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Composing with Abstract Algorithms and Dynamical Systems: Nonstandard Sound Synthesis as a Conceptual and Compositional Framework

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1. Introduction

This thesis aims to present a particular approach to algorithmic composition and performance of computer music, and show a common line between the author's conceptual framework and that underlying the work of the composers of so-called 'non-standard synthesis' (the term will be specifically defined in the second chapter).

A certain vision of composition and performance as an experimental activity linked to a certain vision of technology, seen not so much as a pre-defined object destined for certain functions but as a dynamic object to be defined and transformed, will be presented here.

The second chapter of the thesis will deal in detail with the conceptual framework of 'nonstandard synthesis' by comparing the artistic positions of the members of the 'nonstandard synthesis' experiments of the 1970s and the author himself, attempting to clarify the common points and concepts underlying the compositional activity.

The third chapter will discuss the author's compositional framework in detail, clarifying the aesthetic motivations in the use of two particular classes of models for algorithmic composition (abstract algorithms and dynamic systems) and the particular possibilities of interaction they offer from a critical perspective.

2. Conceptual Framework

2.1 Role of Technology, Nonstandard Synthesis, Experimental music

The research I intend to conduct rejects the conception of technology and technological means as neutral to artistic creation, but rather seeks to intensify and explore their interaction: the development of the technology involved thus becomes an indispensable part of artistic practice. This process takes place in the same spirit as the so-called 'nonstandard synthesis' experiments of the 1970s (Holtzman, 1978), articulated artistic positions in which 'the interdependence between the means used and the possible artistic and aesthetic ideas' is an essential aspect (Döbereiner, 2011) and the development of models of sound production coincides with the development of models of musical organisation. In the artistic practice presented here, technology is not "merely a means to realise a preconceived goal", but must "be determined, defined" (Döbereiner, 2011). Considerations and reflections on the technology employed, therefore, occur at every level of the musical composition process and the medium becomes an object of exploration in which the musical organisation is the result of its singularities. I am convinced that the practice of developing the technology used to compose forces one to reflect on one's own compositional practice and as composer and theorist Agostino di Scipio states his 1998 article '*Cognitive Relevance of Music Technology*' in 'Questions Concerning Music Technology':

> 'Artistic concepts are born while acting upon materials and designing the techniques of art. Acting within and upon the available or specially designed tools may even dissolve pre-existing concepts or ideas: moving to the technicalities unveils the unreal, metaphysical purity of a given musical idea, as well as the very theoretical assumptions behind it. That is the way composers question their material and, hence, enrich their language.'

In the artistic practice presented here, the conceptual does not necessarily come before the perceptual but rather a dynamism is established between the two, a relationship that the artist continually transforms and that transforms the artist: ‘i.e. forcing her/him to interrogate experience’ (Di Scipio, 1998).

Particularly in my research as the 'nonstandard synthesis' experiments mentioned above, there is an attempt to create an idiomatic aesthetic of computer music. It is an attempt to make the specificity of computation an 'object of composition' (Hoffmann 2009), ‘to hear that which could not be heard without the computer, to think that which could not be thought without the computer, and to learn that which would not be learned without the computer’ (Berg 1979). So what makes this aesthetic idiomatic to computer music? What underlies it is the digital nature of the computer, the fact that sound can be represented in a stream of digital samples each encoding the sound pressure value as a digital binary number. Instead of processing existing sounds or simulating conventional sounds Koenig, Berg, Brün, Xenakis and others exploited access to the micro-temporal dimension of the samples with an experimental approach. The attitude towards technology in this sense can become 'heretical': the intention is to adopt a misuse of technology in relation to its original conception, a reinterpretation. In this sense, following a tradition that has its origins in the 1940s and 1950s with the 'Musique concrète' in France and the Cologne School in Germany, where instruments intended for control and measurement were used as tools for artistic production. Technology became an object of re-interpretation and lost its status as an object with a pre-determined function. The same will that gave rise to different types of approaches in the history of electronic music such as the first forms of live-electronics, in which there was an intention to bring the instruments used in the studio to the stage. Karlheinz Stockhausen in the introduction to ‘Mikrophonie I’ writes:

> ‘The microphone has, up to now, been treated as a lifeless, passive recording instrument for the purpose of obtaining a sound playback that is as faithful as possible: now it also had to become a musical instrument, and to be used in turn to affect every aspect of sound (Stockhausen 1964, pp. 9).’

The aesthetics proposed by the composers of 'non-standard synthesis' do not aim at a 'humanisation' of technology, but rather to show its cruder mechanical nature, to show its specificities. This kind of vision is called 'Explicit Computer Music' by Paul Hoffman in 'Music Out of Nothing? A Rigorous Approach to Algorithmic Composition by Iannis Xenakis", as opposed to "Disguised Computer Music" in which one wants ‘machines to do what humans do’ (Hoffmann 2009). My artistic practice similarly presents the sonic ideal of 'Explicit Computer Music' and a 'heretical' approach to technology.

Julius O. Smith in his article 'Viewpoints on the History of Digital Synthesis' in Proceedings of the 1991 International Computer Music Conference gives an overview of the development of digital synthesis techniques up to that time, proposes a classification of digital synthesis techniques, and indicates future trends. In this article, an objective emerges in the design of digital sound synthesis systems: the intention to realise technologies that can recreate what is pre-existing and expand its possibilities. The author, quoting Computer Music pioneer Max Matthews, writes that since the dynamic range of hearing and the bandwidth are bounded we can produce any perceivable sound and the fundamental difficulty becomes ‘finding the smallest collection of synthesis techniques that span the gamut of musically desirable sounds with minimum redundancy (Smith 1991). This defines a common intention in the past and future of digital synthesis algorithm design and the natural need for a generalisation, for a model where ‘a large number of samples must be specified or manipulated according a much smaller set of numbers’. In particular, it emerges that what the standard is, and will be, are models based on principles of mathematics, acoustics and psychoacoustics. About twenty years prior to this classification, independent composers experimented with various synthesis techniques, experiments termed 'nonstandard synthesis' (Holtzman 1978). The term 'nonstandard' refers to the fact that these sound synthesis experiments were based, according to Steven R. Holtzman, on compositional processes rather than on a 'superordinate model', and in this sense my artistic practice also falls under this term.

> ‘The nonstandard approach, given a set of instructions, relates them one to another in terms of a system which makes no reference to some super-ordinated model, […] and the relationships formed are themselves the description of the sound (Holtzman 1978, pp. 53-61).’

Steven R. Holtzman in his article ‘*A Description of an Automatic Digital Sound Synthesis Instrument’* names Herbert Brün, Gottfried Michael Koenig and Iannis Xenakis among the various composers belonging to 'nonstandard synthesis'. In particular, this change of perspective implies that the composer also becomes responsible for the design of sound synthesis systems. This fact leads to a different necessity in approaching system design than that of finding the smallest collection of synthesis techniques that cover the range of musically desirable sounds: that is, narrowing down the range of possibilities and designing systems for the purposes of one's own artistic ideas. In an article dated 1970 entitled 'From Musical Ideas to Computers and Back', composer Herbert Brün states:

> ‘The composers, having all at their disposal, have to create and to define the subsystem in which they want their musical idea to expand into a musical event. They have to learn how to think in systems, how to translate ideas and thoughts into network systems of interlocking and mutually conditioning instructions, statements, stipulations and equations. (Brün 1970, pp. 9)’

The ‘nonstandard synthesis’ techniques share the goal of ‘composing timbre, instead of with timbre’ (Brün, 2004) and unifying ‘the macrostructure and microstructure of compositions, opening an experimental field in sound synthesis’ (Luque, 2009). Taking as an example the case of G. M. Koenig and his composition programmes developed in the 1960s and 1970s, called Project 1, Project 2 and SSP, and that of Herbert Brün and his computer music system SAWDUST created in 1976, for example, musical composition takes place at the micro-level of individual samples, which define ‘waveform in terms of amplitude values and time values’ (Roads, 1985), and eventually large-scale musical structures are constructed (Roads, 1985): timbre thus emerges "from sound design processes at the microlevel (Di Scipio, 1994)”.

