# *Symbolic music in the age of the algorithm*

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May 2021

*"To discover the various uses of things is the work of history."*

*Karl Marx, Das Kapital*

# Acknowledgments

Firstly I wish to thank my mentor Bjarni Gunnarsson for the immense support, knowledge, and patience during these two years; but also for his music, which was a lighthouse in the foggy days of the pandemic. Furthermore, I wish to thank Richard Barrett, Peter Pabon, Gabriel Paiuk, Joel Ryan and Kees Tazelaar for their invaluable insights and knowledge, and the Institute of Sonology for accepting my application and giving me this opportunity.

I wish to thank my family and especially my brother, Nenad, who always urged me to pursue my passions and dreams. A great thanks to all of the colleagues with whom I shared this rocky path and an immense thought of gratitude to all lifelong friends for their support.

Lastly, I wish to specifically thank Ena Taranis, Alec Gordon, Anna Cicogna, Elisa Battistutta, Davide Andriani, Saurav Narain Sharma and Denis Diafano. Without them my world wouldn't be the same.

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# Introduction

This work started as an enquiry upon Xenakis' “Symbolic Music”[1], a generalized compositional theory he developed and published as a part of “Formalized Music”[2] in 1963, which tries to account for sonic phenomena through a mathematical framework.
Initially, my fascination towards the concepts forwarded in that text was mostly toward the idea of using mathematical properties which stand at the basis of his theory, namely vector spaces and Abelian groups. This strongly resonated with subjects I studied in the field of Civil Engineering, namely Statics and classical Mechanics, where vector spaces are used extensively to describe static and small disturbance phenomena as well as dynamical systems (the latter being of particular interest for this study). This correlation between the models with which we describe the world surrounding us and Xenakis’ intuition about how the underlying mathematical principles (which define basic concepts such as summation, multiplication, order etc.) translate to the formalization of music, prompted me to try to formulate a system which could account for both rational and intuitive solutions to practical mathematical-logical and musical questions.
The initial approach I used for this work included making a detailed study of the mathematical properties and the development of a compositional tool in Max/Msp[3]. This system implemented a control structure through periodic functions — analogous to Xenakis' sieve construction of scales.[4] Periodic functions interacted on the basis of an established logic and

[1] Iannis Xenakis, *Formalized Music*, (revised edition - Stuyvesant NY, Pendragon, 1992), p.155
[2] Iannis Xenakis, *Formalized Music*
[3] https://cycling74.com/
[4] Iannis Xenakis, *Formalized Music*, p.xii, p.194

controlled the parameters of the defined vector space. However, the results of this experiment made me reconsider the use of a generalized system, such a system would permit a direct manipulation of frequency and amplitude, together with an *in-time* organisation leaving the logical and thus compositional decisions open to any possibility.

Although already the use of such a system brings inherent idiosyncrasies generalized systems have[5] – as well as an account of problems of numerical error and over usage of resources for basic functionality – the need to change the approach was mainly dictated by the lack of organisational possibilities on a musical level – meaning that there were no logics concerning how and why any given sound should be present at any given moment. In the case of the implemented system numerical errors arose when relying on trigonometric functions to determine an exact calculation of a logic in time meant that not only the practical implementation of the system needed to be implemented but also a series of mechanisms to make the data itself comprehensible to the algorithm; moreover, the conditions for this type of event were tied to the local minima and the maxima of the functions. Given that these functions are approximations and numerical error spreads along mathematical operations (ex. Frequency modulation or multiplication[6]) the result is a need for higher tolerances upon the control structure; implying a decrease of precision proportionally to the number of mathematical operations used in a particular logical construction. The second, I saw limitations of this generalized approach due to a lack of practicality. The interaction with the system reduces to having control over very basic properties, such as an event's position in time or its pitch, parameters which have simpler and more direct ways of specification.

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[5] C.C. Chang, H.J. Keisler, *Model Theory: (Studies in logic and foundations of mathematics),* 3rd ed (North-Holland 1973), p.4, definition 1.2.1;
Elliott Mendelson, *Introduction to mathematical logic,* Sixth edition, Discrete mathematics and its applications, (CRC Press/Taylor & Francis Group 2015) ,p.208. Godel's incompleteness theorem;
The consequence of Godel's incompleteness theorem upon model theory is that any strong theoretical model is unprovable.

[6] https://web.mit.edu/fluids-modules/www/exper_techniques/2.Propagation_of_UncertainModel Theoryt.pdf

# Symbolic music

In symbolic music Xenakis describes frequency, amplitude and duration (H, G ,U) as a set of linearly independent basis vectors of a vector space. Xenakis, interprets these measures as being derived from observing a *sonic event* by systematically refusing qualitative judgements[7] and taking into account only the "abstract relations"[8] and the possible "logical operations which may be imposed on them"[9]. By specifying the nature of a generic *sonic event* element through logic, a series of axioms are established – namely addition (internal law of composition, meaning a third element is made to correspond to the result of adding two elements together), associativity, neutral element, inverse and commutativity. These axioms are fundamental for a specification type of an algebra, in this case Xenakis specifies two types of algebra, one inside-time and another outside-time.

Furthermore, Xenakis specifies a *metric*, implying by this term that the properties of a sonic event are measurable. A *metric* by definition requires a notion of distance which is defined by analysing a set of three elements (for example pitch intervals) and putting them into a binary relation with an operator (≥). In this way  properties of an ordered set can be proven (reflexivity, antisymmetry and transitivity) and thus satisfying criteria needed to specify a metric.

All of these properties put together form an *abelian additive group* on the sets of properties (pitch intervals, intensity intervals and durations – or more briefly (H, G, U)). This structure

[7] Xenakis, *Formalized Music*, p.156
[8] Xenakis, *Formalized Music*, p.156
[9] Xenakis, *Formalized Music*, p.156

can subsequently be organized into a vector space through the addition of other two properties; namely scalar multiplication and the specification of a unit interval (*basis*) for all the three measures (H, G, U). By having these properties the *sonic event* is measurable and its measures are linearly independent. Linear independence implies that any of the three coordinates (frequency, intensity, time) cannot be obtained by combining the remaining two through operations of addition or multiplication and their value is a multiple of a unit of measurement.

After this definition, Xenakis constructs sets and subsets of sonic events, which are vectors defining "state classes of sonic events"[10] through logical operations of intersection, union and negation, and thus forming a Boolean Algebra based on the aforementioned sets. Additionally, his boolean algebra between sets of sonic events, in my view, represents a fundamental tie which connects music to computation. This is to say that it (boolean algebra) can be a generalized affirmation of musical computability as well as offering the possibility of systematically organizing music as a consequence of mathematical properties.

## A case of technical mediation

Another deduction arose from Xenakis' somewhat cryptic introduction to symbolic music. Before proceeding with the algebraic description of a sonic event, Xenakis has to set the hypothesis for his mathematical model. This means that any kind of preceding knowledge has to be discarded in order to study pure phenomena, which will "begin by imagining that we are

[10] Iannis Xenakis, *Formalized Music*, p.171

suffering from sudden amnesia"[11]**.** In other words, as a mathematical model is inferred upon a *sonic event* by means of model theory – a theory which replaces intuitive logical statements and their combinations with "precise mathematical objects"[12] – a set of *basic truth* definitions also has to be specified.

Xenakis rejects any informal truth about musical phenomena by studying it analytically, a procedure which in my view can be connected to what Latour[13] describes as "*technical mediation"*[14].

An "*episteme"*[15], which represents scientific and theoretical knowledge (reason) is thus needed to proceed with the development of "*daedalia"*[16] (techniques) through application of "*metis"*[17] (strategies) in order to resolve problems. Latour therefore argues that a shift in perspective must be taken in order to evade the dualist paradigm. Here the dualism lies between humanity and objectivity, on one hand Heidegger's materialism and on the other a purely dogmatic humanist view on the role of technology.[18] This shift is taken by redefining the role of technology not simply as mediating human actions but as a part of a larger human socio-technical entity. This entity is defined as a spatio-temporal agglomerate, an assemblage of agency and mediation; subjectivity and being are thus made inseparable from technology.

This realization shifted the attention of my enquiry towards the ontological aspect of what we are dealing with in musical practice. More precisely could symbolic music be conceived, with a sense of techno-historical awareness, as a guideline for an inquiry into algorithmic music and human interaction.

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[11] Iannis Xenakis, *Formalized Music*, p.155
[12] C.C. Chang, H.J. Keisler, Model Theory, p.4
[13] Bruno Latour, "On technical mediation". *Common Knowledge*, V3 N2, (Fall 1994)
[14] Bruno Latour, "On technical mediation", p.30
[15] Bruno Latour, "On technical mediation", p.29
[16] Bruno Latour, "On technical mediation", p.30
[17] Bruno Latour, "On technical mediation", p.29
[18] Bruno Latour, "On technical mediation", p.30

## Algorithms and ontology

In order to approach questions such as the relationship between human intervention through a physical or virtual input interface and algorithmic systems which acquire and process information thus obtained, it is useful to understand how concepts of logic and algorithmicity[19] reside into the perspective of technical mediation; the latter being a concept which tries to account for relationships between human intuition, rationality, and action in the material world through the use of technology. While Parisi[20] turns to the concept of metamodeling[21] when defining *algorithmic objects,* stating " . . . mathematical model, no matter how deterritorialized it is, cannot fully explain the actuality of algorithmic objects"[22] She still uses a dualistic perspective in which algorithms are defined as objects and thus "spatiotemporal actualities"[23]. These objects, although finite, according to Parisi contain an infinite potential. She traces this infinite potential to the notion of computability, by definition a computable number is any number calculable to a given degree of precision. On the other hand, the quantification of the probability which expresses whether a random algorithm is going to provide an output, is an uncomputable quantity. This leads Parisi to consider *algorithmic objects* to be defined by uncomputabilities - and considering them as spatiotemporal "finite actualities"[24] and "imbued with infinity"[25]. This definition tries to encapsulate some phenomenal aspects of algorithms; namely an algorithm acts upon data

[19] Hanns Holger Rutz, "Marking a space of algorithmicity". *xCoAx .org Computation Communication Aesthetics &X,* Bergamo, Italy, (2016)

[20] Luciana Parisi, *Contagious architecture: Computation, aesthetics, and space.* (Mit Press, 2013)

[21] Felix Guattari, *Chaosmosis: An ethico-aesthetic paradigm.* (Indiana University Press, 1995), p. 29, "There is no personological totalisation of the different components of Expression, or the self-enclosed totalisation of Universes of reference, either in the sciences, the arts or in society. There is an agglomeration of heterogeneous factors of subjectivation."

[22] Luciana Parisi, *Contagious architecture*, p.5

[23] Luciana Parisi, *Contagious architecture*, p.xiii

[24] Luciana Parisi, *Contagious architecture*, p.62

[25] Luciana Parisi, *Contagious architecture*, p.3

(which in the simplest case could be a number) and the data acquires contextual meaning in the process itself (a number can represent an angle or the cost of a bill or another arbitrary meaning). Furthermore, these processes can be described as states of transformation of information in a certain moment in a certain context (thus spatio-temporal), the process itself - the algorithm - has conditions which interrupt the mechanism once a result is recognised (an angle has been calculated with enough precision). There is no formal guarantee that a result will be reached and that an algorithm will end and provide a result, this is known as the Halting Problem. The impossibility of determining that an algorithm will reach its result, given the data, was demonstrated by Alan Turing[26]. The possibility of an algorithm reaching it's halt (by obtaining a result) is expressible as *halting probability*, expressed by the Chaitin number[27] and this number, among other interesting mathematical properties, is uncomputable. From the axiomatic principles of computation theory (and the subsequent existence of the Chaitin number) to the actual implementation (coding) of algorithms where not only the code is prehended by the *interpreter* but the same *daedalic* act of writing a set of instructions must exclude infinite possibilities which arise from this intrinsic potential.

Although it could seem that Latour's total rejection of considering techniques as objects, "We are not able even to count their [techniques] number, nor can we tell whether they exist as objects or as assemblies or as so many sequences of skilled actions . . . .Yet there remain philosophers who believe there are such things as objects"[28], a parallax can be constructed in my view between the concept of algorithmic object/architecture and Latour's (non-)definition of techniques.

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[26] Alan M. Turing, "On Computable Numbers, with an Application to the Entscheidungsproblem", *Proceedings of the London Mathematical Society*, Volume s2-42, Issue 1, (1937), Pages 230–265, https://doi.org/10.1112/plms/s2-42.1.230

[27] Gregory J. Chaitin, "A Theory of Program Size Formally Identical to Information Theory", *Journal of the ACM,* Volume 22, Issue 3,( July 1975), https://doi.org/10.1145/321892.321894

[28] Bruno Latour, "On technical mediation"., p.38

In order to avoid Parisi's conclusion - in which algorithmic objects are spatio-temporal actualities - I turn to a definition of Algorithm which may exclude totally all of the preceding discourses, simply because of its strictness but nonetheless admits the property of abstractness.

