Indeterminacy / Unfigurability

Lucie Nezri
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Abstract

This thesis looks at the relation between the computational notion of indeterminacy in relation to unfigurable percepts, and specifically how the microscopic motions emerging from stochastic processes can prompt situations of perceptual confusion.

The research bridges different contexts and disciplines, pertaining mainly to music but also choreography and computer science theory. It is anchored in Iannis Xenakis's experiments with Stochastic Synthesis, which is the central compositional tool presented in this thesis to illustrate the notions of indeterminacy and unfigurability. The works and writings of James Tenney, Michael Winter and Catherine Christer Hennix are also influential in this research.

As it played an enlightening role in my work, stochastic synthesis will have a key place in this thesis, both in its content and organization. Chapter 1 introduces the theoretical frame in which the research has evolved and preliminary discussions on indeterminacy and unfigurability. The next chapters follow from stochastic synthesis' two basic elements of definition: its random walks on the amplitude and time dimensions. Chapter 2 presents compositions suggesting degrees of noisiness caused by the presence and manipulation of stochastic amplitude modulations. Chapter 3 examines other pieces making use of stochastic modulations on the frequency/ time dimension, and addresses the question of the scalability of stochastic processes in time and its effects on perception.

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Table of Contents

Introduction — Composition

My choice to adopt a non-strictly musical approach throughout this thesis is connected to the way I conceive composition. Having a background in dance, I first engaged with composition by trying to find points of connection between sounds and body-movements. To start with, I had the rather vague belief that both sounds and movements belonged to space. Sounds and movements would be born into space and create "spaces"—which I would now call shapes: lines, points, heights, volumes. These shapes would neither be static nor dynamic. Rather, they would continuously appear and disappear. The impermanence of these shapes seemed to be at the core of the activity of musical and choreographic composition. Composition would somehow compensate for the ephemeral, fleeting and unpronounceable[1] but also unrepeatable features of sounds and body-movements' shapes. In that sense, I was considering composition as a unique, nomadic, generic activity of framing and organizing, i.e. formalizing the reproducibility of sonorous or corporeal motions. Such formalization was an abstract model of composition. As it usually cumulated more than one parameter to work with, it seemed permeated with multidimensionality, and, for this reason, spatiality. This pandisciplinary, generic, and spatial notion of composition has remained at the basis of my compositional thinking until today.

This said, what has profoundly changed over the years is my way of perceiving sounds and bodily motions, and the scale at which I was interested to compose with them. My discovery of Eliane Radigue and Alvin Lucier's music was especially important in that regard.[2] It made me realize that the vibrant microscopic differences or deviations of a tone from another stationary one could become the main material of a piece—something which I had never really encountered in choreographic works. From then on, I became interested in composing degrees of microscopic and random deviations from a fixed sonorous or bodily shape, which, most of the time, resembled a "line". This new way of composing also contributed to refine my understanding of space.

> Space is not only a collection of preexisting points set out in a fixed geometry, a container, as it were, for matter to inhabit. [… Spatiality] is an ongoing process of the material (re)configuring of boundaries—an iterative restructuring of spatial relations.[3]

[1] See Bonnet, François: the "fugacity and unpronounceability of sound", in *The Order of Sounds—A sonorous Archipelago,* Urban Media Ltd, Urbanomic/Mono, 2016*,* p.245.

[2] To mention only two of their pieces: Radigue's *Occam Ocean Hepta 1* (2017) and Lucier's *So You … (Hermes, Orpheus, Eurydice)* (2018).

[3] Barad, Karen, *Meeting the Universe Halfway: Quantum Physics and the Entanglement of Matter and Meaning,* Duke University Press, 2007, pp.180-181.