The idea of timbre composition by 'non-standard synthesis' composers could in a way be seen as a development of the vision on electronic music of some important members of the so-called Cologne School, with which the mentioned composers shared several ideas. In 1953, the then director of the Studio for Electronic Music of the West German Radio in Cologne Herbert Eimert, speaking about electronic music in an article for the music magazine Melos entitled "Was ist elektronische Musik?", wrote:

> ‘[…] (elektronische Musik ist) der Weg, den entlang man zu gehen hat, um ins Zentrum der gleichsam bis in den innersten Kern aufgeschlagenen Klangmaterie zu gelangen. [[…](electronic music is) the path along which one has to go in order to reach the centre of the sound matter that has been opened up, as it were, to the innermost core.] (Eimert 1953, pp. 2)’

In an article entitled *‘Experimental Music’*, which first appeared in *The Score* and *I. M. A. Magazine*, London, June 1955 John Cage gives a definition of the term ‘experimental’ in music, affirming that:

> '[...] and here the word “experimental” is apt, providing it is understood not as descriptive of an act to be later judged in terms of success and failure, but simply as of an act the outcome of which is unknown'

The conscious choice of the mentioned composers to develop algorithms that are not based on the principles of the types described indicates an experimental practice that aims, indeed, at not predicting the outcome in terms of results, where the computer plays a central role as it proves to be a chosen tool to achieve unforeseen results. The central idea in Smith's vision is to model the sound source or its effect, and this implies a desire for prediction. It is therefore useful for a technique to be 'intuitively predictable', particularly when it intends to recreate what is pre-existing, when it intends to imitate and exploit analogies 'with well-known musical instruments, familiar sounds from daily experience, or established forms of communication' (Smith 1991). In Smith's classification, however, there is a category that is not based on mathematical, acoustic, or psychoacoustic models: processed recordings. Even if they do not address such models, they usually intend to imitate something pre-existing, such as samplers that 'try so hard to imitate existing instruments'. The approach of the 'nonstandard synthesis' experiments was completely at odds with the idea of imitation. Gottfried Michael König stated in an interview with Curtis Rhoads in 1978 that he was annoyed by composers using new modern technologies to create dodecaphonic series or to 'imitate existing instruments'. Once again, the experimental approach of the two composers could be seen as a development of a certain type of thinking from the Cologne School. Herbert Eimert in his article 'Was ist elektronische Musik' refers to a certain approach to the novelty brought by analogue electronic music:

> 'man kann auf elektronischem Wege die bisherige Tonwelt imitieren, und man kann mit dem elektronischen Mirakel eine neue, sozusagen paramusikalische Klangwelt erschließen, von deren ungeheuerlichen Dimensionen wir jetzt gerade den ersten Begriff gewinnen. Es wird richtig sein, wenn man sich darauf einigt, allein diese neue Klangwelt als die der "elektronischen Musik" zu bezeichnen. [It is possible to imitate the previous world of sound electronically, and it is possible to open up a new, so to speak paramusical world of sound with the electronic miracle, of whose monstrous dimensions we are just now gaining the first concept. It will be correct if we agree to call this new world of sound alone that of "electronic music".] (Eimert 1953, pp. 1-2)'

In the same spirit, many years later, 'non-standard synthesis' composers approached the potential of digitally composed sound. Of particular interest is the example of composer Iannis Xenakis, who theorised the implementation of stochastic functions to synthesise sound. His research, which began in the 1960s, saw results in compositions such as 'La Légende d'Eer' (1977) and 'Cluny' (1972). In 'Formalised Music: Thought and Mathematics in Music' we find:

> 'In fact within human limits, using all sorts of manipulations with these grain clusters, we can hope to produce not only the sounds of classical instruments and elastic bodies, and those sounds generally preferred in concrete music, but also sonic perturbations with evolutions, unparalleled and unimaginable until now. The basis of the timbre structures and transformations will have nothing in common with what has been known until now (Xenakis 1992, pp. 47).'

The classification of Julius Smith of digital synthesis techniques consists in four categories: processed recordings, abstract algorithms, spectral models and physical models. Methods of "nonstandard synthesis," such as the methods employed in my research, belong according to Julius Smith's taxonomy to the category of abstract algorithms, methods that according to his predictions will disappear. According to Smith's taxonomy, the synthesis techniques that belong to abstract algorithms are: VCO, VCA, VCF, some Music V, Original FM, Feedback FM, Waveshaping, Phase Distortion. According to Smith, as the category of processed records will also lose importance, being absorbed by spectral modelling, the only categories that will remain will be those of physical modelling and spectral modelling (Smith, 1991). Thirty years after this article, however, we can say that digital synthesis methods based on abstract algorithms have not lost importance as predicted by Smith, but rather "are widely used in a wide range of musical styles and are still being implemented, developed, and integrated into new software systems" (Döbereiner, 2010). My work, like 'nonstandard synthesis' experiments, implies a reluctance towards synthesis methods that simulate the sound source or its psychoacoustic by-product as accurately as possible, in favour of the experimentalism expressed here. This means a rejection of spectral modelling synthesis (SMS) methods that are based on signal models in the frequency domain, since the parameters of spectrum analysis are in this case closely related to the characteristics of hearing, as Julius Smith suggests in his 2011 book 'Spectral Audio Signal Processing', the ear can be seen as 'a kind of spectrum analyser' and spectral models therefore 'are well matched to audio perception'. And, in addition there is also a move away from Physical Modelling Synthesis (PMS) as, by definition, it is an imitation of pre-existing behaviour, i.e. imitation of the sound source. Here the model is usually a set of mathematical rules describing the interaction of the individual parts, hence it is often called a 'mathematical model’. My position, however, does not exclude the use and development of signal analysis and transformation methods that are unusual combinations and alterations of 'standard' synthesis methods, if the attitude towards the sonic result remains non-predictive.

2.2 Listening, Communication and Society

In the article 'Models of Constructed Sound: Nonstandard Synthesis as an Aesthetic Perspective', composer Luc Döbereiner intends to defend the positions of 'nonstandard synthesis' composers against what he reports as 'stigmatising criticism that regards these techniques as purely speculative, far removed from empirical reality and negligent of the perceptual effects of their audible output'. Luc Döbereiner argues that they not only offer profound and radical views on composition, technology, society but also on listening and communication. The experimentalism expressed above by non-standard synthesis composers is a natural consequence of their desire to actively change the listening habits of the listener rather than pure speculation, since acting predictively to 'tune the music with the receiver' is nothing more than 'a strategy of preventing change of habits’ (Döbereiner 2011). In the specific cases of G. M. König and Herbert Brün, their aesthetic positions reflect an experimental attitude that wants to achieve another kind of listening: it requires listening to the algorithms and processes of the sound generation. In the introduction to an article published in 1985 entitled '*Composers and Computers*' Curtis Roads states:

> 'In keeping with the tradition of experimental music, both Koenig and Brün have at times cultivated a detached attitude toward the audible result of their composing labors. They concentrate on the generative system; the sound produced by it is a by-product. For this reason, their music calls for a different kind of listening, based on attention to musical algorithms and processes. (Roads 1985, pp. 15)’

In König's case, what was more precisely being sought was an approach defined by him as 'objective' to electronic music, a minimisation of his own influence on it in favour of music that could say 'something about the sound generator' (König 2014). The profound aesthetic reflections of these composers thus lead not only to new compositional models, but also to new ways of listening to music, the exact opposite of neglecting the perceptual effects of music production, where listening is closely connected with specific ideas of music and art in society. In Brün's case, the experimental approach and his attempt to create new ways of listening to music is part of a broader reflection on communication, where the central concept is defined as 'anticommunication'. This concept is described in various lectures and texts by Herbert Brün. It could be described as the 'attempt to say something through a channel which is not yet available' where the 'meaning assignment' is delayed. This delay in the assignment of meaning is described by Herbert Brün in his 1972 essay entitled '*For Anticommunication*' in the same way as 'an offspring faces its progenitor' and the 'offspring eventually will in turn become a progenitor'. The situation created by this delay allows, according to Brün, the possibility of creating non-trivial connections to occur. 'Anticommunication' is thus something very different from non-communication, where there is no intention to communicate, where the message is not understood, it is:

> 'an attempt at saying something, not a refusal of saying it. […] The syllables "anti" are used here as in antipodes, antiphony, antithesis; not meaning "hostile" or "against" but rather "juxtaposed" or "from the other side". […] Communication is achievable by learning from language how to say something. Anticommunication is an attempt at respectfully teaching language to say it. (Brün 2004, pp 3)'

'Anticommunication' is therefore at the antipodes with the aims of 'tune the music on the receiver', it has rather the intention of creating a disturbance, of provoking a structural change, a novelty, aware that this novelty will be meaningless at first. This concept in Brün's thinking is part of a broader vision regarding the function of art in society, and a vision of a utopian future society. In his 1970 paper 'Technology and the Composer' he writes:

> ‘I challenge technology to escalate its push towards a socially beneficial technological era by designing and constructing for all of us the compound facility wherein and wherewith many people can be induced to come and enjoy the effort of learning how to compare and measure their languages against and with their imagination and their desires. […] Language is not the standard against which thinking is to be measured; on the contrary: language is to be measured by a standard it barely reaches, if ever, namely the imagery of human doubt and human desire. To measure language, with imagery as a standard, is the function of art in society. The arts are a measuring meta-language about the language that is found wanting. (Brün 2004, pp. 6-8).’