“An *algorithm* is a finite, abstract, effective, compound control structure, imperatively given, accomplishing a given purpose under given provisions”[29]

With the acquisition of abstractness, an *algorithmic entity* can be defined as part of a broader perspective which not only arises from “within mathematical truths and physical laws”[30] but is also part of the process of technical mediation as its existence to put it simply – is not dictated merely by the presence of electrical power.

Somewhat similarly to as a building is designed to defy gravity, according to Parisi, algorithmic objects are combined into architectures which are built around uncomputable data, data not containable solely by mathematical form or physical objects[31].

A combination between input data and a certain algorithm has a certain (also uncomputable) probability of halting (providing result - thus computed data) specified by the Chaitin number; this leads to a potential of searching for an uncomputable result (for example an algorithm which calculates decimal cyphers of an irrational number)- for which an algorithm will never halt. The relationship data-algorithm can be seen somewhat in a biunivocal fashion, data (symbolic representation of values) needs a provider of context in order for information to be meaningful. This role is provided by an algorithm, which on the other hand reaches a halting condition (a meaningful result) if the data provided to it specifies a case that can reach a

[29] Robin K. Hill, “What an Algorithm Is”, *Philosophy & Technology,* 29, 35–59, Springer ,(2016), https://doi.org/10.1007/s13347-014-0184-5, p.24

[30] Luciana Parisi, *Contagious architecture*, p. 3

[31] Luciana Parisi, *Contagious architecture*, p. 33

halting condition when processed by the algorithm itself.

As seen earlier, the probability of the outcome of such a relationship is incalculable. By extending this idea to networks of communicating algorithms - where data is shared between algorithms which do not necessarily have the same halting conditions - it is clear how the possibility of such networks to operate and interact with the physical world requires an architecture which is able to resist the potential of incalculability.

## An infinite potential for a finite entity

As discussed earlier, mathematical models based on axiomatic systems do not suffice to describe studied phenomena. There is to say a concept of a lacking residual which reemerges, which in my view can be also related to Xenakis' change in axiomatics; he reformalizes his basic assumptions[32] by means of sensations, differences and comparisons. The ontological shift is that the measurables "(pitches, instants, intensities...)"[33] become discrete sensations and are part of the same set **Ω,** where an informed phenomenal observation substitutes the amnesiac listener; these observations or measurements of a musical parameter are then organized together with differences Δ (increments and decrements) from a given value, and by the iteration of a rule that attributes the difference to the value in order to produce another (set E). This gives a new set of dimensions (**Ω,** Δ , E) which for Xenakis seems more "natural"[34].

This shift does not undermine the possibility of a formalized study as there is a direct

[32] Iannis Xenakis, *Formalized Music*, p.377 note VIII.14
[33] Iannis Xenakis, *Formalized Music*, p.378
[34] Iannis Xenakis, *Formalized Music*, p.377

relationship to the “foundations of mathematics”[35] where the concepts of logic, sets and observability are ultimately traced to interactions between brain “hemispheres”[36], as to say, concepts of logical relationships, observability, definitions of sets and appurtenance are emergent from processes related to human understanding.

In order to contextualize the relationship of algorithmic entities to sonic events it is in my opinion important to consider that “there is no essential difference between propositional and Boolean algebras, and the use of one or the other only specifies what operations are involved in the given context”[37], meaning that the axiomatization adopted by Xenakis' and it's subsequent Boolean algebras are part of one formalization and algorithms acting within the logical relationships of the system act ultimately on the (linearly independent) basis of the vector space.

By taking into consideration another insight into the nature of algorithms “The truth table procedure to determine whether a statement form is a tautology is an algorithm within logic itself”[38] It is clear how abstractness is essential to the extension of algorithmic objects to non material manifestations of decision processes, in short even the choice of fundamental truths (axioms) is an algorithmic procedure.

If on one hand, models based upon finite axioms inherently lack the possibility of describing the totality of sonic phenomena on the other, algorithmic architecture is more than an autopoietic form, it arises from an “extra space of incomputable data”[39] present within the algorithmic object itself making these objects acquire more meaning than permitted by the finite axioms which are at their basis.[40]

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[35] Jet Nestruev, *Smooth Manifolds and Observables*, (Graduate Texts in Mathematics 220, Springer 2003), Appendix A. M. Vinogradov Observability Principle, Set Theory and the “Foundations of Mathematics”, p.209

[36] Jet Nestrunev, *Smooth Manifolds and Observables,* p.214

[37] Jet Nestrunev, *Smooth Manifolds and Observables,* p.210

[38] Elliott Mendelson, *Introduction to mathematical logic*: *Discrete mathematics and its applications,* Sixth edition, (CRC Press/Taylor & Francis Group 2015), p.311

[39] Luciana Parisi, *Contagious architecture*, p.36

[40] Luciana Parisi, *Contagious architecture*, p.36

Even though this may seem a call for a Gestaltian “more than the sum of its parts”[41] the surplus of meaning doesn't arise from physical manifestation, it arises from considering algorithmic prehension both as physical and speculative[42], a speculative prehension which takes place within the exchange of potentially infinite amounts of data and the relationships that it (the data) forms between algorithmic objects. While Parisi resorts to object-oriented metaphysics, at the same time the ontological differentiation between “human and nonhuman, between animate and inanimate entities”[43] is abolished and the question posed is “how change defines what is an object”[44].

With this in mind, a parallel can be traced with Latour's metaphysics where algorithms could be seen as actants involved with interactions which give rise to meaning when forms of delegation pass from one actant to another in time.

This in my view can translate to a context where sequences of logical operations upon data -with the goal of assembling musical parameters into a musical form- do not have an *a priori* meaning, but it is the relationships which regulate *how* the data is changed so the continuous differentiation and restriction of potential forms to an actuality determines the outcome of the process and thus the musical form. One extreme example being the application of a transposition to a melodic sequence and sequentially re-transposing it inversely, producing no variation at all. While conceptually and materially different, the outcome of the operation, ultimately, doesn’t affect musical form.

To define *data* in a more appropriate context, Koenig[45] provides a useful analysis for bridging the gap between the information relative to the context of the material and the one concerning aesthetics:

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[41] Bang Wong, "Gestalt principles (Part 1).", *Nature Methods*, vol. 7, no. 11, (2010), p. 863
[42] Luciana Parisi, *Contagious architecture*, p.70
[43] Luciana Parisi, *Contagious architecture,* p.36
[44] Luciana Parisi, *Contagious architecture*, p.47
[45] Gottfried Michael Koenig, “Summary Observations On Compositional Theory”, Utrecht State University, Institute of Sonology, (1971), p.66

“ . . . the term data field is used in a double sense: it first means the pre-structured data material with which the composer composes, and secondly the result of composition which it constructs in the listener’s ear according to aesthetic aspects. The data field thus tells us nothing about the quality or the significance of a composition, but merely describes the physical premises without which significance could not be communicated.”[46]

The data seems to hold the potential for an aesthetic form and provides grounds for communication but at the same time doesn’t provide any reference to a context. This is in my opinion in accordance with what was stated earlier about data being abstract towards its use, necessitating context provided by a listener, composer or an algorithm.
Furthermore, Koenig’s definition of “form potential”[47] arises when potential form becomes actuality, and the various results provided by the same system describe the relationship which a variant has with the potential. This definition is not only useful to comprehend how structures of algorithms can provide a potential for musical form by regulating the logics of a system, it presents a solution to the “chicken and the egg”[48] problem; where differences between instances (sonic results of a systematic composition) provide a source of information in order to define an *ideal* (examples of “general models”[49]) , or in other words a possible formal *a posteriori* categorization based on the interpretation that a listener has by giving context to the data (as defined above). The differentiation between instances, forming a *cut view* onto a noumenal *ideal form* is thus interpretable in terms of *parallax*.[50]
A system defining sonic fields and sonic possibilities - through interaction, contextual imprecision (drifting voltages, different interpreting musicians)[51]), and context dependent

[46] Gottfried Michael Koenig, “Summary Observations On Compositional Theory”, p.91
[47] Gottfried Michael Koenig, “Summary Observations On Compositional Theory”, p.66
[48] Nick Collins, “Musical form and algorithmic composition”, *Contemporary Music Review* , 28 (1), 103–114, (2009), p.104
[49] Nick Collins, “Musical form and algorithmic composition”, p.104
[50] Slavoj Žižek, *The Parallax View*. (Cambridge, Massachusetts: The MIT Press, 2006)
[51] Gottfried Michael Koenig, “Summary Observations On Compositional Theory”, p.65;

parameters - provide a potential for different actualities of a musical work. These different actualities can be traced through their qualitative or quantitative differences to appartain to an *ideal form*. An ideal form is thus not providing a goal toward an instance or compositional work from which these results are lacking from and failing to arrive at, but it is defined by the difference between musical works. Thus it is the difference itself between actualities of a work that permits the ideal form to come to exist and not a differentiation from an ideal *prototype*. Algorithms are thus accountable in systematic composition as a part of the system which is both *being composed* and *composes*, providing a further actant into what Koenig defined "System Composition"[52].

## Music as a ***transparent sandwich***

"Music is like a multiple sandwich, but a transparent one. Whilst in the middle of it, one can see at the same time lower or higher layers everywhere. "[53]

In his 1996 publication "Determinacy and indeterminacy"[54], Xenakis tackles the complexity of describing musical phenomena in three stages. Firstly, he refers to a "strong abstraction"[55] into defining ***pitch***, ***intensity*** and ***duration***[56] "with any degree of precision"[57] but nonetheless " . . . necessary to attempt this in order to be able to go forward and manipulate more complex phenomena."[58].

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Iannis Xenakis, "Determinacy and indeterminacy", *Organised Sound*, Cambridge University Press, Volume 1 , Issue 3 , (December 1996) , pp. 143 - 155

[52] G. M. Koenig, "Summary Observations On Compositional Theory", p.9

[53] Iannis Xenakis, "Determinacy and indeterminacy", p.146

[54] Iannis Xenakis, "Determinacy and indeterminacy"

[55] Iannis Xenakis, "Determinacy and indeterminacy", p.145

[56] Namely referring to *Symbolic Music,* where he defines pitch, duration and intensity as linearly independent measures.

[57] Iannis Xenakis, "Determinacy and indeterminacy", p.145

[58] Iannis Xenakis, "Determinacy and indeterminacy", p.145

The reference to the necessity of defining these parameters derives not only from the historical significance, but also from the mathematical-logical properties which permit a symbolic representation of musical form, the clearest example being mensural notation. While the inscription of notational values into a staff satisfies a need to gain precision at expressing musical ideas, on the other hand it avails onto basic mathematical properties of vector spaces – namely linear independence, order, and measure – long before Descartes' innovations.

Linear independence guarantees separability between sets, stating that any sum of two elements appertaining to two different sets (for example a pitch and a duration) cannot result into being an element of one or the other (summing two pitches returns a pitch).

The three sets of pitch, duration and intensity are ordered sets, meaning that if we have any three elements of the same set (for example pitch) we can define which is higher and which is lower by applying the binary relation of inequality ($\leqslant$) between the elements. This ultimately is reduced by Xenakis to a distribution of values upon a straight line (or a curved line which doesn't intersect itself, the topology is the same).[59]

“The definition of an ordered structure is as follows. Given three elements of a set, they can be ordered in just one way by saying that one of the three is between the other two. In other words a set of elements has an ordered structure if you can put them in a string, placing each between two others and completing the set by applying this rule. ”[60]

Ultimately, metric (measure) guarantees that distance between elements of the same set can be quantified. Furthermore, this quantity is always written in proportion to the unit of measure defined for a certain set given by its basis (unit vector), this translates to the possibility of

[59] Iannis Xenakis, “Determinacy and indeterminacy”, p.145
[60] Iannis Xenakis, “Determinacy and indeterminacy”, p.144

having for example different tempos but a common unit of measure (seconds, beats per minute etc).

Linear independence, furthermore, leads to the definition of compound measures such as density or disorder (*ataxia*) which result from ratios and probetween quantities pertaining to different dimensions.

For example one could measure the rate of change of frequency over duration, giving a measure which is not linearly independent. To elucidate how this occurs it is useful perhaps to refer to the concept of rational dependence; through this concept a number is said to be rationally independent if it cannot be written as a linear combination of other numbers (multiplication and addition), one clear case being linear independence of irrational numbers over the field of rational numbers as one cannot construct by any means a number such as π from a combination of rational numbers.

As such, compound measures are dependent by construct - their value is the result of relationships between other (independent or compound) factors - reflecting on the possibility of describing parameters and thus, ultimately, operations on sonic entities which can have a complex impact on the resulting musical form.

Furthermore, what is then important to highlight is that with our definitions any aesthetic intervention onto the musical material (i.e. an action of the composer, musician or an algorithm changing its parameters which act on compound instructions[61]) will ultimately (and always) act upon one or all of the independent parameters (frequency, amplitude, duration). Thus, an argumentation for *strong abstraction* and *degree of precision* seems to transpire as a necessary precaution when a statement such as the one above is held. As even in the most reductionist situation, one cannot simplify music to three measures.

[61] Robin K. Hill, "What an algorithm is"

The second property *order* permits to tackle the formalization of unordered characteristics such as timbre because of the close relationship between order and dimensionality.