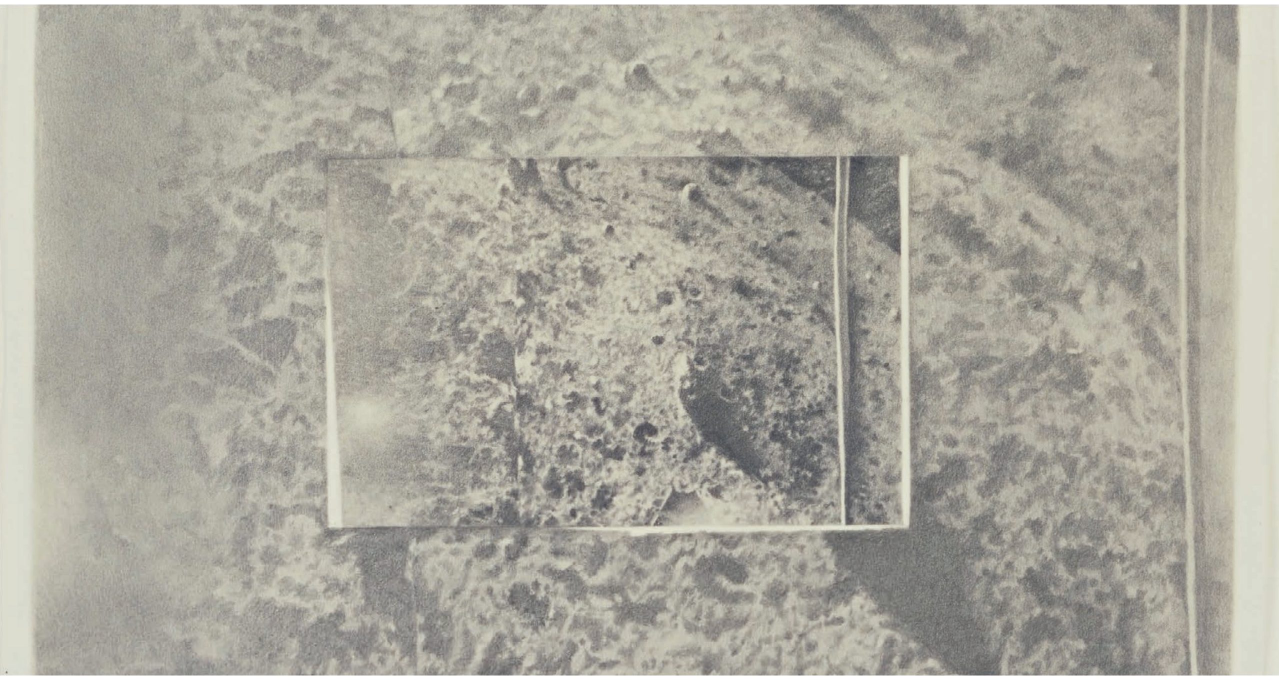

Fig 1: Vija Celmins, "Moon Surface (Luna 9) #1" (1969)[4]

[4] Graphite on acrylic ground on paper, Credit: Mrs. Florene M. Schoenborn Fund, © 2020 Vija Celmins, See https://www.moma.org/collection/works/37426

Chapter 1: Indeterminacy, Unfigurability

This chapter provides some theoretical and historical grounds to this research. I will contextualize and delineate the notions of indeterminacy and unfigurability, and explain how stochastic synthesis can be a suitable tool to bridge them.

1.1 Delineation of Indeterminacy and Unfigurability

Indeterminacy touches on questions relating to formal systems and compositional structures. Unfigurability echoes to morphologies which seem to escape our perceptual and cognitive abilities.

1.1.a) *Indeterminacy*

"Indeterminacy" is a well-known feature and driving force of XXth century contemporary music. It entails the anticipation of the "problem of the unforeseeable, […] to what extent it constituted an integral part of the composition" and its determinism.[5] Most of the time, "indeterminacy" is invoked to describe a procedure, used to generate unforeseen situations in musical pieces with respect to their performances.[6] In this thesis, I attempt to depart from this traditional and procedural perspective. I approach the notion of indeterminacy from a more abstract standpoint, borrowed from mathematics and computability theory.

Computability theory is a branch of mathematics, logic and computer science which is concerned the study of computable functions. Among the many ways of defining them, computable functions suppose the existence of a finite procedure, i.e. an algorithm with a precise set of instructions and a finite number of discrete steps, telling how to compute the function. Ideally, a computable function allows from the minimum of instructions, the maximal complexity in its outputs. In *computations*, i.e. any type of information processing that can be represented mathematically, *indeterminacy* is the "property of formal systems that evolve in time in which complete information about the internal state of the system at some point in time admits multiple future trajectories."[7]

Stochastics or *randomness* is an "explicited" version of indeterminacy.[8] A *stochastic model* is a model for a process that has some kind of randomness. In probability theory, *a stochastic process* is a process involving the operation of chance, that is a sequence of events in which the outcome depends on some probabilities. The latter point to the chance(s) that a particular event will occur, in a scale between impossibility and certainty. Since stochastic processes allow for a multiplicity of rea-

[5] Xenakis, Iannis, *Determinacy and Indeterminacy*, in *Organized Sound*, 1, 1996, pp. 143-155.