In the case of Xenakis, although we still have the same experimental approach and the intention to create new ways of listening to music, the conceptual framework is totally different. In Xenakis' music, sound is understood as an energy that transforms over time, that changes form, state, domain like ‘a sort of fluid spanning through time’ (Xenakis 1985). This vision allows in an operational sense to identify music with phenomena of nature, of physics in terms of energy, and to use models of these to compose. However, the approach to these models is experimental rather than imitative in nature, as ‘it consists of doing like nature, not of re-doing what it already does (Mâche, 1998, p. 79).’ Xenakis intends, through a process of abstraction, to reveal in music the processes and patterns that govern the universe. The mathematical language is the one used to implement the abstraction and transfer of energy in the various domains. In addition to the mathematical aspect, there is another equally important one for understanding his music: the desire to question nature and the universe and their secrets that 'evade human understanding', a 'dyonisiac' aspect (Duhautpas, Meric, Solomos 2012). Xenakis therefore intends to create a way of listening to music that is physical, bodily, that provokes the listener on a sensitive level through movements of energy, ‘Like alcohol. Like love.’ (Xenakis, 1987). Unlike Herbert Brün, here music is not thought of in terms of language or meta-language but rather tries to escape the linguistic model ‘in favor of a conception of music as an “energetic” and “spatial” phenomenon’ (Duhautpas, Meric, Solomos 2012, p. 1), as a force of nature. Xenakis in a way also accepts the possibility of eventual non-communication in his music. This process does not happen by direct intention, but is a necessary consequence of the desire to do something ‘interesting’ and ‘different’, with the risk of not being ‘understood or appreciated by lots of people’ (Xenakis 1992). In an interview at the Delphi Computer Music Conference in 1992, he clearly explains what he expects from the audience, reporting that the interest of a certain artistic experience is fully the responsibility of the audience, one is not 'responsible for what has been done' and that he is not interested in 'what they think'. There are many different types of audiences and it is not possible to 'make a statistic' nor is it the right way to write 'specific music' for a specific audience. His disinterest in the listener's reactions should not, however, be confused with a disinterest in creating an artistic experience that has an effect on the listener. For Xenakis, music is in fact a medium that stimulates ‘like a crystal catalyzer’ in the listener processes that pre-exist the music itself. He intends to provoke and provide the material for the listener to experience something of himself (Xenakis 1978).

In my compositional work, I relate to the reaction of the audience in a way not unlike the composer Iannis Xenakis. I am convinced that art, as described in the first chapter, has a transformative power and that in order to achieve a certain intensity, it must not compromise on this level. In my case, experimentalism becomes necessary to provoke a transformative experience. My work differs in some respects from the examples of 'non-standard' synthesis described in this thesis on a purely aesthetic level. While I share the premise of 'non-standard' synthesis to create an idiomatic computer aesthetics, the mode of listening that my aesthetics intends to propose is in no way that of active listening to algorithmic or computational processes. This aspect is common to almost every composer mentioned in this thesis with perhaps the sole exception of Xenakis. The most extreme case in this direction, as Peter Hoffmann points out in 'Music Out of Nothing? A Rigorous Approach to Algorithmic Composition by Iannis Xenakis', is that of the so-called ‘school’ of Utrecht. Berg and Holtzman's composition practice can be seen as a kind of 'programme audification', a common practice today to help a programmer find bugs or anomalies in a complex software system. Program audification' is a kind of attempt to make a computer programme sound (Hoffmann 2009). A recurring pattern in approaching the possibilities offered by computation (and technology more generally) is what can be formulated with the sentence 'making the impossible possible'. In computer simulation in science, this has often been expressed in the practice of realising algorithms by means of mathematical models that express situations otherwise impossible in the physical world. We can also find experiments in this direction in the field of physical modelling synthesis: by means of mathematical models, we can hear, for example, what a simulation of a 500 km long tube or a miniature piano sounds like. In particular, I believe that the concept of 'possible' and 'impossible' often defines what becomes to idiomatic to means used: when the medium considered becomes the only possible way to achieve a certain result, that result becomes idiomatic to the medium considered. The possibility of composing music by acting on individual samples, unique to computers and hitherto impossible, led to the fact that the aesthetic results of 'non-standard' synthesis were idiomatic to computation. We can imagine an alternative group of composers composing music made with algorithmic simulations of musical instruments as large as entire cities as another possible idiomatic outcome to computation. In artistic terms, a vision implies operational possibilities that have aesthetic consequences on the result, so it is important to specify in which direction this 'impossibility' is sought. In the latter example, we can consider this 'impossibility' as an 'increased possibility', whereas in the case of 'non-standard' synthesis, an attempt has been made to achieve a result that has nothing to do with what was previously possible, a ‘contrast’ to the sound of vibrating bodies or analogue electronic music. The main parameter that artistically defines this is therefore not what is now possible with what was previously 'impossible', where the only limit in our case might be one's own imagination (or computational resources), but rather the way this relates to what was possible, to what is 'familiar'. Over time, the perception of certain types of sound or aesthetics changes: what was not part of reality becomes part of what is 'possible' and 'familiar'. The desire to create aesthetics and music that suggest active listening to algorithmic and generative processes with time stops being an experimental act and becomes part of a well-defined historical and artistic context. With my work I try to create an idiomatic aesthetic of computer music that is also an act of experimentation. The possibilities of 'augmenting' physical reality (as in the example expressed above) or being in ‘contrast' to it (as in the 'non-standard' synthesis described so far), are not the only possibilities unique to computation to relate to reality.

In my work I aim to create a singular perceptual dimension that does not imitate the resonant bodies of the physical world and is not intuitively relatable to the ‘now familiar' artefacts of digital synthesis, a dimension that on a perceptual level contains elements of both but belongs to neither. This is done by means of abstract algorithms that, among other things, also control elements and components usually used to algorithmically simulate resonant bodies, acting with an experimental attitude on parameters that, when listened to, provoke possible, unpredictable, vague, indirect connections with the physical world.