The clearest example of loss of order is the transition from the real line (one dimensional space) to a bi-dimensional space. While one could state that a number $x_1$ is smaller than another $x_2$ ($x_1 \leqslant x_2 \mid x_1, x_2 \in \mathbb{R}$), a point $p_1 = (x_1, y_1)$ on the bi-dimensional plane ($\mathbb{R}^2$) has no clear order in respect to another $p_2 = (x_2, y_2)$. This permits a certain freedom of choice for a composer, where one is free to consider one trajectory over another freely, much as taking one route or another to reach a certain geographical destination. This is seen when considering a passage from one timbre to another, there is no preferred route which a musician could take to transform a sound, instead the multidimensionality of timbre permits the arbitrary transitions to be taken.

All of these aspects constitute the zeroth level of musical complexity and it is the first of the three layers which in Xenakis' synthesis constitutes music as a complex entity.

Secondly, the measures (both linearly independent and dependent) can be organized into a multidimensional space. Each measure is graphically representable as a distribution of values on a straight line (as axes in cartesian representation). This distribution is describable in terms of repetition (distances between pitches, durations etc) or it can be viewed in terms of geometrical symmetries which indeterminacy can break.

“So the problem of determinacy and indeterminacy is the problem of distribution of points on a line in such a way that a very strong symmetry or repetition will not occur. It is easy to imagine or design patterns which are more or less repetitive or absolutely non-repetitive. The latter can be created by hand or by other means to ensure that there is no repetition at all.”[62]

Furthermore, the zeroth layer measures are assignable to a single “sonic event”[63] which in turn

[62] Iannis Xenakis, “Determinacy and indeterminacy”, p.145
[63] A wording used by Xenakis to express the single n-dimensional vector.

can be considered a point in this multidimensional space:

"Each point in an *n*-dimensional space is defined by an ordered set of *n* values. In the case of musical multidimensional space these values represent the characteristics of a sound"

This layer, in Xenakis' analysis, leads to the organisation of *sonic entities* into "aggregates"[64] such as musical phrases, themes, chords etc. Further layers of musical organisation lead to high-order structures such as movements or sonatas.[65] The last two layers can be thought respectively to resolve into the *meso* and *macro* timescales.[66]

When addressing the subject of the ontology of musical form, these timescales seem to become the point of departure or arrival of a compositional technique. From one side a bottom->up approach[67], typical of the "Cologne school"[68]. And on the other, a top->down relationship which is "template"[69] driven. This epistemological stance about the "Container and contents"[70] problem provides a useful separation when the subject of the analysis is historical development of musical form in electronic and algorithmic music.

One clear example being the conclusion to which a material-driven approach can fall into; where material is shaped into a form which is, to paraphrase Berg, "guaranteed"[71] to emerge by the manipulation without requiring thought to a broader compositional work.[72]

"Koenig surprisingly mentions that

form was not really a topic in Cologne because everyone was concerned with

material. Form was taken for granted because otherwise how could you recognize art

[64] Iannis Xenakis, "Determinacy and indeterminacy", p.146
[65] Iannis Xenakis, "Determinacy and indeterminacy", p146
[66] Curtis Roads, *Microsound*, (MIT press, 2004), p.5;
Paul Berg, "Composing Sound Structures with Rules", *Contemporary Music Review*, Vol. 28, No. 1, (February 2009), pp. 75–87, p.82
[67] Nick Collins, "Musical Form and Algorithmic Composition", *Contemporary Music Review,* 28, no. 1 (2009): pp. 103–14, p.105
[68] Paul Berg, "Composing Sound Structures with Rules", p.77
[69] Nick Collins, "Musical Form and Algorithmic Composition", p.105
[70] Nick Collins, "Musical Form and Algorithmic Composition", p.104
[71] Paul Berg, "Composing Sound Structures with Rules", p.77
[72] Nick Collins, "Musical Form and Algorithmic Composition"

if it had no form?"[73]

This delegation was clearly surpassed by Koenig's work, where the internal relationships and the development of the material regulated by the combinations between parameters and rules, traces a residual which is attributable to form; in this way form is not predetermined but a "process of creation . . .  experienced by the composer as well as the listener".[74]

Collins (2009) - by citing Laske: "As Otto Laske (1985, pp. 558–559) expresses it, 'Compositional activity is difficult to analyze because it is characterized by instantaneous changes in compositional strategy from top-down to bottom-up approaches in the material'."[75] - argues that an "iterative design cycle"[76] is a possible solution for a more accurate analysis of musical works. This resonates, in my view, with Xenakis' approach to composition in "Free Stochastic Music"[77] where he defines "*FUNDAMENTAL PHASES OF A MUSICAL WORK"*[78] as loosely organized stages of treating material and form. This loose hierarchy would permit a composer to jump from organizing *microcomposition* to the reorganisation of the sonic result. Furthermore, Xenakis states that "Most of the time these phases are unconscious and defective"[79], leaving freedom to a composers' intuition into the organization of musical form. This reflects on further analysis of Xenakis' works, such as Solomos' individuation of "bricolage"[80] operations unto what Xenakis would identify with the 7th stage (symbolic result of the programming).

This implies that Xenakis reorganized manually the numerical output of cellular automata algorithms used for calculating successions of chords in the composition Horos, clearly

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[73] Paul Berg, "Composing Sound Structures with Rules", p.77
[74] Bjarni Gunnarsson and Darien Brito, "Implementing Koenig's Project 2", https://www.researchcatalogue.net/view/1081939/1081944
[75] Nick Collins, "Musical Form and Algorithmic Composition", p.105
[76] Nick Collins, "Musical Form and Algorithmic Composition", p.105
[77] Iannis Xenakis, *Formalized Music*, p. 1
[78] Iannis Xenakis, *Formalized Music*, p. 22
[79] Iannis Xenakis, *Formalized Music*, p. 22
[80] Makis Solomos, "Cellular Automata in Xenakis' Music. Theory and practice", *Proceedings of the International Symposium Iannis Xenakis,* (Athens, May 2005), p.7

intervening into the formal material to obtain structural coherence. Solomos, furthermore, concludes: " . . . his use of formalization is mediated through manual interventions."[81] and " . . . This is always the case when he uses formal procedures: stochastics, symbolic logic, game theory, group theory, sieve theory, dynamic stochastic synthesis."[82].

This, according to Koenig's suggestion about form as being experienced by the listener as much as the composer, in my view offers the possibility of the composer assuming the position of the listener (although more informed about "parametric hierarchies"[83]) retracing aesthetic aspects to relationships between material and parameters. Although Xenakis equates "aleatoric music"[84] with "improvised music"[85], by reducing the time and the complexity of the operations needed in order to make an intervention (informed both by the knowledge of the parametric hierarchy and listening) into the system, in my opinion a liminal space between composition and improvisation can be explored.

"Both Busoni and Schoenberg suggest that the composer and improviser use similar techniques, but the improviser has the riskier task of succeeding extempore and cannot, like the composer, resort to pencil and eraser."[86]

The informed intervention of the composer-performer in this case obviously couldn't alter the past development of the musical form but at the same time presents a possibility at accelerating the concept of composition as being a "slowed down improvisation"[87] (as stated by Schoenberg).

So the opening analogy of the sandwich can be seen as a summary of Xenakis' excursus on

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[81] Makis Solomos, "Cellular Automata in Xenakis' Music", 3.4. Theory and practice
[82] Makis Solomos, "Cellular Automata in Xenakis' Music", 3.4. Theory and practice
[83] Bjarni Gunnarsson and Darien Brito, "Implementing Koenig's Project 2"
[84] Iannis Xenakis, "Determinacy and indeterminacy", p.144
[85] Iannis Xenakis, "Determinacy and indeterminacy", p.144
[86] George Lewis and Benjamin Piekut. *The Oxford Handbook of Critical Improvisation Studies.* Volume 2. (New York, New York: Oxford University Press, 2016), chapter 10, Sabine Feisst, "Negotiating freedom and control in composition, Improvisation and its offshoots, 1950 to 1980", p.207
[87] George Lewis and Benjamin Piekut. *The Oxford Handbook of Critical Improvisation Studies.* Volume 2, p.207

the complexity of musical phenomena. He argues that conscious or unconscious perception of music is always presented to the listener in all of its complexity; while there may be an active focus on one or more of its characteristics such as melody, durations, dynamics etc. music always presents itself in its totality.

“It has a structure of many simultaneous layers, which surround the listener. One has to listen to pitches, time instants and durations, dynamics, phrases, themes, structures of movements and so on simultaneously, even if one is not entirely conscious of it. While perceiving music one is in all the domains, on all levels at the same time.”[88]

The transparency and integrity (music as *a whole*) argued by Xenakis, in my opinion, can serve as a guideline to his approach at organizing these inseparable layers. As one listens even to a structured piece of musical work, intervention into its formal details and even generating principles is still made possible, leading to a fluid hierarchy of relations between material and form. The meaning of automated or human intervention into the layers which were described by Xenakis does not reflect a research for an ideal form, rather by considering systematic composition as “arbitrary”[89] the composer is free to explore the “parameter field”[90] and, to make an analogy with physics, trace paths through the field’s potential.

“It will be clear that system composition in its ideal form can hardly be realised because of the multi-dimensionality of music which must leave it to the listener to direct his attention at will to one or another dimension or to perceive an always receding sum of all dimensions as if it were ,“diagonally”.”[91]

Koenig’s perspective reminds that the complexity of a system which intervenes into the multi-dimensional parameter space becomes uncontrollable by any meaningful means. At the

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[88] Iannis Xenakis Determinacy and indeterminacy, p.146
[89] Gottfried Michael Koenig, “Summary Observations On Compositional Theory”, p.20; The term *arbitrary* refers to the free will of the composer to make decisions within a system.
[90] Gottfried Michael Koenig, “Summary Observations On Compositional Theory”, p.32
[91] Gottfried Michael Koenig, “Summary Observations On Compositional Theory”, p.23

same time, Xenakis in my view provides a perspective where intervention is not a *totalitarian* process, where an *ideal system* would be necessary to accomplish absolute control on musical parameters. But can rather be a system where processes and interaction are informed by and act upon parameters which are not necessarily appartening to the same layer. Furthermore, by taking into account that a system acts upon the dimensions independently of the amount of control that is given by the implemented technique to realize the process, Xenakis' *sandwich* and *bricolage* interventions provide an alternative heuristic for a system which intervenes into the actualization of musical form.

# On time

While addressing the issue of time, Xenakis employs two different definitions. One defines a structure *outside-time* and the other *in-time*, thus forming separate algebras.

Xenakis' definition of *outside-time* characteristics can be seen as the choice of a restricted set of possible values of a parameter independent of time. The simplest example of the distinction between *outside-time* and *inside-time* structure is that of the comparison between the atemporal structure of a scale and a definite time collocation of a melody formed by the inscription in time of the elements of the scale.[92]

In the case of a musical scale, this means the restricted set of pitches over the field of all the possible frequencies. This concept can be further generalized to the choice of a logical architecture that provides the possible values; such as the guiding principle of the construction of a scale (the choice of how to divide an octave, choice of the intervals, root pitch etc).

This for Xenakis can be translated into choosing possible values/steps on a line, the line representing any dimension of a musical parameter;[93] so possible ranges of densities, pitches,

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[92] Ronald Squibbs, "Some Observations on Pitch, Texture, and Form in Xenakis' Mists", *Contemporary Music Review*, Vol.21, Nos2/3, (2002), 91-108 , p. 104

[93] Iannis Xenakis, "Determinacy and indeterminacy"

time durations, amplitudes, modulation indexes etc are divided and organised into sets of possible values defined by some logical procedure or manual selection.

Time for Xenakis is a “space of inscription”[94] in which the outside-time description is put into a temporal flow and manifested inside-time.

It is important to note how musical time itself is “outside-time”[95], namely one can organize “ . . . a chromatic scale in time, which has the same type of symmetry as the outside-of-time characteristics.”[96] in the same way a temperament, scale and melody are defined for pitch. This is somewhat similar to Koenig’s conception of parameter and time fields as “*vertical”*[97] to each other; this separation permits the outside-time *scattering* - or distribution of possible parameter values into the field - to the in-time inscription of parameters defined as *selection*, and ultimately *permutation* where the sounds, according to Koenig, “interrupt the silence of time”[98].