[6] See Cage, John, *Indeterminacy*, in *Silence,*Wesleyan University Press, 50th anniversary edition, 2013, pp.35-40.

[7] See Wikipedia, *Indeterminacy in Computation,* https://en.wikipedia.org/wiki/Indeterminacy_in_computation, my emphasis.

[8] In the context of this thesis and of probability theory, the two notions of *random* processes and *stochastic* processes are interchangeable.

lizations, probabilities describe the general likelihoods, tendencies, directions of the sequences of these stochastic processes' outputs.[9]

Technically speaking, a stochastic process is collection of random variables indexed against some other *deterministic* variable (like time) or set of variables (like time and amplitude).[10] If the outcomes of a stochastic process are not predicticable on a purely sequential, element-to-element standpoint, a large number of realizations of this stochastic process reveal the probability distribution on which it is based. Thus, stochastics are a mixture of formalism and determinism on one hand, and degrees of predictability and randomness on the other. They result in dynamic, nonlinear, inconstant yet consistent data trajectories.

The multiple facets of indeterminacy are at the core of stochastic synthesis. Like any other nonstandard synthesis, stochastic synthesis is solely based on a mathematical description, combining physics and computability of sounds, with no reference to some other super-ordinated or acoustic model[11]. Dynamic Stochastic Synthesis (DSS) consists, in the words of its creator Iannis Xenakis, in "a probabilistic waveform (random walk or Brownian movement) constructed from varied distributions in the two dimensions, amplitude and time (a, t), all the while injecting periodicities in (t) and symmetries in (a)."[12] Its waveforms depend on the recursive and stochastic generation of pairs of values in (t) and (a). The latter constitute breakpoints, interpolated one after the other. The synthesis' indeterminacy pertains to the presence and recursivity of these two sets of random walks. They are the successive steps taken within a predefined mathematical space delineated by barriers, according to probability distributions and following more or less discernible trajectories or patterns.

The synthesis' random walks make its waveforms vary in more or less sophisticated and predictable ways. Contrary to "sine", "triangle" or "square waves" which appellations refer to a regular and repeated structure over time in the collective imagination, "stochastic" synthesis' waveforms evoke a lack of figurable contour. In fact, stochastic synthesis' waveforms present an infinity of possible contours: they can vary between triangular-like waveforms, noise, or truly indescribable, complex motions, depending on how one composes with the synthesis' parameters. However, according to Xenakis, stochastic laws can transpire through stochastic synthesis' sonorous renderings, as a perceptible form:

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[9] Monica Franzese, Antonella Iuliano, *Hidden Markov Models,* in Encyclopedia of Bioinformatics and Computational Biology, 2019, https://www.sciencedirect.com/referencework/9780128114322/encyclopedia-of-bioinformatics-and-computational-biology

[10] Britannica Dictionary, *Random variables and probability distributions*, https://www.britannica.com/science/statistics/Random-variables-and-probability-distributions

[11] For an overview on nonstandard synthesis, see Döberiner, Luc, *Models of Constructed Sound: Nonstandard Synthesis as an Aesthetic Perspective,* Computer Music Journal, Massachusetts Institute of Technology, 2011, pp. 28–39.

[12] Xenakis, Iannis, *Formalized Music,* rev. ed. Stuyvesant, N.Y: Pendragon Press, 1992, p.289.

> One gets the *impression of the whole form of [its] stochastic law which is coherent and […] perfectly perceptible also for the ear.* […] It means that form and randomness are not really a contradiction.[13]
> We do not know much about [the laws of perception and] shall confine ourselves to examining general entities and to tracing an overall orientation of the poetic processes of a very general kind of music, *without giving figures, moduli, or determinisms*.[14]

Differently from Xenakis, who, in my opinion, was not primarily engaged with *conventional* psychoacoustics and analysis,[15] I decided to delve into the analysis of stochastic synthesizers' behaviors. My initial intention was to straightforwardly link the synthesizers' degrees of randomness to their degrees of perceptibility as "sonorous forms" as suggested by Xenakis. I gradually changed this approach over time.