2.3 Material, Form, 'Sonological Emergence’

In non-standard synthesis works, the production of sound becomes the compositional activity itself: there is the intention to unite the ideas of sound and the ideas of music. In a 1970 text called 'From Musical Ideas to Computers and Back', composer Herbert Brün describes the new possibilities of computers, in particular the possibility of using a ’combination of analog and digital computers and converters for the analysis and synthesis of sound’ (Brün 2004). This technology according to him provides the access point to be able to scan and register even the 'most complex waveforms in the audio frequency range’, but above all it allows ‘the composition of timbre, instead of with timbre’. Digital representation is thus seen as the key to a temporality hitherto inaccessible, to a "different scale" where timbre can be composed by operating directly on samples which are seen as acoustic atoms. A large quantity of such atoms would thus be used for the formation of structures of musical interest, or of the entire composition. Some of these 'nonstandard synthesis' approaches operate directly on the sample level, without requiring the formation and organisation of intermediate structures. This is the case with Paul Berg and Steven R. Holtzman and techniques called 'Instruction

Synthesis' by Curtis Roads (Roads 1996), where they applied logical and arithmetical operations on binary numbers to produce sound. The 'timbral meaning', however, only emerges when a large number of samples are ordered, so most 'nonstandard synthesis' composers found the most natural way to handle 'musical grains' rather than individual samples. In handling and ordering these grains, each composer developed his own modus operandi. Gottfried Michael König applied serial composition techniques to groups of samples that formed waveforms, in Brün's case they were abstract operations on waveforms and in Xenakis they were stochastic processes that decided the shape of a waveform. The procedures to bring order to the large number of samples needed to create musical structures of aesthetic interest therefore needed theories that did not start from notions of acoustics or psycho-acoustics but rather from notions of musical organisation, from 'possible theories of sound' where 'one explores them, and learns how they can mediate the sonic structure' (Di Scipio 1994). Each composer of 'nonstandard synthesis' thus elaborated his systems into new models and theories of sound, according to his own aesthetic position. We can take the examples of Iannis Xenakis and Gottfried Michael König as opposing aesthetic positions that led to different theories of sound and approaches. In particular, from a historical point of view, we can observe the two responding differently to a problem of their time: the perceptual complexity of serialism, which reigned in much of contemporary music. Koenig designed the computer programme PROJECT I to experiment with the perceptual results of the structures generated with his models through an empirical 'trial and error' approach:

> 'The basic idea was to make use of my experience in serial music and also the aleatoric consequences drawn from serial music. I tried to describe a model in which certain basic decisions were described, and where besides that the user-the composer would have some influence over the musical variables. In that way you could ask for any number of variants which would evolve from the same basic principle; you could compare them and see to what extent the musical characteristics laid down in the program were really experiencable in music. (König and Roads 1978, pp. 12)'

In the case of Xenakis, the problem of the perceptual complexity of structures generated by the processes of serialism leads to a new theory of sound, I refer to the theory of sound in terms of 'sound quanta', closely linked to the laws of stochasticity. After an initial curiosity towards serialism, Xenakis, like many other composers of his time, took a critical stance towards it. Xenakis' response to serialism is the use of stochastics in music, which saw its most direct expression in computer music works where ‘the laws of the calculus of probability entered composition through musical necessity’ (Xenakis quoted by Di Scipio 2012, pp. 2).

> ‘Xenakis viewed the principles of rigourous serial composition as a particular instance of combinatorial calculus, resulting mostly into sonic structures that human perception could only grasp statistically. That way – argued Xenakis – the linear polyphony that serialism was born of, in actuality collapsed because of the sheer complexity achieved (Di Scipio 2012, pp. 2).’

The composer was opposed to the idea of using sums of electronically generated sine waves as a starting point and was always uninterested in the early work in the Cologne studio, as well as in the early computer music experiments that showed this approach. This approach starts from the harmonic paradigm of Fourier analysis where 'all sound is an integration of a large number (ideally an infinite number) of circular functions (sine and cosine)' (Di Scipio 2012), and in an operational sense the model suggested an 'impasse of harmonic analysis' (Xenakis 1992, p. 243). For Xenakis, this model did not provide the key to access a certain dynamic richness present in nature, that of non-periodic signals, which in Fourier theory are borderline cases. It therefore became natural for Xenakis to think of starting from non-periodic signals, from situations of non-order, and to develop strategies to achieve degrees of order. In order to do this, it is therefore necessary to represent sound differently, not using circular periodic functions but rather finite-time functions, thinking of sound therefore as 'decomposed into tiny acoustical atoms'. Where a large number of these atoms go to form 'a variety of lively, internally rich sound materials, ideally ranging from noise to periodicity' (Di Scipio 2012).

Iannis Xenakis talking about his composition Gendy3 in the interview at the Delphi Computer Music Conference/Festival in 1992 moves attention to a particular phenomenon:

> ‘About phrasing and things like that, they have to be part of the mathematics. If you heard phrasings, I didn't do anything at all […]. I thank you that you have heard that, because that's an important feature of it. It's not produced by any kind of pianissimo or something like that, the evolution of pitch and so on. It's directly taken from the result of the probability functions (Xenakis 1992).’

The particular phenomenon is that the macroscopic temporal and dynamic structures of composition are derived from the rules applied to the microscopic structures of composition: macro-composition is a by-product of micro-composition. The potential therefore appears for music in which macro-level structure and micro-level structure can be modelled by means of same rules, they become inseparable. Music and sound can be articulated virtually by a single compositional process. This phenomenon is by no means unique to Xenakis but we find it in several 'non-standard synthesis' techniques of different composers. A radical case is certainly that of Holtzman and Berg with their 'Instruction synthesis' techniques, where this aspect depends not only on the algorithm but also on the hardware used since the sound depends directly on the timing of the instructions and the internal clock frequency of the computer. In the literature of Computer Music, this concept is first described by composer Agostino Di Scipio as 'Sonological Emergence’:

> ‘In much the same way as subsymbolic paradigms of cognition try to capture how sensorial data are mentally pre-processed to constitute a symbol, and then how symbols are treated as components of higher forms of organization, a holistic approach to composition - understood as a theory of sonological emergence - may find it appropriate to describe its models of sonic design in

terms of subsymbolic processes yielding the musical structure we experience by listening (Di Scipio 1994, pp. 207).'

The concept of 'sonological emergence' has entered my compositional practice naturally over time in order to create musical macro-structures used in my compositions, given my particular aesthetic interest in certain temporal morphologies obtained from this generative approach. In my work, in addition to an approach of a generative nature, there is a process of recomposition of material that is not present in historical examples of 'non-standard synthesis', a less pure and somewhat more traditional approach that moves away from the intention of proposing musical form as pure algorithmic generation. In a perspective where the real material to be composed is not so much the sound itself, but the relationships that constitute the perceptual context that is created.

2.4 Models of Reality, Models of Composition

Central aspects of my compositional practice include my approach from an 'operational' point of view to the notion of model, how the model relates to physical reality and how this relationship conditions the aesthetic outcome of my work. We can define the term model as a systematic description of an object or phenomenon, which can be understood in different forms such as: visual representation, mathematical formulation, theory or algorithm. The definition of 'non-standard' synthesis, as expressed in the first part of this thesis, implies an aesthetic choice with respect to the use of the models one works with, a choice that was probably the reason why, as Luc Döbereiner states, for years these experiments were labelled 'purely speculative' (Döbereiner 2011). The lack of a direct correlation with the physical world, the absence of a physical reference to reality in the models on which the algorithms for composing were based, was probably the reason for considering the 'non-standard' compositional models as results of pure speculation: as purely abstract and unrelated to physical or psycho-acoustic principles. Musical composition, however, does not have the function of representing aspects of reality, but rather that of creating an aesthetic experience. From this point of view, the model can therefore become the means or the basis of the means to create this aesthetic experience.

> ‘Models allow a very particular access in that they define operations. These operations, however limited they might be are fundamental to the composition process. In nonstandard sound synthesis the model is also a model of composition, or at least forms the basis of models of composition (Döbereiner 2011, p. 34).’