To derive a logico-mathematical model of this differentiation, the necessity for two sets of algebras arises when one notes the difference between the obvious perceptual difference of two events happening in time, *a before b* is different from *b before a*. The need is thus for a commutative (and associative) “independent”[99] set of metric time T (also having the structure of an abelian group) and another non-commutative time where events correspond to instants, perceptual time. Upon defining sets of sonic events, the appurtenance to one class or another, and even the characterization of a sonic event itself are considered with the aid of time as a separator, time as a boundary upon which logical connections can form.[100] To reconcile a seemingly paradoxical conclusion, where even metric time must be purged from the concept

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[94] Dimitris Exarchos and Yannis Stamos, “Iannis Xenakis’s writing and outside-time musical structures”, *Proceedings of the fourth Conference on Interdisciplinary Musicology,* (CIM08), (2008), p.3
[95] Iannis Xenakis, “Determinacy and indeterminacy”, p.144
[96] Iannis Xenakis, Determinacy and indeterminacy, p.144
[97] Gottfried Michael Koenig, “Summary Observations On Compositional Theory”, p.32
[98] Gottfried Michael Koenig, “Summary Observations On Compositional Theory”, p.70
[99] Iannis Xenakis, *Formalized Music*, p. 161
[100] Iannis Xenakis, *Formalized Music*, p. 171

of sonic entity, a different setting can be imagined for the amnesiac listener; Firstly when Xenakis speaks about independence of metric time from the space (H,G,U) he is not referring to linear independence, as the sets (H,G,U) are already linearly independent between each other and the same can be concluded by taking the relationships between T and the other sets. On the other hand, claiming *independence* could point to the fact that (H,G,U) can be functions of T, thus changing their value in function to the value of T. As modern technology enables us to operate on temporal levels by means of memory, even from a simple practical level the opposite can be concluded, there can be an arbitrary time mapping upon out-of-time musical entities.

In my view the only practical difference of considering the metric time T as one of the basis vectors of a sonic event at this point is the change of experimental settings. By defining a *compositional space* it can be argued that the listener must be exposed independently to the sonic events, with a sense of temporal independence. This implies that a new temporal space must be created in order to isolate the event and describe it.

The consequences of this new definition are on the other hand that there can be a potentially infinite variety of mapping between non commutative and commutative time as one can be transformed into another with use of memory.

By taking into account the layered structure defined above, there can be an inversion in which the outside-time characteristics such as the selection of the scale itself (or the set of possible scales in that *movement*) is ordered in *macro* time.

Firstly, the method by which outside-time parameters are chosen can be organized into logical sets and rules by which elements from these sets are selected[101], furthermore, the choice of the rules themself can be organized into a procedure, as opposed to a manual *bricolage*. This organisation - which reflects the implementation of the system presented in this research - can

[101] Iannis Xenakis, *Formalized Music*, p.155

be summarized by considering one or multiple algorithms acting upon a musical parameter as a *procedure.* An example of an implemented procedure is the common goal of variation of frequency between independent/parallel algorithms which choose: the scale, a sequential distribution from that scale and the variation of tonality. Each of the algorithms are guided by independent sets of logical rules.

Secondly, this potential of possible outside-time organisations is further organisable as a dynamic system, where choices done by the composer determine instantaneous interruptions and changes in the logical structure. These choices also influence the possible future choices and logical states of the system. The distinction between " . . . potential and actual form"[102] proposed by Koenig - while referring to the musical possibilities given by a choice of a compositional paradigm and its particular iteration and formal outcome - in this case would be delegated to an interplay between the composer and a formal system. This higher-order operation in my view offers a possibility of both manual and algorithmic intervention in the "long-term form"[103], by constructing the interaction between human and algorithmic decisions as a dynamical system[104] and enabling the intervention of both into all layers of musical complexity.

The results of interactions in a dynamical system become unique as every variation which occurs in the system contributes not only to what is currently happening within it, but also the possible future states.

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[102] Denis Lorrain, "A Panoply of Stochastic 'Cannons'" , *Computer Music Journal*,Vol. 4, No. 1, MIT Press, (Spring, 1980), pp. 53-81, p.53

[103] Nick Collins, "Musical Form and Algorithmic Composition", p.105

[104] A system whose results are based upon memory and the output values are dependent on it's past states as well as it's outside-time inputs such as the decisions given in time by an algorithm or a human. In more formal dynamical systems this could be seen as time dependency and spatial dependency of variables and their relationships to the same point in time. see Appendix A.

## Intuition, improvisation, intervention

Xenakis, furthermore, clarifies two fundamental questions:

"These aspects of music are often referred to as 'parameters', but I prefer 'characteristics of sound'. 'Parameter' is a mathematical term, which has a very specific meaning; it has been borrowed from mathematics by composers in the wrong way, just as the term 'aleatoric' has been borrowed from physics in the wrong way. Aleatoric music simply means improvised music."[105]

"There are many probabilities available as functions, many with their own 'personality' which one can perceive from the different kinds of noise that they produce. "[106]

These two statements in my view permit to justify firstly human intervention in the form of improvisational practice instead of an atemporal *fixed media* composition in my musical practice. Secondly, an adaptation of different mathematical models (such as chaotic oscillators, feedback neural networks and non-linear dynamical systems in general) as opposed to stochastic processes to synthesize material[107] which also present rich potential "personalities"[108][See Appendix A].

[105] Iannis Xenakis, "Determinacy and indeterminacy", p.144
[106] Iannis Xenakis, "Determinacy and indeterminacy", p.152
[107] This decision is motivated by the properties which certain discrete dynamical systems (for example a discrete dynamical system which exhibits periodicity 3 is able to generate any length of periodicity as specified by Sharkovsky theorem and their importance in Physical Modelling but mostly by the variety of possible timbral characteristics and the their control, see Appendix A.;
Keith Burns and Boris Hasselblatt, "The Sharkovsky theorem: A Natural Direct Proof", *The American Mathematical Monthly,* 118(3), (2011), doi: 10.4169/amer.math.monthly.118.03.229)
[108] Iannis Xenakis, "Determinacy and indeterminacy", p.152

“From a theoretical computer science perspective, a program that modifies itself non interactively can be reduced to an equivalent non-self-modifying program due to its logical determinism. Only changes coming from outside the system, such as live coding edits, constitute irrational cuts that divide islands of rational history.”[109]

By considering improvisational practice as a source of indeterminacy, the act of composition is shifted to decisions which occur and unfold instantly and constitute, within the system, an act which cannot be undone. The process of atemporal composition is thus invalidated rendering the act of decision a momentaneous event informed by both rationality and intuition as well as unconscious and irrational reactions to the musical context.

The relationship of indeterminacy can be thus seen as a causal relationship between rational observation leading to an intuition which is tested through the act. At the same time the indeterminacy of irrational decisions in my view presents an additional degree of freedom as opposed to an atemporal rationality through which musical material is organised in minute detail through a potentially long decisional process.

Returning to Xenakis’ interventions - where he heavily alters both into the results of the calculated *algorithmic* structures and the symbolic implementation, thus giving the return to the redefinition of allowed transformations a possibility even when the final symbolic result (the score) is written - in my view also strongly reflect his stance upon the importance not only of rationality but of human intuition in sciences and moreover in arts[110] as:

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[109] Charlie Roberts and Graham Wakefield, “Tensions and Techniques in Live Coding Performance”, *The Oxford Handbook of Algorithmic Music*, Oxford University Press, (2018), p.18

[110] Iannis Xenakis, “Determinacy and indeterminacy”, p.148

“There is no such thing as creation by rationality. The computer, which has arisen through the wealth of achievements of the human mind through the millennia, cannot create anything new.”[111]

And is translatable to a role of *metis*[112] *,* where intuition mediates in form of strategies to resolve a *daedalic*[113] path which enables material solutions for abstract problems (it is Daedalus who acknowledges the problem and not the shell nor the thread nor the ant) leads to Xenakis' “Ex nihilo”[114] or more simply put “something from nothing”[115].

“The problem of nothingness is identical to the problem of originality. A composer should be original, should create his music uninfluenced by the past. In a way he should act as the whole universe does: Nothingness creating....”[116]

The aim of the act through technology in this research is thus not a construction of an autonomous entity capable of musical discourse but rather, by taking the analogy of the universe, a holistic interaction which accounts for the indeterminacy of thought.

Or to quote Sebastian Rodl “I think 'new ways of thinking' is not a good idea, . . . thinking is new and that's it.”[117]

[111] Iannis Xenakis, “Determinacy and indeterminacy”, p.148
[112] Bruno Latour, “On technical mediation”, p.30
[113] Bruno Latour, “On technical mediation”, p.30
[114] Iannis Xenakis, *Formalized Music*, p.207
[115] Iannis Xenakis, *Formalized Music*, p.258
[116] Iannis Xenakis, “Determinacy and indeterminacy”, p.155
[117] Sebastian Rodl, 250 anniversary of Hegel, “Is it too late for Hegel?”, personal transcription https://www.youtube.com/watch?v=tUWzPUJvFp8

# The System

To further clarify the concepts used throughout this thesis, I refer to *system* as the set of physical and logical entities that form the whole performance environment. The *physical* aspect being a drum machine, a computer, and the composer/performer. The *logical* being the *program* implemented through software. Furthermore, the term *algorithm* and the more loose definition *control structure* refer to the definitions in the previous sections. I refer to the material *process* of the execution of the commands specified by the algorithm within a musical context as *procedure* and a set of procedures as *decisional process.* Lastly, the term *structure* (without the *control* prefix) is used to indicate the *data* - which is necessary for a program to execute an implemented algorithm - in the context of a procedure.[118]

The program which is the software component of this research was written in the SuperCollider[119] programming language. This choice was guided by practical reasons; the object oriented paradigm upon which SuperCollider is built permitted the organisation into discrete parts which could be assembled independently and integrated into a system.[120] Practically, the development of the single parts (oscillators, sound processing algorithms, control structures etc) can be thought of as a parallel process to the construction of the system itself. This allowed me to define the heuristics, variable limits, and exploring the sonic possibilities of a single procedure independently before it being integrated with the other parts into a whole. Furthermore, the system is built in such a way that while it is executing, the user can rewrite the existing code and recompile it on the fly - a process typical of live coding

[118] Variable names found throughout the text are referred to the source code linked in Appendix B
[119] https://supercollider.github.io/
[120] Gottfried Michael Koenig, "Summary Observations On Compositional Theory", p.11

performances, for which SuperCollider is widely used.[121] This allows it to make structural changes to the whole program without having to stop it and reinitialize its operations.

Another fundamental aspect was the possibility of easy use of standard protocols such as MIDI[122], SysEx[123] and OSC[124]. This allowed for an integration with a hardware drum machine and midi control surface (Elektron Machinedrum[125]) and an OSC controller from a mobile phone (Clean OSC[126]).

The choice of using this specific drum machine was due to its intuitive workflow, the possibility of storing, managing, modulating and communicating data – secondly, over years of practice I acquired practical knowledge and experience with which I feel confident enough to affront live performance. Additionally i used a Bela.io[127] computer for some extra processing power needed for a reverb based on a physical model.

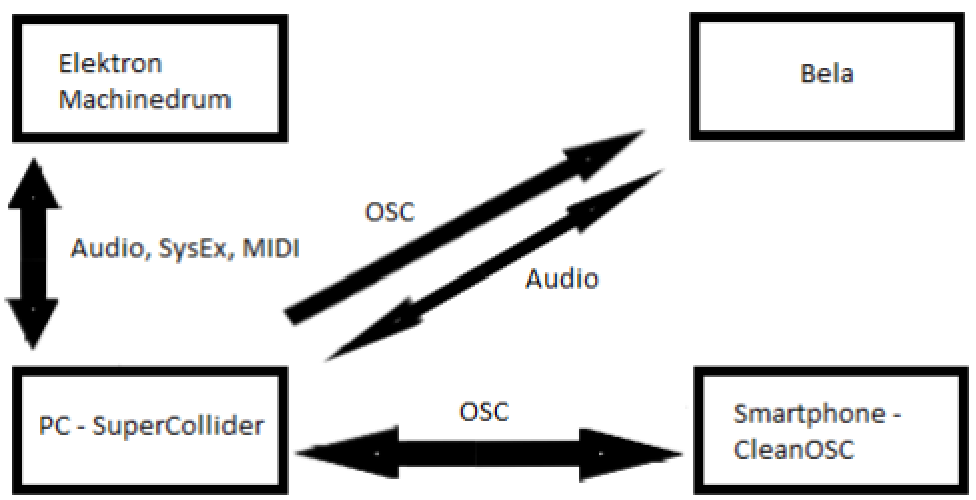


*Illustration 1 - A simple diagram of the system and its protocols*

[121] Charlie Roberts and Graham Wakefield, "Tensions and Techniques in Live Coding Performance"
[122] https://www.midi.org/
[123] https://www.midi.org/specifications-old/item/the-midi-1-0-specification
[124] https://www.cnmat.berkeley.edu/opensoundcontrol
[125] https://www.elektron.se/legacy-products/
[126] https://apps.apple.com/us/app/clean-osc/id1235192209
[127] https://bela.io/

The implementation of the system tries to tackle the need to build musical narrative in a context of real time performance and composition. The choice of the procedures regulating how musical parameters are organized through time tries to take into account a translation of the atemporal aspect related to the moment of "*bricolage*"[128] and replace it with interactive procedures which happen in *real-time*. These procedures allow the user to interact with a process by changing its parameters or redefining it completely while at the same time other processes (groups of algorithms in the control chain) are influenced by the same decisions or contribute directly together with the user to the outcome of the targeted process.
The necessity for the quotation marks in the term *real-time* resides in the fact that these procedures act mainly on the *outside-time*[129] organisation. This organisation of parameters independent of time, such as the choice of a musical scale, requires the procedures to be effective on different time scales and execution rates.

