12
13
14
S


15
T
Fl.
B. Cl.
Vln.
Vc.
p
pp
p
Copyright © 2013


16
U
Fl.
B. Cl.
Vln.
Vc.
f
mf
Copyright © 2013


17
V
Fl.
B. Cl.
Vln.
Vc.
mp
pizz.