The model in ‘nonstandard’ synthesis is thus seen in an 'operational' sense, in the sense that it suggests or consists of operations, which have aesthetic consequences. Continuing in this logic, the formulation of 'possible theories' can become as valid as theories describing physical reality, or models describing other fields as valid as those describing sound. The particular case of Xenakis highlighted before shows the example of how a 'possible theory’ is the opening of a real aesthetic horizon. It is logical following this thought that the formulation of a 'possible theory' starts from an aesthetic problem and not from the need to explain physical reality. In the case of Xenakis, the aesthetic problem consists of the possible musical results derived from the synthesis based on the Fourier theorem: the Fourier theorem that proves valid for describing an acoustic phenomenon is not in Xenakis' view a valid starting point for generating an aesthetically relevant experience. In the article '*Stochastic and granular sound in Xenakis' electroacoustic music*', composer Agostino di Scipio describes the 'possible theory' devised by Xenakis underlying his stochastic synthesis techniques as the fact that all sounds are nothing more than combinations of a number of appropriately arranged grains in time, formed by "replacing timeless circular functions with time-finite functions" to obtain “a variety of lively, internally rich sound materials, ideally ranging from noise to periodicity" (Di Scipio, 2012). From the point of view of the model as 'operational', even the classical concepts of algorithm optimisation lose their meaning, e.g. a more faithful representation of a mathematical model conceived at the beginning does not necessarily imply a more aesthetically interesting result. Furthermore, optimisation often implies an ideal solution in a quantitatively well-defined sense, which in this case cannot be defined, since what is sought is a possible aesthetically convincing result through an experimental approach that is not intended to make predictions. Another aspect to point out is that due to the fact that the processes in the micro-structures of sound are so decisive for the macro-structures, classical audio components such as DC blockers or various filters change their function from the one they were created for (‘heretical’ use): a simple low-pass filter in a given context might no longer perform an equalising function, but be an element that leads the system to behave temporally in a totally different way. Even for these components, classical engineering optimisation strategies lose their meaning and I have often implemented unusual combinations of them or de-optimised audio components in my synthesis systems. So how does it become possible to establish approaches if every 'possible theory' is a possibility? In my work, the starting point is a purely technical speculation on abstract algorithms operating in the microstructures of sound, a quest to find mechanisms whose results I cannot predict in terms of sound, and then move on to a purely empirical phase of expecting, listening, verifying and correcting. Through constant exploration and experimentation over time I have found my own strategies to optimise this process. In particular, I am interested in the generative possibility of the model in terms of temporality, focusing mainly on two aspects: temporal behaviour and interaction possibilities.

3. Compositional Framework

3.1 Abstract algorithms

The totality of the sound synthesis systems I use for my compositional work are based on abstract algorithms, where by abstract algorithms I refer to Smith's taxonomy described chapter 2. However, Smith merely gives a list of common abstract algorithms up to that point without giving a specific definition. By abstract algorithms I therefore refer to algorithms where the sound is only generated by elements that are part of the apparatus itself (excluding the category 'processed recordings') and which do not make any kind of prediction by invoking a pre-existing reality (excluding the categories 'spectral modeling synthesis' and 'physical modeling synthesis'). It is important to divide the abstract algorithms I use into two categories: abstract models that work on micro-structures of sound (at the level of individual samples or somewhat larger aggregates of samples, which cause a 'sonological emergence') and abstract models that work on larger structures of about 1-2 minutes (where there is no real 'sonological emergence'). Almost all the algorithms I use in my compositional work belong to the first category. The other category of algorithms departs from the premise of 'non-standard' synthesis, in that the idiomatic possibility of the digital world to work on individual samples, to compose timbre at a microscopic level that is only possible through the use of computation, is not fully exploited. This category in Smith's taxonomy is on the borderline with what is called 'spectral modelling synthesis', these are algorithms that handle harmonic/spectral processes controlled by abstract algorithms based on uncommon generative processes of organising harmony or spectral development over time. Two particular characteristics of the abstract algorithms I use for my composition practice are important to mention: the systems are entirely deterministic and in some cases work with non-stochastic random signals. A deterministic system is one that given a certain value in input will always give the same value in output: no element of chance is involved. The exact opposite of deterministic is stochastic: the same input in will not always give the same output. The term stochastic is often confused with 'random' and here I define the two terms. It is important to distinguish the properties of a process that generates a result and the properties of the result itself: random is a property of the result. We can have a stochastic system that produces a random result or a deterministic system that produces a random result. The term random can be defined without invoking the idea of chance, we can define randomness more intuitively in terms of incompressibility: if it is not possible to describe a sequence of elements in a more compact way and the only possibility is to list the elements one by one, then the output of the system is random. There are several reasons for my choice of using deterministic systems. The first is that it makes it easier to explore the technological medium due to the fact that it allows for a trial and error process in which one can observe the results and they do not change if one keeps the same input unchanged. Secondly, I am particularly interested in certain types of deterministic systems called 'dynamical systems' in which simple sample-level operations create specific structures and phenomena in the musical form. Another reason, which at first sight might seem a contradiction, is that some deterministic systems are unpredictable, and this characteristic relates to the experimental approach described in Chapter 2.

3.2 Dynamical Systems

Part of the abstract algorithms I have integrated into my sound synthesis systems are based on so-called 'dynamic systems', a special case of the so-called ‘complex systems', considering them objects of interest from an aesthetic perspective. In the academic landscape we do not find commonly agreed definitions of ‘complex systems’. However, we can recognise patterns in these definitions, some agreed characteristics. One of them is that it is not possible to encapsulate the system in a few simple equations: often because they are evolving and adaptive. Often non-linear interactions lead the system to unpredictable behaviour, and often all components modify their behaviour in some way while the system is behaving. Moreover, the system is often organised in a decentralised manner: there is no central control. In particular, however, the notion of 'emergent behaviour' is present in all definitions: these are systems composed of a huge number of agents that interact in a non-linear way and lead to emergent phenomena. Later in this chapter, I will describe the notion of non-linearity. ‘Emergent’ are properties that cannot be understood by reference to the sum of the behaviour of individual components of the system or of a small group of individual components: they are the collective result of the whole system. A connection between the notion of 'emergent behaviour' and that of 'sonological emergence' from the previous part becomes intuitable here. Examples of ‘emergent behaviours’ are: hierarchical organisation, information processing and complex dynamics. In particular, the last type of 'emergent behaviour' is what I usually look for in a complex system: the system could change its patterns in time (and space). The particular category of complex systems that I have implemented in my compositional processes is that of so-called 'dynamical systems’. The term 'dynamic' in physics indicates the quality of something that exhibits temporal evolution, in particular referring to phenomena that exhibit patterns of temporal evolution at one time that are interrelated with those at different times. Intuitively, we can define 'dynamical system' as any system that evolves over time according to a well-defined and unchanging rule. By this definition we can consider the synthesis systems of Steven R. Holtzman and Paul Berg described above to be a particular instance of dynamical systems. This definition implies a characteristic: dynamical systems are deterministic (the rule is not changing, the same input will always give the same output), which allows me to devise strategies to understand where to look for an unpredictable result (necessary for the experimental approach expressed in Chapter 2). I will explain later where this unpredictability comes from. The same definition reveals another essential characteristic of dynamic systems: a formulation given by a simple rule can lead to complex behaviour that is difficult to understand, to be solved in mathematical terms with a few simple equations. In other words, with dynamical systems we have very simple formulations for very complex problems. When they are chaotic (I’ll give a definition of chaos later) and in most cases when they are non-linear, these problems have no mathematical solutions: the behaviour of the system cannot be decomposed into a y(t) function of time. A non-linear system (like parts of the dynamical systems I have used, or elements of these systems) is defined as a system that does not satisfy two conditions: the homogeneity principle and the additivity principle. Considering the equation: $f(c * x) = c * f(x)$, the homogeneity principle states that in a non-linear system, given a constant ‘c’, the output is not directly proportional to the input (i.e. that equation is true). The additivity principle states that we can sum the output of two systems and the resulting system will be nothing more than the simple sum of the output of each system separately. In mathematical terms: $f(x1 + x2) = f(x1) + f(x2)$. So how is it possible to study these systems if we cannot solve them? One possible method to study these types of systems is through so-called 'numerical simulation', as these systems are not solvable they provide us with the rules of their time evolution. The strategy is therefore to do computation and observe the flow of the system: start from an 'initial condition' (initial value) and watch what 'orbit' (the outputs list, the ordered sequence of numbers) it produces. In particular, often these systems are studied from a more general perspective by observing the set of ‘orbits’ they produce.

The idea is that, since these systems are not solvable, but provide defined rules of evolution in time, in order to observe the behaviour of this evolution (i.e. what type of ‘orbits’ it produces), one could simply follow the evolution of a single point. That is, actually sit on this chosen point, calculate the output at that point and take a small step in that direction, then recalculate the output at that point and take the next step. Repeating this process means simulating the system. In my work I explored the possibilities offered by two types of dynamical systems, namely 'iterated functions' and systems that can be described in terms of 'ordinary differential equations’ (or ‘ordinary difference equations’), both forms have already been explored in various ways by different composers before me.