A clear example of this is a procedure which organises information about time events (in the implementation as binary strings), informed by time-variable parameters such as density (number of events/duration). Specifically, the resulting data is used on rhythmical as well as micro-time timescales leading to the requirement of new information at different time rates. On the other hand, two more considerations have to be taken into account. Firstly, the performer or an algorithm, may interrupt an ongoing *precomputed* structure and force a recalculation. The structures are organised into a discrete number of steps, specifiable by the user, generally between 32 and 128 steps. The time scale of these structures depends on the selected BPM as well as on the local division of time (specified inside the data itself or given by the user), making it possible to address variations which are on timescales of minutes to an execution of an arbitrary division of a bar for each step, making the limit depend on the

[128] Makis Solomos, "Cellular Automata in Xenakis' Music. Theory and practice", p.15
[129] Iannis Xenakis, *Formalized Music*, p. 183

computational power of the device which is executing the system.

Secondly, *outside-time* organisation is directly related to the underlying architecture specified by the algorithms. Meaning that the "combinatory capability"[130] offered by the system targets different levels of logical organisations. As an example, a system which governs variations of musical scale related to temporal collocations can have different decisional processes that govern the choice of which scale should be adopted at any particular time. These decisional processes make up different *combinatorics* each of them defining a criteria for admissible solutions and thus resulting in different sets of possible sound events. The choice of which decisional process to adopt then can become the target of another *higher order* process. Nonetheless, this concatenation of decisional processes, although hierarchical, admits intervention and possible interruption directly or *horizontally*. Meaning that the implementation of the system offers a possibility of changing relevant parameters of a certain process independent of the level at which the process occurs. For example local auto-regulation mechanisms for grain densities are implemented which in response to changes of grain durations, their time positions etc. keep the density consistent with a target value. But the same parameter of grain density can become target of a sequence of values from a running process, changed by the user or depend on the outcome of another higher level regulating self regulating mechanism (as stated above); the in-time unfolding is thus the real-time result of the particular logical states of the system in any given moment together with the actions of the user. With this organisation of possible *combinatorics* a parallel can be made to the act of bricolage described by Solomos. His work illustrates how the compositional work done by Xenakis is written though a manual reorganisation of numerically generated structures (numeric sequences associable to musical parameters). This intervention reflects the possibility to permute the phases of a musical work[131] and thus

[130] Iannis Xenakis, *Formalized Music*, p. 208
[131] Iannis Xenakis, *Formalized Music*, p. 22

reorganise the current material and its parameters.

In the current implementation of the system, reorganisation of source material (with its generating parameters and procedures) is made as an unfolding process, parallel and integrated to the performing act. This is achieved through systematic use of feedback networks and of the analysis-synthesis paradigm[132] (expand on inference and deduction) on one hand and on the other through a selection of algorithms whose end goal is to enact a musical procedure.

As an example the measure of amplitude of the sound output or density of the current rhythmical pattern can be placed in relationship with the procedure which generates the same patterns. This allows not only to specify the future reactions of the system to a change of output density but also gives access to the organisation of how the reaction must be handled by the system (the polarity of the response). At the same time a MIDI interface gives access to a target density parameter which specifies a target density if set.

Ultimately, the correspondence between single algorithms and the logical and manual operations upon the material requires access to operations which govern different time scale levels. As such this system tries to enable the performer to make decisions which govern arbitrarily not only micro or macro time scale parameters but to have an access to the "outside-time"[133] processes and organise them causally during the performance itself.

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[132] F. Brooks, A. Hopkins, Peter G. Neumann, W. Wright, "An experiment in musical composition", *IRE Transactions on electronic computers*, Volume EC-6, Number 3, (September, 1957), DOI:10.1109/TEC.1957.5222016

[133] Iannis Xenakis, *Formalized Music*, p. 207

# Practical outline

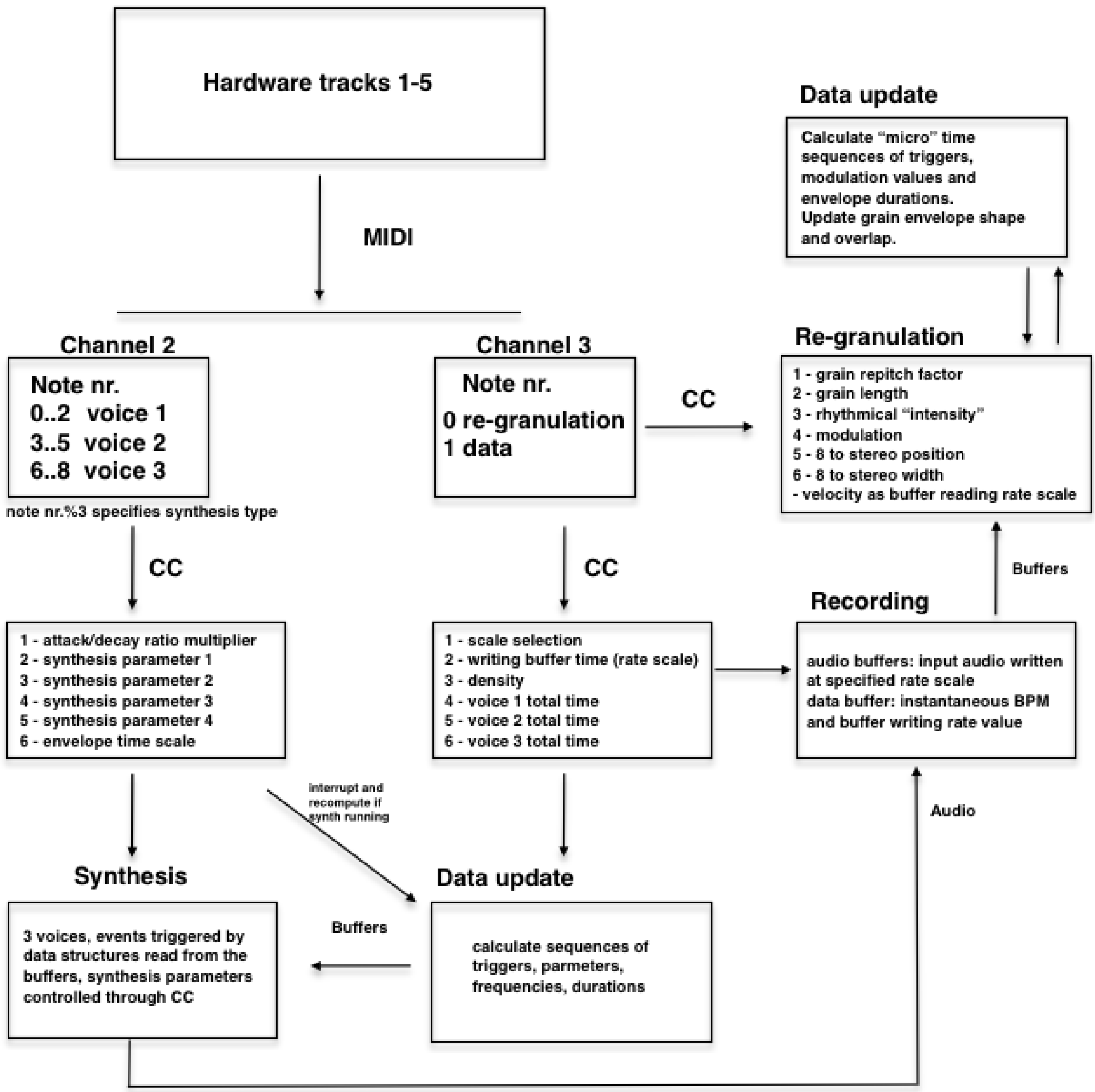


*Illustration 2 - Outline of the system through the MIDI protocol path*

While the program is implemented in the SuperCollider language, the choice of an Elektron Machinedrum provides the role of MIDI control, sequencing, and adding percussive sounds to the palette. At the same time it presents capabilities of input audio sampling through RAM memory, making the sound accessible for playback and manipulation as soon as it is recorded. These different types of *machines* are organised in sixteen voices, allowing to run the aforementioned functions in parallel.[134]

Furthermore, information relative to the state of the whole hardware is accessed through the System Exclusive (ie, SysEx) protocol. This permits access to all memory banks of all the voices, containing the values of set parameters and their timings. Information retrieved in this way can be manipulated and updated during the execution time of the system.

The software written in SuperCollider can be divided into four parts, namely data control (communication protocols and information I/O), logical control and *combinatorics* algorithms which provide analysis and structural organisation for the musical output, sound synthesis, and eight parallel buffers through which recorded material is reorganized in time.

## MIDI, OSC and audio inputs

Firstly, smpte clock information is acquired in the form of 24 pulses per quarter note. From this, BPM information is extracted and offered globally to the whole environment.

Furthermore, this information is written at sample rate to a buffer parallel to the memory buffers used for re-granulation and time manipulation. This allows us to have further information about the rhythmical organisation of the recorded sound.

Secondly, transport information is transmitted from the hardware including play and stop commands which govern the global execution on the system.

The selection of BPM is done manually through a control present on the Elektron hardware. From a practical point of view, the selection of BPM at which I perform depends on the relationship between times of execution of computed structures. This can lead to contrasts such as computation of musical sequences whose durations exceed the time before another recalculation of the whole structure is triggered leading to interruption and often erratic change of the musical output.

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[134] https://www.elektron.se/wp-content/uploads/2016/05/Machinedrum_manual_OS1.63.pdf

MIDI continuous controller (CC) messages are transmitted from five different parallel *machines* and sequenced in time. Each *machine* has six assignable encoders to any CC number controlling the assigned parameters and can trigger up to three different MIDI notes simultaneously.

Although just one note is used for each track, with its value used to indicate which type of algorithm is to be triggered. Of these five parallel MIDI *machines*, three are used to trigger and manipulate sequences of synthesized sound, one is used for the control of the re-granulation procedure and lastly, one *machine* interacts with global and *outside-time* parameters such as scale, length proportions of the computed time sequences to the current measure, density targets and when algorithms which calculate the melodic and rhythmical organisation of control sequences should update.

The rest of the available voices on the hardware is used for percussion synthesis and lastly, two channels for recording, manipulation and playback of recorded sound.

The control of the execution times of algorithms which recalculate rhythmical structures and retransmit information through the SysEx protocol to the hardware is implemented through the use of CleanOSC software for iOS. This application transmits OSC information in the form of triggers to the analysis-synthesis algorithm which in turn reconfigures the hardware with its result. It is important to note how in the case of the first five *machines*, the rhythmical information refers to

when structures get executed and how and when algorithms should be changed or updated.

Sound from the hardware is acquired by the system through an audio interface, the sources are organised in one stereo pair from the percussion synths and one channel from the resampling *machines*. Furthermore, a physical model of a toroidal surface is implemented on a Bela.io[135] computer and provides another stereo pair. This material is offered for direct output as well as recorded into five of eight channels of buffer memory in the SuperCollider software.

# Control Structures

Triggers arriving from the fifth hardware *machine* force a recalculation of the data provided to the synthesis algorithms and the update of general parameters used throughout the system. Three of the six CC parameters specify the duration (in bars) of each synthesis voice (contextualizing into the temporal domain the results of *outside-time* structures such as binary sequences, melodic and harmonic progressions etc). The other three parameters target respectively the selection of musical scale, total length of the resampling/re-granulation buffer, and density (a value used throughout the system as target density).

After updating the global parameters, the triggered procedure provides new data for the three synthesis voices. This data is organised firstly into a matrix which rows are sequences of the following parameters: frequency,total time of the amplitude envelope, amplitude, attack/decay ratio for the amplitude envelope,envelope curve factor,attack/decay ratio for modulation envelope 1 ,attack/decay ratio for modulation envelope 2, feedback parameter , integer number generally used as degree of nonlinear feedback, event trigger.

Each column is subsequently written to a buffer which as result contains the interleaved data from the matrix. A second buffer containing the duration of what is each column in the matrix is sent together with the interleaved buffer to the synthesis voices running on the server, implying that this procedure is executed independently for each voice.

Triggers from the first three *machines* create, update or interrupt the running synths on the server, the synths in turn execute the sequences previously written to the data buffers.

[135] https://bela.io/

# Measuring rhythms

In the implemented SuperCollider program this algorithm is used across various procedures to obtain bit strings (bit vectors), by fixing a measure of time for a single unit these strings represent events in a time cycle. The commodity of expressing information in such a way is that it can represent any arbitrary rhythmical combination.

The number of combinations is easily deduced by the maximum number a bit vector can represent (2 to the power of the number of bits) which poses the problem of the logical organisation of these combinations. The use of these bit strings is comparable to analogue trigger signals which can be used to instantiate functional events in dedicated components. Consequentially the generalization of the procedure which would provide the logical organisation of the events emerged through deduction led by practical issues.