1.1.b) Unfigurability and borderline cases

What I always found most intriguing in stochastic synthesis are the instances when the sounds it generates are equally unpredictable and redundant or repetitive. Such a situation prompts an ambiguous listening situation. The motions of these sounds waveforms, the nuances of their modulations are complex, convoluted and volatile, and yet: they convey an overall sonorous cyclicality and steadiness when sustained for a while. The fragile equilibrium between unpredictability and cyclicality in these complex waveforms can give an impression of semantic black hole for the listener. The composer, poet and mathematician Catherine Christer Hennix[16] describes this particular situation when writing about her "mathematical instruments," i.e. her synthesis methods and the tambura:

> [A] semiotical *borderline case* [is] posed by sounds perpetuated by persistent regularities but which remain unfigurable, sounding an unanalysable sonic enigma. […] This borderline case, defined by sustained stationary sounds, is also as a modality of cogni-

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[13] Delalande, François, "*Il faut être constamment un immigré*"*— Entretiens avec Xenakis,* INA/GRM: Bibliothèque de Recherche Musicale. Buchet/Chastel, Paris, 1997. (Edited broadcasting interview from 1981 by Peter Hoffmann in his thesis: Hoffmann 2009, p.167) [my emphasis].

[14] Xenakis, Iannis, *Formalized Music,* Chapter *Markovian Stochastic Music*, p.62 [my emphasis].

[15] I am writing this in comparison to James Tenney who was, around the same times, already engaged with analysis of the harmonic structures of compound sounds (including synthetic sounds). Differently, when he started working on DSS, Xenakis's initial intention was to depart from the general, *conventional* idea of placing harmonic series/ overtones at the centre of a synthesis technique. I believe Xenakis' posture incidentally meant to depart from Fast Fourier Transform Analysis, which is one of the basic bulding blocks of psychoacoustics. That said, Xenakis was certainly interested in the effects of applying mathematical models in listening and how these models could be conveyed (see Xenakis's concept of *symbolic music*).

[16] Importantly, even if Hennix understands music through logic and mathematical frameworks, she had a radically different artistic approach compared to Xenakis—perhaps because of the influence intuitionism had on her work.

tion most paradoxical in that [these] sounds seem to *autonomously* generate a *cascading semantics* that spell-binds the listener […].[17]

In the case of stochastic synthesis, I believe that this "unuanalysable sonic enigma" or semantic black hole comes from randomness.

Outlining these concepts of borderline cases and unfigurability is a delicate task. Simply put, unfigurability indicates the resistance occurring in one's perception and cognition, the difficulty to figure a phenomenon out. It is as if the phenomenon in question is too complex to be known, extracted and memorized in its contours; ending in a perceptual, cognitive blur. Borderline cases are "disembodied sound wave maps which weave themselves tracelessly through time and space,"[18] in an interval between perception and conscience. In my frame of thought—thus, arguably— unfigurability is a generic notion, not only applicable to sounds but also any sustainable motion over time. Unfigurability exists in time, and perhaps, through non-linear experiences of durations. It binds three concepts differentiated by François Bonnet: "the *informe* [formless]," i.e. "a dilution of formal outlines"[19] where "perception [is] deprived of its faculty of recognition;" "the *imperceptible*" which "is positioned at the very limits of our perception,"[20] and finally "the *indistinct*" which "[resists] exhibiting a structure [and] being legible."[21]

[17] Hennix, Catherine Christer, *SOLITON(E) STAR, RESONANCE REGION lA [ZERO-TIME SONIC MIRROR] FOR COMPUTER,* Berlin, 2015 [Hennix' emphasis].

[18] ibid.

[19] Bonnet, François, *The Order of Sounds, A Sonorous Archipelago,* Chapter *The Informe and the Heterogeneous*, Urban Media Ltd, Urbanomic/Mono, 2016. p.280.

[20] ibid, p.286.

[21] ibid, pp.295-296.

1.1.c) Approach adopted: Indeterminacy (structure) / Unfigurability (morphology)

My compositional position and methodology alternates between questions touching on stochastic processes and the potential mathematical structuring of laws of perception. I am in agreement with Hennix's interest in pitch as a psychoacoustic variable and the general direction of her work: to come closer to apprehending these borderline cases' psychoacoustic effects through the implementation of suitable algorithms and maps. The comparative, metrics-oriented theory of music and compositions of James Tenney and (his former student) Michael Winter also navigate a similar area.