3.3 Iterated Functions and Differential Equations

One notable work on ‘iterated functions' (and perhaps the first in the context of computer music) is that in the 1990s by composer Agostino Di Scipio and the so-called Functional Iteration Synthesis. In particular, his work focused on a certain class of functions called 'sine map’ where ‘due to the nonlinear dynamics in the iterated process, time-changing sonorities are synthesized reminiscent of environmental sound events and effects of “acoustic turbulence.” ’ (Di Scipio 2001). In the case of Scipio (as well as many other composers), iterated functions are used directly in the form of oscillators, which is why he is able to clearly describe their sonority. In my work they are used extensively as components of more complex systems, where not so much the sonority is exploited as the temporal patterns they present and their sensitivity to so-called 'initial conditions' or ‘seed’: the so-called ‘butterfly effect’. Let us therefore define what iterated functions consist of. A function is an operation (a rule) that takes an input value and returns a new value, it is therefore deterministic: the output is determined entirely by the input. The iteration of a function can be considered a feedback loop of a function: the output value becomes the new input for the function, which calculates a new output value again.

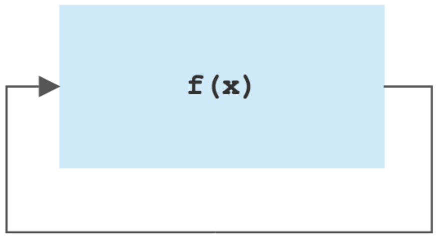


Figure 3.1: iterated function f(x+1) = f(x).

To initialise the flow we have an initial value called a 'seed' or 'initial condition', and the ordered sequence of numbers we obtain as a result of iterating our function is known as an 'itinerary' or 'orbit'. In the iterative process we can have values that do not change when iterated. Taking the function as an example:

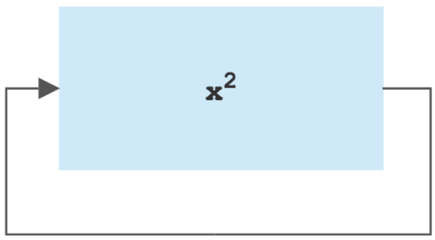


Figure 3.2: iterated function f(x+1) = x^2.

We have that for input values 0 and 1 the resulting orbit shows no variation: f(0) = f(f(...(0)))), f(1) = f(f(...(1)))). Values such as 0 and 1 for the function described are called 'fixed-points'. So-called 'fixed-points' are only one of the particular phenomena that can occur with dynamic systems. Another phenomenon that is particularly exploited in my synthesis systems is that of 'limit-cycles' that occur under certain special conditions. A 'limit-cycle' is an isolated closed 'orbit' of a dynamic system: an oscillation around a ‘fixed point’.

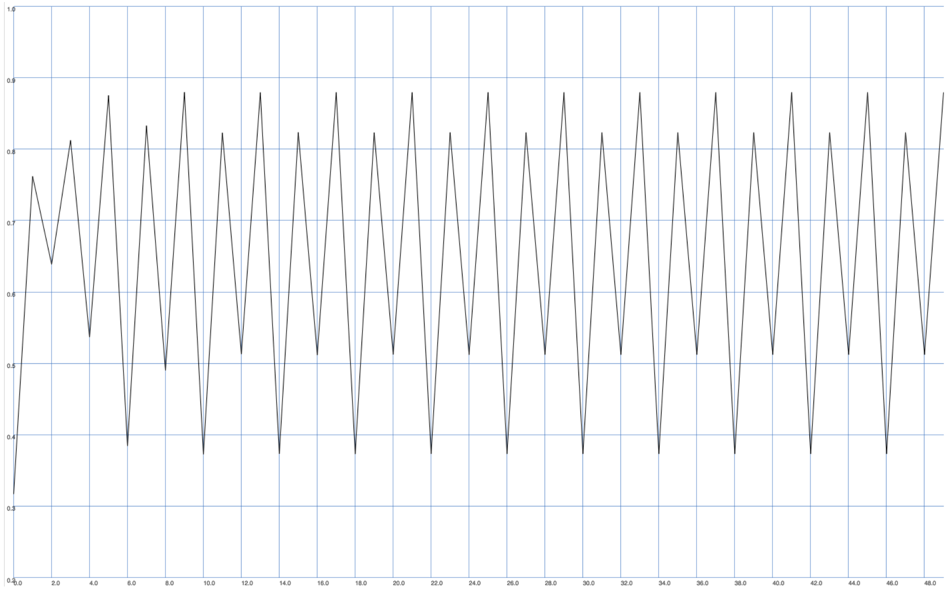


Figure 3.3: limit-cycle behaviour as result of an iterated function.

To show another feature of these systems used in my synthesis algorithms, I will use a well-known example of an iterated function class: the 'logistic map' in the form:

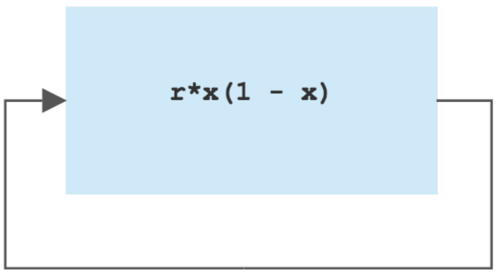


Figure 3.4: the logistic map loop representation f(x+1) = r*x(1-x).

The logistic map is a model that describes the growth of a population at each iteration, or rather a kind of 'caricature' of it: a model that can somehow highlight certain characteristics about the growth of populations, 'useful' rather than 'true'. In this formulation 'r' is a coefficient, called the 'growth coefficient' and 'x' as in the previous examples is the input value. The introduction of the 'growth coefficient' makes the 'logistic map' a set of iterated functions: each with its own 'growth coefficient' rather than a single iterated function as in the previous examples. The 'orbits' of the logistic map at this point differ from each other by two conditions: the 'initial condition' and the

'growth coefficient'; the relationship between the resulting orbits and these two conditions will exhibit a particular phenomenon called the 'butterfly effect'.
Consider the following example of an iterated function belonging to the 'logistical map':

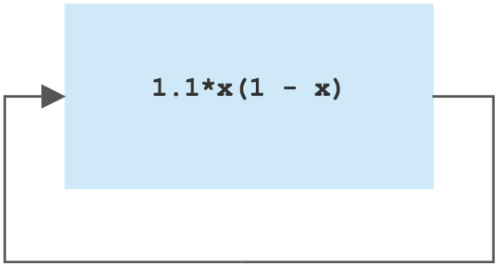
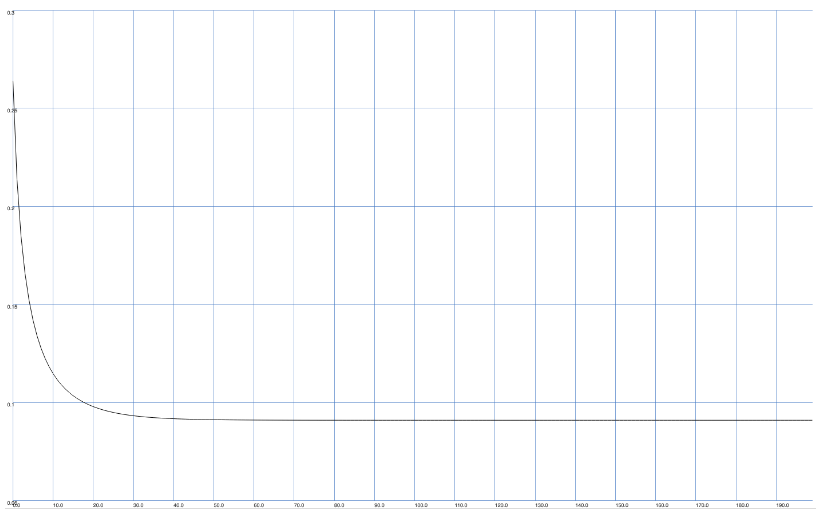


Figure 3.5: the logistic map loop representation (growth coefficient: 1.1).

We now calculate two different 'orbits', with 'seed' s1 = 0.1 and s2 = 0.4 respectively.