One of these issues was the selection of times on where to apply *cuts* (A rhythmically structured re-scrambling of a reading index into a circular buffer[136] and thus cuts the rhythmical content of the output.).[137]

An idea came to me by remembering a notion from the course in analytical and functional harmony which i took during my bachelor's course; where the weight (*hard* or *soft*) of each subdivision is given in a binary fashion (4/4=h-s-h-s, the further subdivision of a quarter would be done in the same way), so by dividing a *measure* in 16/16 one would have the weights expressed in *Illustration 3*.[138]

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[136] A circular buffer is needed in order to have a constantly updated memory of a certain duration of an input signal. While the writing index circulates through the buffer, a reading index can be used to access a delayed representation of the signal by specifying the distance from the writing index. By controlling the distance from the writing index and the instants when it is changed, the chronological order and thus the rhythmical content of a signal can be manipulated.

[137] Nick Collins, "Interactive evolution of breakbeat cut sequences.", *Proceedings of Cybersonica, Institute of Contemporary Arts, London, England* (2002).

[138] Walter Piston, *Harmony*, 5th Ed., (revised by Mark Devoto, W.W. Norton & Company, Inc., 1987), p.189

1010101010101010 level %2 - 8 1/8 notes

1000100010001000 level %4 - 4 4/4 notes

1000000010000000 level %8 – two 2/4 notes

1000000000000000 level %16 – one 4/4 note

weights: 4010201030102010

and inverted to give how soft the beat is (0101010101010101 ...)

*Illustration 3 - Calculation of beat weight in a 16 bit vector*

I used this algorithm across various applications, the first was to apply a process of controlling the indexing of an audio buffer dynamically at moments in time which have a low rhythmical weight. This approach led me to enquire about how to summarize in a single value an ordering the rhythmical weights.

While there can be various methods to organize the distributions of ones and zeroes by density[139] and statistics[140], the same could be applied to the weights (an average value of *soft* or *hard* beats) but the mathematical relationships which are used to calculate the weights are based on basic principles (transforming numbers between bases). The curiosity of finding out how to find a solution drove many sleepless nights but during a fortunate bicycle ride i had a deduction which led me to first simply turn around the page where I wrote the distribution of weights in a measure and secondly to search for any other reasonable source of information upon this operation, the only one being a similarity to a "Markov Odometer"[141].

---

139 number of ones or zeroes on a bit array divided by the length of the array

140 for example by selecting/ordering bit arrays by average number of ones or by other means of statistics

141 Danilenko A.I., Silva C.E., "Ergodic Theory: Non-singular Transformations". (Meyers R. (eds)) *Encyclopedia of Complexity and Systems Science*. ( Springer, New York, NY, 2009), https://doi.org/10.1007/978-0-387-30440-3_183, p.8; https://en.wikipedia.org/wiki/Markov_odometer

| *0* | *1* | *2* | *3* | *4* | *5* | *6* | *7* | *8* | *9* | *10* | *11* | *12* | *13* | *14* | *15* | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | $2*\frac{1}{2}$notes | ↑2^3 ↓2^0 |
| 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | $4*\frac{1}{4}$notes | ↑2^2 ↓2^1 |
| 0 | 0 | 1 | 1 | 0 | 0 | 1 | 1 | 0 | 0 | 1 | 1 | 0 | 0 | 1 | 1 | $8*\frac{1}{8}$notes | ↑2^1 ↓2^2 |
| 0 | 1 | 0 | 1 | 0 | 1 | 0 | 1 | 0 | 1 | 0 | 1 | 0 | 1 | 0 | 1 | $16*\frac{1}{16}$notes | ↑2^0 ↓2^3 |
| 0 | 8 | 4 | 12 | 2 | 10 | 6 | 14 | 1 | 9 | 5 | 13 | 3 | 11 | 7 | 15 | Inverse bitmap (MSB[142] flip) index as measure of *softness* of beat | |

*Illustration 4 - calculation of weights by index in a bit array (0-strong beat, 1 soft beat)*

The advantage of this approach is that with a simple mathematical inversion, there is a self similar bijective mapping together with an inverse function which measures the amount of rhythmical instability; this value is given by remapping an arbitrary (in this case 16bit long, see *Illustration 4*) bitstring with the indexes obtained from the last row and reconverting the binary number to a base 10 representation (decimal number).

As seen from the last row, if taken as example the sequence of 4 quarter notes give the following values 0-2-1-3, exactly as the soft-hard weights from classical harmony (the first and the third beats are the strongest but the first is a little bit stronger than the third, the second and fourth are soft, with the fourth a bit softer than the second).[143]

For a pulse of ¼ the inverse bitmap yields:

[142] MSB - most significant bit, the number having the maximum value in a bit vector. In this case used to keep track of the inversion (flip) of the vector during the operations in this procedure.

[143] Richard Parncutt, "A Perceptual Model of Pulse Salience and Metrical Accent in Musical Rhythms", *Music Perception,* Vol. 11, No. 4, University of California Press, (Summer, 1994), pp. 409-464 , https://doi.org/10.2307/40285633

1000100010001000 → 1111000000000000 for simplicity and consistency with the values in the bitmap which express softness the result can also be MSB flipped:

0000000000001111 = 20 on a scale from 0->65535, the values can be furthermore scaled logarithmically to give a linear measure.

Firstly I used this procedure to measure the *weight* of entire sequences, throughout this text and in the code I refer to this value as *rhythmicity* or *intensity.*[144]

The first practical application of calculating this value was to the sequences (bit arrays) written by hand on the Elektron Machinedrum; by reading it's internal information through the SysEx protocol and analyzing it with this procedure.

The simplest implementation offsets the value by a random amount and calculated the inverse mask to obtain the corresponding sequence, which results to be a variation of the original one (giving a feeling of stability between *near* sequences and of *modulation* for distant ones, making the use of this procedure as a *relative* measure) and re-transferring it to the Machinedrum.

The second insight from this process[145] comes by looking at the bitmask, it's easy to see that the correspondence between the mapping and the position in time of the event (on the left):

1000100010001000 → 0000000000001111

0100010001000100 → 0000000011110000

0010001000100010 → 0000111100000000

0001000100010001 → 1111000000000000

[144] see Appendix B: _MAIN_2021.scd line 163 to 199;
The global variables ~weightFunc and ~revWeightFunc express the described algorithm in SuperCollider language. ~weightFunc takes a pattern/bit array and a base as input and calculates the intensity, while ~revWeightFunc takes an intensity and base as input and outputs the associated bit array.

[145] see Appendix B: __beatAnalysis.scd

*Illustration 5 - map correspondences of simple rhythms*

This mapping works in all bases, in order to reconstruct periodicities of different length it is enough to change the base by which the index is expressed (MSB flip). In base 3 and with sequence length of a multiple of 3 yields 100100100100 → 000000000111 etc (*Illustration 5*).

The number of levels present in a sequence is calculated as nBits/base (where nBits is the length of the sequence and base is the base used to express the index), for sequences of length non multiple of the base number, the bitmask has a number of offsets that corresponds to nBits%base, easier to see with the example in *Illustration 6* in base 4:

| sequence | | level bitmask |
|---|---|---|
| 10001000100010000 | → | 00000000000011101 |
| 01000100010001000 | → | 00000000111100000 |
| 00100010001000100 | → | 00001111000000000 |
| 00010001000100010 | → | 11110000000000000 |
| 00001000100010001 | → | 00000000000011110 |

etc

*Illustration 6 - map correspondences of different multiplicity*

It can be seen from the first line that the last time slot is the second in weight, because it falls exactly on the onbeat of the next hypothetical 4-period on the lowest level (biggest time span).

This decomposition is intended to measure all periodicities without having a process which has to compare all the relative offsets between events.

The practical implementation is the following:

1. Acquire data from the Machinedrum (16 sequences of the same length)
2. Measure the function value in all bases starting from 2, up to the length of the sequence (if the sequence is to be looped, a doubling of the sequence can improve the definition of the searched periods, for example doubling the 17 long sequence 10001000100010000 → 1000100010001000010001000100010000 would find 10000 as a 5-period)
3. the resulting value is bitmasked (bit and operation &) by the corresponding level and analysed if full, periodic (has at least two consecutive ones in the masked value 11), *alloperiodic* (is periodic of a different period, ex 1010 in base 4 is periodic in base 8), or if it contains only one 1 (useful for variating a level by adding a consecutive 1 to the level, giving it a period).
4. Any rhythm in this way can be filtered, combined, reconstructed or split into different voices by using the resulting analysis, for example a 3 over 4 rhythm 100110101100 could be split into two different voices, just by separating the masks, a rhythm can be variated just by keeping it's offbeats etc.

Furthermore the expansion and reduction of the number of bits present after transforming a sequence operates level wise, so any alteration in its length converts sequences from a length to another by keeping identities (1000100010001000 (16) has the same resulting rhythmicity measure as 10101010 (8) and 10000000100000001000000010000000 (32) etc).

## Buffering and Re-granulation

As mentioned above, the external audio inputs and the result of synthesis are written to a series of fixed size buffers, one for each input channel. The length of the input buffers is specified in proportion to one bar, calculated at the instantaneous BPM value at a meter of 4/4. The choice of 4/4 is related to its unitary value, by taking one bar as measure, all other tempi are specifiable in relation to this reference simply by linear combination. To avoid dynamic reallocation of the buffer which would fit the buffer size to a determined duration, the physical size of the buffer in the memory is kept constant and initialized at 20 seconds at the current sample rate.[146]

In consequence of this, the speed of the writing index is altered in order for it to cover the buffer in the specified time (in bars), interpolation and upsampling being managed internally by SuperCollider[147]. The rate at which the index writes is given by the following formula:

$$R_w = T_b/(T_{bar} * N_b)$$

where $T_b$ is the physical time of the buffer in seconds (number of samples*sampling rate), $T_{bar}$ is the duration in seconds of a bar at current BPM and 4/4 meter (240/BPM) and $N_b$ is the specified target duration of the buffer (time in which the writing phase completes one whole cycle).

Obviously an alteration of the rate while the phase is not zero would make the duration of the buffer not a rational proportion of musical time referenced to the BPM. In order to tackle this problem, two additional buffers are added which store, for each sample, the information about the instantaneous BPM and $R_w$. Additionally, the current writing position is shared with the reading part of the algorithm through the use of a Bus SuperCollider object which permits the

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[146] The choice of 20 seconds is mainly due to having a buffer big enough not to have resampling artifacts. The "real" duration of the buffer varies due to the change in speed of the writing and reading indexes, introducing the necessity of resampling.

[147] https://doc.sccode.org/Classes/BufWr.html

routing of audio rate data between different dsp objects (SynthDefs).

At this point the recorded material is ready for reading, this is achieved through the use of the Warp1 class already present in the SuperCollider language. The class presents itself as a “A granular time stretcher and pitchshifter”[148], meaning that for a given buffer it offers a reading operation through overlapping grains[149]. These grains are enveloped parts of the buffer with controllable duration, read at a specified rate (frequency shift) with the reading position specified by a pointer parameter.

The default envelope is not zero-padded resulting in accumulating energy (and thus audible artefacts) even when no signal was present in the buffer.

This required a manual specification of an envelope. The choice I made was to use a zero-padded Hamming window[150], with an additional control over the shape, namely the extension of the centre point (when the value of the function is maximum). This choice is mainly due to the flatness of the frequency characteristics with the aim to preserve the spectral content of the source signal.

After this operation the window is resampled to the given length of the window (a parameter manually controlled through MIDI CC), giving a proportional increase in the sharpness of the edges of the envelope as the extension of the maximum value gets higher.

In the implementation the choice of how this extension is controlled is given by the following constraints:

- the overlap between grains decreases inversely proportional to the grain time
- length
- the window envelope is sharper at longer durations

[148] https://doc.sccode.org/Classes/Warp1.html
[149] Curtis Roads, *Microsound*, p.20
[150] https://ccrma.stanford.edu/~jos/sasp/Hamming_Window.html

The first constraint tries to manage the passage from micro-time to the “sound-object”[151] transition at about 100-200ms, giving a possibility for rhythm to emerge.[152] Being that at these durations (>100-200ms) the sound content of the re-pitched source begins to be intelligible in consequence an overlap results in a reproduction of the same material offset by an amount of time (window duration/overlap). Being this operation musically quite uninteresting, the control of the absence of overlap to retain rhythmical organisation seemed necessary. Sequently the second constraint deals with another musical aspect, a Hamming window results in a dull fade-in/fade-out at these time lengths. In order to accentuate the rhythmical aspect of the musical gesture the *attack* and *decay* times are shortened and the maximum extended by extending the centre point and resampling the envelope. This operation is implemented in discrete steps depending on the overlap factor (fixed extension size for each integer valued overlap).

## Reading index

The indexing into the buffer is specified as an offset from the writing position, typical of a circular buffer. The said offset depends on different factors. Firstly, a buffer containing 32 intensities specified by the algorithm described for the rhythmicity bitmask is read (Index.ar[153], non-interpolated reading) by a ramp signal (Phasor.ar), the result of this operation can be defined as the *current* or *momentaneous intensity*. Secondly, the same ramp signal reads a sequence of ones and zeroes, namely triggers also provided by the same bitmask algorithm (while the first is just the values of the intensities of the single timesteps, the second

[151] Curtis Roads, *Microsound*, p.20
[152] Richard Parncutt, “A Perceptual Model of Pulse Salience and Metrical Accent in Musical Rhythms”, p.437
[153] https://doc.sccode.org/Classes/Index.html

is the result of the algorithm which provides sequences by given intensities).