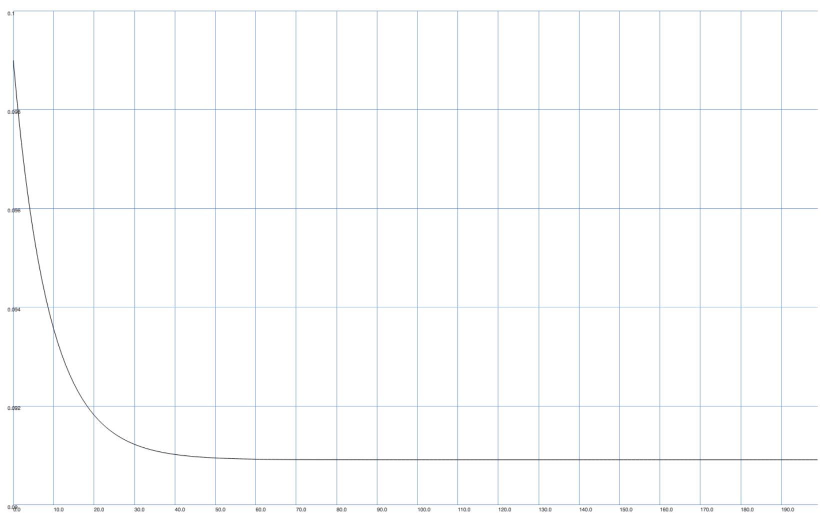


Figure 3.6: the logistic map orbit representations (gr. coe.: 1.1, seeds = 0.1 and 0.4).

Let us now consider the following example of an iterated function belonging to the 'logistical map':

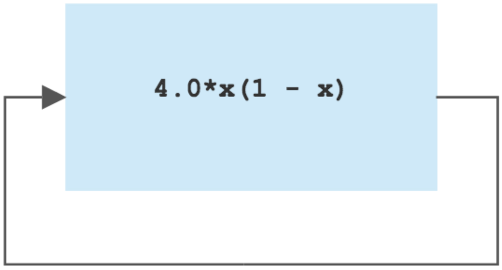


Figure 3.7: the logistic map loop representation (gr. coe.: 4.0).

We calculate, once again, two different 'orbits' with 'seed' s1 = 0.1 and s2 = 0.4 respectively.

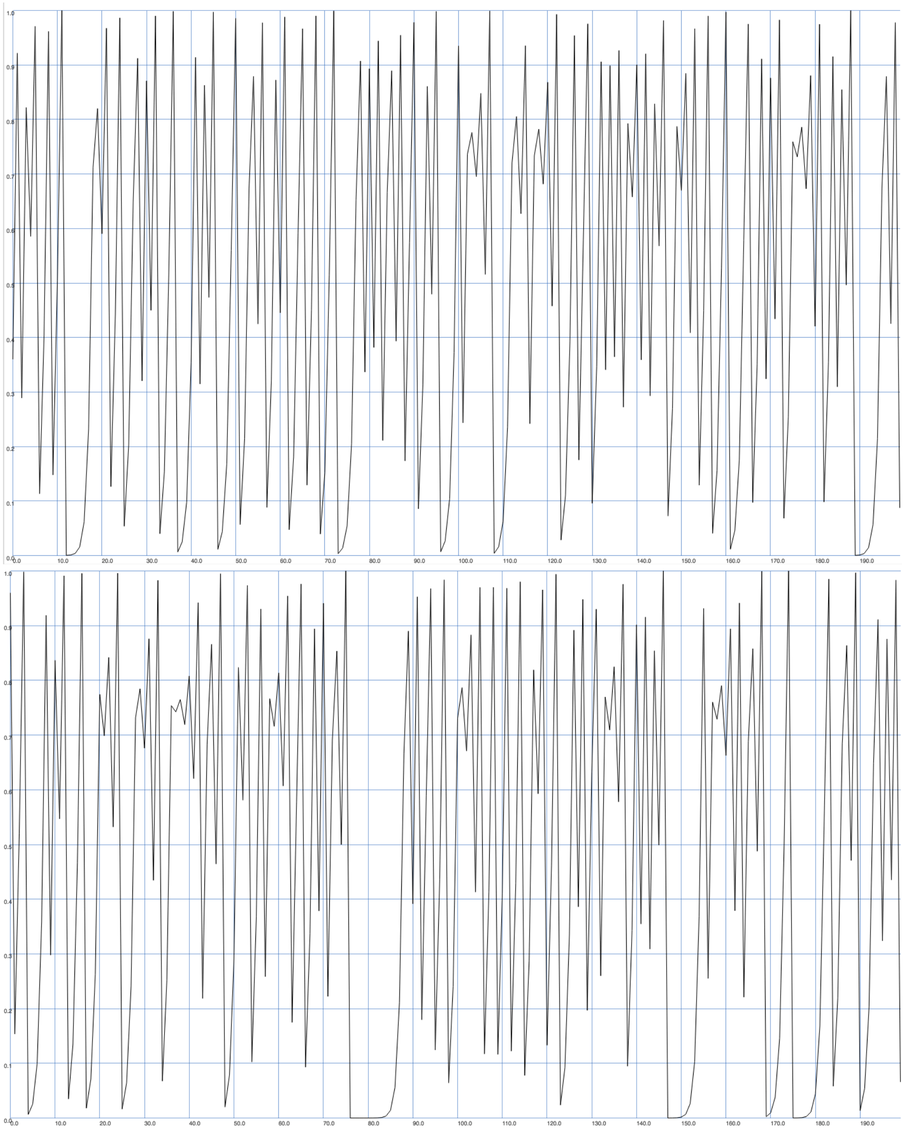


Figure 3.8: the logistic map orbit representations (gr. coe.: 4.0, seeds = 0.1 and 0.4)

We can observe that in the case of the two orbits with 'growth coefficient' r = 1.1 after a series of iterations we arrive at the same temporal behaviour, whereas in the orbits with r = 4.0 we have always a completely different temporal behaviour. This exact phenomenon is called the 'butterfly effect' or 'initial condition dependence'. With r = 1.1, the system considered is therefore not 'dependent on initial conditions', i.e. we can choose any value of 'seed' and the orbit considered will sooner or later assume that particular behaviour in time. On the contrary in orbits with r = 4.0 the value of 'seed' is fundamental, it will condition dramatically on which value the orbit is in a given sample (iteration) considered. Considering orbits 'sensitive to initial conditions' with 'seeds' of ever closer value we will have orbits that will start to differ dramatically later and later. We can calculate a so-called 'prediction error' between two orbits by subtracting the values of one from the other orbit and observing when this sequence of samples becomes 'significantly' large. We observe that to get a better prediction of a few samples, we need to increase the precision (i.e. how close the seeds are numerically) by millions of times. The term 'error' is derived from the realistic measurement situation, where the precision is not infinite, and refers to the fact that an approximation (an 'error' in fact) leads to a completely different 'orbit'. The extremely small error in defining the initial seed causes unpredictable behaviour, predictability therefore causes unpredictability: the rule is so deterministic and so dependent on the initial conditions that it requires incredible precision and causes unpredictable behaviour.

My algorithms implementing these types of systems therefore become extremely dependent on the hardware and software in which they are implemented. The same algorithm implemented in two different programming languages will often produce completely different sound and (above all) temporal behaviour, and similarly under certain conditions is dependent on the characteristics of the hardware in which it is executed. The example of the iterated function of the 'logistical map' with r = 4.0 is an example of a chaotic system. We now have all the notions to be able to define the notion of chaos. A system is considered chaotic when: it is deterministic, the 'orbits' are bounded (assumes values between a minimum and a maximum), the orbits are aperiodic, and the system is 'sensitive to initial conditions'. One way to measure the predictability and sensitivity of a system to variations in initial conditions (i.e. its 'stability') are the so-called ‘Lyapunov exponents’. Without describing their mathematical meaning, which would diverge from the objectives of this thesis, we can say that when Lyapunov exponents have a negative sign, the system has no sensitivity to initial conditions. Numerical techniques are also often used in the calculation of Lyapunov exponents, since it cannot always be done analytically. We therefore observe a representation of a numerical computation of ‘Lyapunov exponents’ as a function of the growth coefficient (control parameter “”).