This ramp signal [contained in the variable barPtr] is synchronized to the MIDI clock, the re-triggering of the phase occurs at large timescales (128 bars of MIDI "ticks"[154], set manually) to offer a rescaling of the reading index to large timespans. The scaling is obtained by controlling the rate of the ramp signal which is specified manually as a multiple of one bar. After defining this signal it is useful to cover how the data which it is used for to read is generated.

An *intensity* and a *density* value are provided by the control structures. The *intensity* value, as seen earlier is an integer having a one to one mapping with the sequences it represents, the *density* value is used to specify the wanted proportion between ones and zeroes.

The nearest value of *intensity* is then found by flipping the LSBs[155] until the wanted density is obtained and thus the corresponding sequence.

This sequence is written to a buffer, which is read by the indexing signal defined above defining a trigger [intT in the code]. When this trigger occurs, the current intensity value is used to find a randomly smaller (more stable) value which will be the target time offset for the reading index from the writing index, producing jumps or cuts in the reading index.

Furthermore, a bar offset value is specified randomly, indexing the same time place (slot) in different bars. Being the ramp signal rate manually definable (and sequenced by the Machinedrum hardware), it offers a direct control of the time scaling of these operations.

Musically this results in a wide spectra of gestures which have the potential to rescale time structures, densities and organize swiftly outside-time structures of rhythmical differences.

With the latest I imply that the rhythmic intensity as a value is a construct of hypothesis which do not (nor try to) describe perception of rhythm in absolute terms.

An additional modulation is added as an offset to the reading index, originally linear with a

[154] midi ticks are received as 24ppq (pulses per quarter note)

[155] LSB - Least significant bit, the bit having the lowest value, see footnote *119*

duration obtained from a gaussian distribution TgaussRand[156] with average specified by the density parameter in proportion to the total duration of the ramp input:

```
modTime=( (modT.collect( {|i| TGaussRand.ar(-1.0,1.0,i-0.01).abs } ))  *(oneBar*nBars))
+((oneBar*intMod)/(density.linlin(0.0,1.0,1.0,32.0)));
```

Furthermore, this signal is then reshaped by exponentiation (the degree of which is given by a Dbrown[157] object). Musically this adds a contrast to the discrete jumps induced by the first method, smoothing out or even destroying the rhythmicity at higher amounts (specified manually by MIDI CC and stored in the modAmt variable).

Frequency offsets and re-pitching are manually (or hardware sequenced) assigned by MIDI control and specified in proportions to the ratios of the scale currently chosen by the whole system[158]. Lastly this value is divided by the value $R_w$
and thus rescaling the re-pitch parameter to the rate at which the signal was written to the buffer, guaranteeing a stable reference pitch.
Lastly an additional envelope is generated at each of the triggers with the same duration of the modulation, the envelope controls the amplitude of the audio signal resulting from the granulation.

The whole structure of control acts on eight parallel buffers so all of these parameters are calculated for each of these instances. The audio output, being of eight different processes is

156 https://doc.sccode.org/Classes/TGaussRand.html
157 https://doc.sccode.org/Classes/Dbrown.html
158 The SuperCollider language provides a Scale class which permits the specification of new scales and contains a ready-made exhaustive list of musical scales.

mixed through the SelectXFocus[159] class, which allows mixing of multichannel audio by the specification of a *centre* channel and the *width* of amplitude decay in function of the distance from the centre channel, the two controls are specified by MIDI CC parameters.

This process is repeated twice to create a stereo pair in output, each channel having a different mix of all the eight inputs, this is obtained from one control by *mirroring* the centre channel (L=N, R=7-N , N=0...7).

[159] https://doc.sccode.org/Classes/SelectXFocus.html

# Musical Output

The first compositional output from this research consists in a published work of three pieces named "Line of Aion"[160]. The guiding principle into making this work was to delocalize repetition by shifting rhythmic material in time through regranulation. The layers of repetition originate from the hardware drum machine which permits me to save and recall the state of the parameters and the programmed events. The recalled structures control both the generation/synthesis of the material and its regranulation. As seen earlier, the drum machine is both used as a sound source as well as a midi controller which acts upon the algorithms by both providing real-time changes and setting parameters for the calculation of data structures.

Due to the nature of the algorithms and their behaviour, the resulting layer of control which is generated by the algorithms upon the synthesis and the regranulation doesn't necessarily provide a one-to-one mapping of results and inputs.

The simplest example of which would be setting a range on a random number generator, while the parameters can remain constant, the nature of the operation necessarily has to provide uncorrelated results.

This constancy of heuristics prompted me to study how the provision of repetitive parametric structures provokes different sonic output, and how my interaction with the system could follow the evolution of the differences in a subtle and undisruptive way.

The differences thus created on the unfolding material derive from the differences in the results provided by the algorithms with the same input conditions and secondly from my interaction to the changing musical situations throughout the compositions. The aim is a

[160] https://mossa.bandcamp.com/album/line-of-aion

homogeneous dialogue which tries to follow the instances of repetition and highlight the differences in the musical output throughout its manifestation in time.

The repetition of parameters can be described as a time localization of changing properties which does not necessarily correlate directly to an immediately perceptible repetition of the sound heard by the listener/composer. This aspect of rhythmicity transpires through the structural changes and the different unfolding situations resulting in a repetition of change.

In my view this repetition of context and the formal differences which consequently emerge can be viewed through the idea of parallax.[161] Žižek presents the concept of parallax through the work " . . . Tender Is the Night , F.Scott Fitzgerald's masterpiece . . . "[162] where through the concept of *minimal difference* he traces the different versions of the work as an aim at a form which the author (Fitzgerald) could reach only through rearranging the order of the chapters, or by rewriting different perspectives offered by the single characters. The resulting versions all differ but are considerable as the same work of literature, not just by their title but also by their common lack of being an ideal form. This concept of minimal difference, and the change of perspective within the same work, prompted me to focus upon the differences as perspectives on the same underlying logics of the system with my decisions being an active part into shifting the differences and thus the formed perspective.

The second published work is untitled and consists of a live performance performed in January 2021 at Annastate, Den Haag and published the same month.[163]

In this instance the whole system was in its complete form. By offering a feedback of structures through the SysEx protocol, it permits a modification of the repetitive structures

[161] Slavoj Žižek, *The Parallax View*
[162] Slavoj Žižek, *The Parallax View*, p.18
[163] https://ovaal.bandcamp.com/album/aleksandar-koruga

mentioned above through rhythmical analysis and variation by the implemented algorithms. This offered me a possibility of tracking and changing musical situations and to alter the unfolding sound through more or less radical changes. The resulting interaction is in my view describable as tuning a radio receiver to the ether of possibilities, where each move of the tuning also disrupts the configuration of the ether, much as a change of geographical location. This shift in my view offers another perspective on repetition where the interaction itself, given the indeterminacy of my actions into the musical flow, traces a path through the *potential form*. This path is hardly retractable in a systematic way, given the nature of the dynamics which emerge by design and the improvisatory nature of the performance itself.

Nonetheless it represents a form of repetition in the sense that the act itself is a reflection of practice. In order to orient myself in the developed architecture of the system and how my actions result in changes, I needed to develop a performative practice. This practice is in turn the result of repetition of actions, trial, and error. The performance in itself can thus be viewed as an evolving shift of perspectives where instead of the whole *composition* being a different view on the same *ideal*, the flow of interactions itself is the shifting in the *parallax view*. This in my view coincides with different perspectives throughout the multidimensional instances of the *transparent sandwich* described by Xenakis.[164] By acting on different layers throughout the performance and letting intuition and practice guide my improvisatory interactions, I try to address the instantaneous aspect of what could be thought as the organisation on a symbolic level of representation of music through code and digital memory.

[164] Iannis Xenakis, “Determinacy and indeterminacy”, p.146

# Conclusion

This research started from an interest into understanding the limits of symbolic description of music within the context of algorithmic music, specifically the consequences of systematic treatment of material during live-performance. The "uncertainty in the formal methods"[165] led me to consider not only practical aspects of how to implement a system, but also of how the uncertainty of the human decision can dialogue with the deterministic nature of computation.

I tried to understand the role of the musician/composer through concepts such as technical mediation and computability. This results in a dialogue between uncertainty and potential form which places the human in a framework where thought and aesthetics inform and interact with an algorithmic system through the use of dynamics.

Dynamic systems seen in terms of feedback become essential for a dialogue which is thus developed. The interactions between the human and non-human components of the system are placed in a loop whose non-linearity gets ultimately represented by human thought.

Symbolic music, in this work, represents the limit set of potentials which can be described formally. This permitted for the development of a performative and improvisatory practice by using the implemented system and to progressively adapt and expand the technical implementations to new ideas. This research resulted into two published collections of works

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[165] Julian Rohrhuber, "Algorithmic Music and the Philosophy of Time", edited preprint of Chapter 2 in: Alex McLean and Roger T. Dean, *The Oxford Handbook of Algorithmic Music*, (Oxford University Press, 2018), p.9

which try to be a cut into a specific moment of interaction. These interactions try to represent my momentaneous aesthetical ideas which are governed by attentive listening and *feeling* the changes that are fueled by my actions and result into musical context. This brings in my opinion to a dialogue in which formal and improvisatory thought can be merged to express a unique meaning.

# Bibliography


Berg, Paul. “Composing Sound Structures with Rules”, *Contemporary Music Review*, Vol. 28, No. 1, February 2009, pp. 75–87

Burns, Keith and Boris Hasselblatt. “The Sharkovsky theorem: A Natural Direct Proof”. *The American Mathematical Monthly,* 118(3), 2011, DOI:10.4169/amer.math.monthly.118.03.229

Brooks, F., A. Hopkins, Peter G. Neumann, W. Wright. “An experiment in musical composition”. *IRE Transactions on electronic computers,* Volume EC-6, Number 3, (September, 1957), DOI:10.1109/TEC.1957.5222016

Chaitin, Gregory J. “A Theory of Program Size Formally Identical to Information Theory”. *Journal of the ACM*, Volume 22, Issue 3, July 1975), https://doi.org/10.1145/321892.321894

Chang, C.C. and H.J. Keisler. *Model Theory (Studies in logic and foundations of mathematics)*.3rd ed. North-Holland,1973

Collins, Nick. “Musical form and algorithmic composition”. *Contemporary Music Review* , 28 (1), (2009), 103–114

Collins, Nick. "Interactive evolution of breakbeat cut sequences." *Proceedings of Cybersonica, Institute of Contemporary Arts, London, England* (2002).

Danilenko, A.I. and C.E. Silva. “Ergodic Theory: Non-singular Transformations”. *Meyers R. (eds) Encyclopedia of Complexity and Systems Science*. Springer, New York, NY. (2009) https://doi.org/10.1007/978-0-387-30440-3_183

Exarchos, Dimitris and Yannis Stamos. “Iannis Xenakis’s writing and outside-time musical structures”. *Proceedings of the fourth Conference on Interdisciplinary Musicology (CIM08)*, (2008) Guattari, Felix. *Chaosmosis: An ethico-aesthetic paradigm.* Indiana University Press, 1995

Gunnarsson , Bjarni and Darien Brito. “Implementing Koenig’s Project 2”. https://www.researchcatalogue.net/view/1081939/1081944

Hill, Robin K. “What an Algorithm Is”. *Philosophy & Technology,* 29, 35–59, Springer ,2016), https://doi.org/10.1007/s13347-014-0184-5

Jaffe, David A. and Julius O. Smith. “Extensions of the Karplus-Strong Plucked-String Algorithm”, *Computer Music Journal,* Vol. 7, No. 2 (The MIT Press, Summer, 1983): pp. 56-69

Koenig, Gottfried Michael. “Summary Observations On Compositional Theory”. Utrecht State University, Institute of Sonology, (1971)

Ladyman, James, James Lambert, Karoline Wiesner. “What is a complex system?”. *European Journal for Philosophy of Science,* 3(1), (2013), DOI:10.1007/s13194-012-0056-8

Latour, Bruno. “On technical mediation”. *Common Knowledge*, V3 N2 (Fall 1994)

Lewis, George and Benjamin Piekut. *The Oxford Handbook of Critical Improvisation Studies*. Volume 2. New York, New York: Oxford University Press, 2016

Lorrain, Denis. “A Panoply of Stochastic 'Cannons'”. *Computer Music Journal*,Vol. 4, No. 1 (MIT Press, Spring, 1980): 53-81

Mendelson, Elliott. *Introduction to mathematical logic: Discrete mathematics and its applications*. Sixth edition. CRC Press/Taylor & Francis Group, 2015

Nestruev, Jet. *Smooth Manifolds and Observables*. Graduate Texts in Mathematics, 220, Springer, 2003

Parisi, Luciana. *Contagious architecture: Computation, aesthetics, and space*. mit Press, 2013

Parncutt, Richard. “A Perceptual Model of Pulse Salience and Metrical Accent in Musical Rhythms”. *Music Perception,* Vol. 11, No. 4 (Summer, 1994), pp. 409-464 , (University of California Press, 1994), https://doi.org/10.2307/40285633

Piston, Walter. *Harmony*. 5th Ed. revised by Mark Devoto, W.W. Norton & Company, Inc, 1987

Roads, Curtis. *Microsound*. MIT press, 2004

Roberts, Charlie and Graham Wakefield, “Tensions and Techniques in Live Coding Performance”, *The Oxford Handbook of Algorithmic Music*, (Oxford University Press, 2018) DOI:10.1093/oxfordhb/9780190226992.013.20

Rohrhuber, Julian. “Algorithmic Music and the Philosophy of Time”. edited preprint of Chapter 2 in: Alex McLean and Roger T. Dean, *The Oxford Handbook of Algorithmic Music*, Oxford University Press, 2018

Rutz, Hanns Holger. “Marking a space of algorithmicity”. *xCoAx .org Computation Communication Aesthetics &X,* Bergamo, Italy, (2016)

Shaw, Robert. *The Dripping Faucet as a Model Chaotic System*. The Science Frontier Express Series, Aerial Press, 1984

Solomos, Makis. “Cellular Automata in Xenakis' Music. Theory and practice”, *Proceedings of the International Symposium Iannis Xenakis,* (Athens, May 2005)

Sprott, Julien Clinton. *Elegant Chaos: Algebraically Simple Chaotic Flows.* World Scientific Publishing Company, Incorporated, 2010

Squibbs, Ronald. “Some Observations on Pitch, Texture, and Form in Xenakis' Mists”. *Contemporary Music Review*, Volume 21, Issue 2-3, (2002)

Thomas, René. “DETERMINISTIC CHAOS SEEN IN TERMS OF FEEDBACK CIRCUITS: ANALYSIS, SYNTHESIS, "LABYRINTH CHAOS"”. *International Journal of Bifurcation and Chaos*, Vol. 09, No. 10, (1999): pp. 1889-1905

Turing, Alan M. “On Computable Numbers, with an Application to the Entscheidungsproblem”. *Proceedings of the London Mathematical Society*, Volume s2-42, Issue 1, (1937), Pages 230–265

Wong, Bang. “Gestalt principles (Part 1)”. *Nat Methods* **7,** 863 (2010). https://doi.org/10.1038/nmeth1110-863

Xenakis, Iannis. “Determinacy and indeterminacy”. *Organised Sound* , Volume 1 , Issue 3 , (Cambridge University Press, December 1996) , pp. 143 - 155

Xenakis, Iannis. *Formalized Music: Thought and Mathematics in Composition*. revised edition. Stuyvesant NY: Pendragon, 1992

Žižek, Slavoj. *The Parallax View*. Cambridge, Massachusetts: The MIT Press, 2006

# Appendix A: Nonlinear dynamics and chaos

“A dynamical system is one whose state changes in time. If the changes are determined by specific rules, rather than being random, we say that the system is deterministic; otherwise it is stochastic. The changes can occur at discrete time steps or continuously. “[166]

Nonlinear systems are used throughout this work through the described procedures and algorithms. It also plays an important role in the implementation of the various oscillators used for sound synthesis.

I found the description into feedback *loops* and *nonlinearities* categorized by their logical/mathematical connections, proposed by René Thomas[167], particularly useful when dealing with different sonic possibilities. The consequence of this organisation is that similar categories of functions (trigonometric, exponentiation etc.[168]) provide similar time behaviours (output signals), bearing sonic similarities.

Symbolically, dynamics are represented through the concept of differential equations. A differential (dy) represents the variation of the value of a function (y(x)=f(x)). The relation between the differential to an infinitesimal variation of one of its variables (x) - as is the simple case of speed which is represented as a variation of position in respect to a variation in time v=dx/dt - is called a derivative (dy/dx).

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[166] Julien Clinton Sprott, *Elegant Chaos: Algebraically Simple Chaotic Flows*, (World Scientific Publishing Company, Incorporated, 2010), p.1

[167] René Thomas, “DETERMINISTIC CHAOS SEEN IN TERMS OF FEEDBACK CIRCUITS: ANALYSIS, SYNTHESIS, "LABYRINTH CHAOS"”, *International Journal of Bifurcation and Chaos*, Vol. 09, No. 10, pp. 1889-1905, (1999)

[168] https://doc.sccode.org/Overviews/Operators.html

When the derivative is a known function – for example variation of velocity due to acceleration – the system is expressible by a differential equation.

When linear combinations of solutions to the unknown function y give other valid solutions, a system is said to be linear and is expressible as: $a(x)y' + b(x)y = c(x)$ where $y' = dy/dx$ and a, b, c are arbitrary functions in x; furthermore a, b and c are called *dependant variables* while x is the *independent variable* (usually time).[169]

As seen above, the differential involves the relationship between the value of a function in two different points (or instants of time), this permits to reduce an expression of the equation in terms of a recurrence relation, for example in the case of an accelerating object: $v(t2)= v(t1)+a*(t2-t1)$.[170]

This permits categorizing dynamical systems as feedback *loops* where the updated value of a function on each iteration is dependent on its previous value added to a difference; strikingly similar to Xenakis second interpretation of Symbolic Music involving three sets: values, differences and iterations.[171]

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169 Julien Clinton Sprott, *Elegant Chaos*, p.3
170 here for the sake of simplicity i use a finite difference and not a differential, **a** is a "generic" acceleration
171 René Thomas, "DETERMINISTIC CHAOS SEEN IN TERMS OF FEEDBACK CIRCUITS: ANALYSIS, SYNTHESIS, "LABYRINTH CHAOS"", p.1889

# Nonlinearity

“It is essential to realize that both nonlinearity and appropriate feedback circuits are required for such non trivial behavior as multistationarity, stable periodicity or deterministic chaos ”[172]

“Feedback relationships form the logical path of the data which is describing a given state of the system represented by the value of the variables and of the fixed parameters. In the case of time as an independent variable, this path is the relationship between the state of the system in any given moment and it's immediate future.[173]

The behaviour of such systems, even in case of simple equations with one feedback loop such as the *logistic map* ($x_{n+1}= a* x_n (1-x_n)$, where a is a scalar, $x_{n+1}$ and $x_n$ two consecutive instances of the variable x)[174], can be described as “*complex*”[175].

One of the properties of such systems is *long-term* unpredictability meaning that: “ . . . the system state at one instant of time is causally disconnected with its state far enough into the future.”[176]. ( Furthermore, Ladyman et al.[177] try to account for the various cross-field definitions of complex systems, given the numerous scientific fields where the necessity for describing such phenomena exist, stating that “ . . . there is no concise definition of a complex system . . .”[178] and:"Nonlinearity is often considered to be essential for complexity.“[179].)

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[172] René Thomas, “DETERMINISTIC CHAOS SEEN IN TERMS OF FEEDBACK CIRCUITS”, p.1889
[173] Julien Clinton Sprott, *Elegant Chaos*, p.3
[174] n and n+1 are the discrete iterations by which a new value gets calculated, this iteration sequence is thus time-discrete and. The update of the function placed in-time can be calculated asynchronously, as it happens with the macro time feedback between SysEx structures and their analysis and re-synthesis.
[175] Julien Clinton Sprott, Elegant Chaos;
Robert Shaw, *The Dripping Faucet as a Model Chaotic System*. (The Science Frontier Express Series, Aerial Press, 1984);
James Ladyman, James Lambert, Karoline Wiesner, “What is a complex system?”, *European Journal for Philosophy of Science,* 3(1), (2013), DOI:10.1007/s13194-012-0056-8
[176] Robert Shaw, *Dripping Faucet As A Model Chaotic System*, p.2
[177] James Ladyman et al., “What is a complex system?”
[178] James Ladyman et al., “What is a complex system?”, p.1
[179] James Ladyman et al., “What is a complex system?”, p.4

The consequence of this temporal disconnection is pseudo-random behavior known as deterministic *chaos*, nonetheless this leads to a high susceptibility to even small variations of initial values of the variables (known as initial conditions) or perturbation of the system also known as the *butterfly effect.* Even though deemed deterministic, it is hard to physically separate experimentally statistical fluctuations from variations in conditions of the system and replicate the same results even when there is a high degree of precision upon the initial and contour conditions.[180] On the other hand when such systems are implemented in discrete form on digital computers - they pertain to their unpredictable nature - but due to the discreteness of the digital approximation a system run with the same initial values will produce always the same output. The use of feedback loops as logical relationships between the recurrence terms and nonlinearities as components of this logic[181] permits a more consistent organisation of the output states. The end result being diverse strategies for the use of such systems for sound synthesis, parametric control, and as models for interaction between human and algorithmic decisions.

"A first conclusion is that provided a proper logical structure is preserved the mere ability to generate chaotic dynamics is rather insensitive to the precise nature of the nonlinearity used. While the very existence of a chaotic dynamic displays little sensitivity toward the nature of the nonlinearities chosen, it is certainly not a surprise that the shape and other specific characteristics of the chaotic attractor depend at least to some extent on the nature of the nonlinear functions used."[182]

[180] Robert Shaw, *The Dripping Faucet as a Model Chaotic System*
[181] René Thomas, "DETERMINISTIC CHAOS SEEN IN TERMS OF FEEDBACK CIRCUITS", p.1904
[182] René Thomas, "DETERMINISTIC CHAOS SEEN IN TERMS OF FEEDBACK CIRCUITS", p.1892

# Appendix B: SuperCollider code

All the code written during this master's research period is available at the public GitHub repository https://github.com/aleksandarkoruga/SuperColliderCode

- Under the folder System sets of patches and externals which define the developed system can be found:
    - _MAIN_2021.scd Self contained patch which defines the system
    - SysEx_OSC_INTERPRETER2.scd SysEx interpreter, Midi and Osc protocol management, on a Windows computer has necessarily to run in a second interpreter due to a bug[183] in the programming language.
    - __beatAnalysis.scd contains the procedure of analysing SysEx data and separating rhythms into different voices. It returns a collection of 256 rhythmical patterns organised in 16 memory banks of 16 voices each and uploads them to the specified memory slots on the Machinedrum hardware through the SysEx protocol.
    - bela_plate.cpp An implementation of a dynamically resizable toroidal surface model as a reverberant body.
    - The folder Extensions contains:
        - MarkovFb A Markov chain implementation which recalculates the single column probabilities, making the most frequent value more

[183] https://github.com/supercollider/supercollider/issues/5335

probable. This feedback loop in the probabilities is useful to create value streams which start with a random distribution and become more cyclic with each iteration.

- NeuralNetFb This is an implementation of a 4x4 layer neural network with an input and output stage of 16 cells, the output is fed back into the input. The threshold and bias values of the single nodes/“neurons" are regulated in a manner to maximize differences between iterations.
- NumericalExtensions This class contains useful extensions for the numeric classes which are missing in the original language. This includes functions such as converting floating point numbers between bases and calculating logarithms in bases different than e, 2 and 10.
- RhythmKernels A set of functions used in the early stages of the system which contain some deterministic procedures to calculate breakbeat rhythms and combinations of bit shifted binary strings.
- KStrong (and variants) various versions of a Karplus-Strong model based on David A. Jaffe and Julius O. Smith, Extensions of the Karplus-Strong Plucked-String Algorithm.

- The folder Patches contains single oscillators, isolated components of the system and self -contained patches which test procedures.
    - KarplusStrong.scd Various Karplus-Strong techniques explored, the folder KS_String_Sim_SC&cpp/KS_String_Sim_SC&cpp contains c++ sources and descriptions necessary for the execution of the .scd patch.

- OscIntensityDensityFunc.scd Mitigation between rhythmic intensity and pattern/bit array density.
- Oscillators_2020_20201118.scd Various feedback oscillators including a Mandelbulb (3d Mandelbrot fractal) formula, FFT resonators and conformal mapping.
- _Buffers_as_params_20201022.scd Sending data structures as buffers to synths running on the server.
- _Scale_ratio_ordering.scd A method for ordering and constraining scale ratios to predefined length arrays.
- test_periodicity_func_20201109.scd First implementation of dividing a rhythm into sub-periodicities and spreading events through multiple voices.
- _buffers_ (and variants ordered by date) Granulation procedures and buffer cutting.
- _convolutionAnalysis (and variants by functionality) implemented convolution and cross correlation for analysis and control.
- _first_system.scd The very first implementation of a self contained system.
- _standard map.scd Computation of standard-map values.
- blockDecompositionMethod.scd a method to decompose and analyse the complexity of bit strings https://complexitycalculator.com/HowItWorks.html, complexities.txt is needed in order to make it work.
- conformalOSC.scd A feedback oscillator with a conformal map nonlinearity.
- doublependulum.scd Implementation of a double pendulum.

- flanger_ (and variants) A Flanger (buffer index modulation) implementation
- fractalFFT.scd Oscillators based on the Mandelbrot formula
- grainenvs.scd Calculation of envelopes for granulation
- iterating envelopes.scd Iterating envelopes (a variable length envelope retriggers when it finishes)
- synthdefMassSpring.scd A mass-spring model