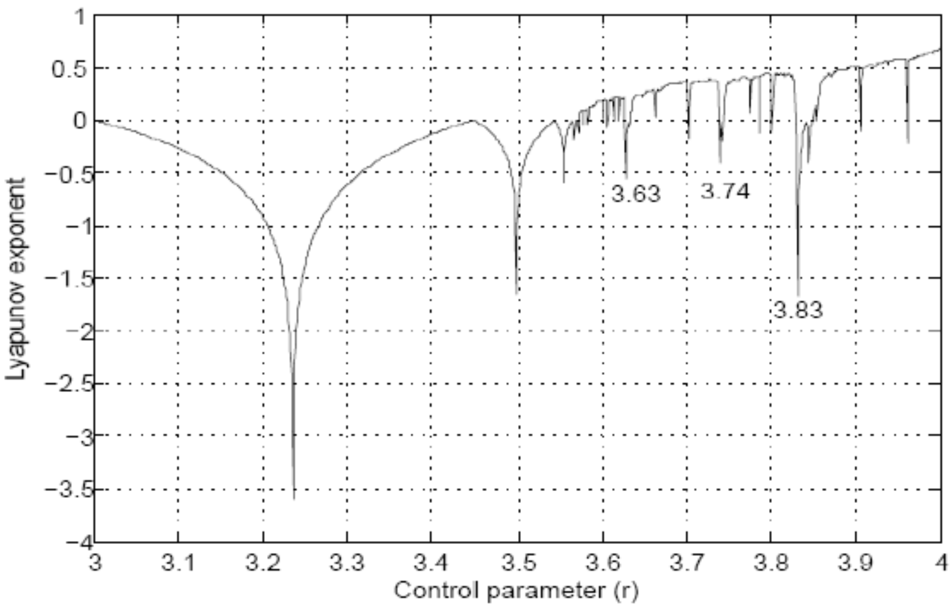


Figure 3.9: the logistic map Lyapunov exponents representations in function of the growth coefficient

We can observe that the logistic map presents the 'butterfly effect' only for certain values above r = 3.5 and with the maximum dependence on initial conditions (MLE: maximal Lyapunov exponent) with r = 4.0. Since my sound synthesis systems often exploit 'sensitivity to initial conditions' to generate temporal structures and 'sonological emergence', the representation of Lyapunov exponents becomes crucial for exploring a dynamical system.

The other category of dynamical systems I have implemented in my synthesis systems is that of certain differential equations, and more often algorithms that can be formalised through 'difference equations', the discrete version of differential equations, systems like feedback networks or various filters. I will therefore intuitively describe the mathematical formulation of these instead of concretely describing the algorithms as they show points of contact, common characteristics with iterated functions and how in my synthesis systems both types form elements of a single system. A differential equation is an equation that involves derivatives of a function or functions. The derivative of x is the instantaneous rate of change of x: the rate at which x changes at a given instant. Unlike iterated functions in which time is discrete (it is defined in steps, in iterations), time in differential equations is continuous and must become discrete in order to form the basis of an algorithm. A differential equation is thus a dynamical system in that we have a system that varies over time according to a well-defined rule: the relationship between the functions and their derivatives. The rule in this case is not direct as for iterated functions, but 'indirect': in our case we are dealing with equations with the derivative of a dependent variable (time function) with respect to time (independent variable). To have a 'direct' formulation, we must calculate the function of time. The function of time is the general solution, to have the specific solution (to calculate the 'orbit') we must have the initial conditions (the 'seeds'), exactly as for iterated functions. We generally have two possible ways of calculate the solution: calculus methods or numerical/algorithmic methods, in our case it is intuitive to use numerical methods. They are variations or direct implementations of a method called 'Euler's method', by which indirect information about the derivative is converted into direct information about the values of the time function. With this other type of deterministic systems, emergent phenomena, chaos and dependence on initial conditions can occur in the same way.

3.4 Non-linear Interactions

Almost all physical systems are non-linear, and similarly, almost all phenomena and systems with which we are confronted in our daily lives are non-linear. Complex, chaotic systems formed by non-linear agents are not rare situations occurring under rare conditions, they are part of our everyday experience. The difficulty of a mathematical understanding of these systems, of finding solutions that describe their behaviour over time, does not exclude other ways of understanding these systems from other perspectives. The fact that we are constantly exposed to them in our daily lives can cause us to develop other types of strategies for understanding the behaviour of complex systems, one of which can be defined as 'tactile and bodily understanding'. The behaviour of these systems could be 'understood' with the hands and ears in a much simpler way than describing mathematical solutions. An example to put this into context would be that of a musician, who understands the instabilities (non-linearities) of his or her musical instrument much more easily than a mathematician can develop models that describe the behaviour of that instrument accurately. Non-linear systems therefore offer special modes of interaction, in that we cannot predict and control precisely what is going to happen but we ‘understand’ its behaviour and react to it. This type of situation in the case of performing music brings us into a special mindset, where we have to constantly interact and be present. This particular kind of mindset, of constantly listening and interacting, is a fundamental aspect for which I find these systems of aesthetic interest. In my compositional work, the interaction with non-linear components often has dramatic consequences on the sound and the parameters I interact with are often few and sometimes only one. I will present here an example of interaction with a dynamic system used in one of my compositions entitled ‘Buckling I'. The synthesis system is implemented in the SuperCollider programming environment and the interaction takes place with a UGen I implemented in SuperCollider called 'LogisticButterfly'. This UGen is part of a more complex dynamic system and acts as a control signal, however, it is the parameter that affects sound synthesis result the most. Among the control parameters in this UGen we have a parameter called 'lambda' which is nothing more than the 'growth coefficient' of the logistic map seen in the previous chapter, this parameter is modified in real time by the performer. The composition is for 24 channels and has the exact same algorithm acting on each of the 24 channels with the only difference being a very small 'prediction error' for each of the channels. In other words, we have the same dynamic system with different 'initial conditions' on each channel, resulting in different 'orbits' in each of the channels. As we saw in the previous chapter, the sensitivity of the system to initial conditions is given precisely, as shown by Lyapunov's exponents, by the 'growth coefficient'. The values of the 'growth coefficient' used range from 3.50 to 4.0, precisely because there are zones of 'sensitivity to initial conditions'. The parameter with which the interaction takes place is thus a single number, where slight variations in the value of this number cause the system to behave drastically differently. This sensitive interaction situation has meant that the best solution for controlling sound synthesis is of a 'tactile' nature, i.e. using an 8-fader MIDI controller, where each fader has been associated with a digit after the decimal point.

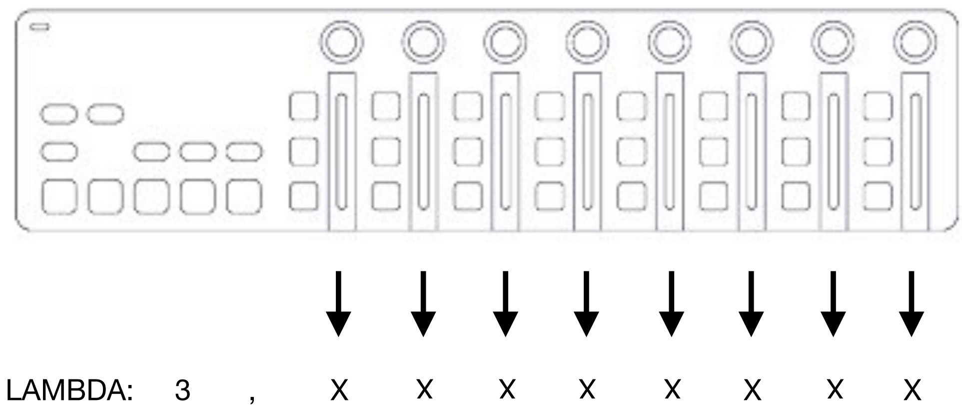


Figure 3.10: MIDI controller control parameters assignment

4. Conclusions

This thesis has shown how, from an experimental perspective, dynamic systems and abstract algorithms in the context of 'nonstandard synthesis' are a particular field of fertile artistic exploration in computer music composition and performance.
The artistic practice presented was analysed from a historical perspective and in relation to the author's work, and seen as a point of access to an idiomatic aesthetic of computer music.
This thesis also shows a particular relationship with technology in the context of musical composition and performance, highlighting particular aspects and their aesthetic consequences, and also showing how the computer is the ideal medium for experimentation in this respect.
Special attention was shown in how the practice of 'non-standard synthesis' opens up unique and singular possibilities on a generative, temporal and formal level in a musical context, and in the case of dynamic systems formed by 'non-linear' elements how these offer a particular form of interaction with sound generation.

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