The two American composers make an essential distinction between *structure* and *shape (*Tenney)*/morphology* (Winter). The shape or morphology of sound (or any other motion for that matter) is its external aspect or completely uncompressed representation.[22] It corresponds to what Xenakis called a form. According to Tenney, shape is time-dependent, to which I would add perception/cognition-dependent: a shape exists when it is perceived and memorized. A shape thus concerns temporal gestalt formation. A shape can exist at many different "horizontal," temporal scales, from the envelop of one single sound or a sequence of several sounds perceived as a group (clang).

The structure of sound concerns the set of rules and relationships between the individual elements that govern the morphology. According to Tenney, structure is the internal aspect of sound, an out-of-time characteristic which is "not necessarily apparent 'on the surface' of the [shape of sound]."[23] Structure is thus foreign to the morphological time*,* and perhaps solely belongs to the compositional time in which it is being set. Structure can also exist at different "vertical" levels. Typically, the structure of a sound relates to the partials characteristics of a compound tone. On the other hand, the structure of a composition refers to the invariant, inner workings of a piece, i.e. the organizing principles of the relations between several layers of sounds. These principles do not need to be perceived by a listener to exist and be essential to a given composition.

To combine Hennix, Tenney and Winter's terminology, my main area of interest lays in the analysis and composition of morphologies originating from stochastic models and processes which prompt unfigurability. Whether these processes and/or morphologies are fully generated by a computer (like stochastic synthesis) or not (like body-movements pieces), I will approach them through the lens of the computational notion of indeterminacy.

Importantly, I have learned through this research that indeterminacy cannot be deduced from unfigurability and the other way around, because concept (structure) and percept (morphologies) are two different things. Thus, the conceptual basis of my pieces can seem irrelevant to the way they are experienced. This discrepancy might be an expression of the *incalculability of the concept-to-percept* transparency of art, "the inability to know the extent that a perceiver will understand the

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22 Winter, Michael, *Structural Metrics: An Epistemology,* University of California, Santa Barbara, 2010, pp.2-9.

23 Tenney, James, *META + HODOS,* Frog Peak Music, Hanover, New Hampshire, 2nd edition, 1986.

logic of a work's concept through musical experience."[24] In my case, it just means that a structure and its corresponding morphology were found equally interesting, even if the first was not efficiently made readable through the second and the other way around.

1.2 Re-contextualizing Dynamic Stochastic Synthesis

One may still wonder why stochastic synthesis is considered a relevant tool in the context of this research, especially when looking at its significant limitations. For some people, I think stochastic synthesis can appear to be tainted by its own historicity: a monotone "standardized non-standard synthesis technique," bound to the aesthetics of its creator and the ways he made it "sound" in his compositions[25]. Similarly, others might label stochastic synthesis as limited and outdated, and/or too complicated for a synthesis technique. Either way, in my opinion, these views put aside Xenakis's philosophical and conceptual reasons for creating this tool in the first place. I will present the latter briefly, sometimes critically, so as to re-actualize them in our current acoustics and technological context.

1.2.a) Minimum of logical constraints, supposedly infinite malleability (Xenakis)

The philosophical framework of DSS presented by Xenakis refers to a specific time in the history of computer science, physics and mathematics. For instance, around the time he started researching on DSS in the mid 70s,[26] quantum computing had just began. Xenakis's enthusiasm for these scientific progresses is perceivable in his statements on music and DSS. When served by such scientific methods, music stood as a source of *episteme* (knowledge), "a [normative] model for being or for doing by sympathetic drive,"[27] that is: a "manifestation and operating mode of philosophy."[28]

Xenakis's approach to philosophy and science could be seen as an embryonic form of what would be called pancomputationalism today, a "dynamic kind of reductionism in which the complexity of behaviors and structures found in nature are derived (generated) from a few basic mecha-

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[24] Winter, Michael, *Structural Metrics*, p. xxx, reminding of Sol LeWitt's quote " Some ideas are logical in conception and illogical perceptually". See LeWitt, Sol, *Paragraphs on Conceptual Art,* Artforum, 1967.

[25] One can think of the "sound" of *La Légender d'Eer* (1977-1978) or at the end of *Polytope de Cluny* (1972).

[26] After starting applying stochastic laws and probability functions for generating electronic sounds during the late 1960s and early 70s, Xenakis investigated the topic more deeply during the late 80s and early 90s. In 1991, he finalized the GENDY computer program and composed the piece *GENDY3*, followed three years later by his second and last stochastic synthesis' piece *ST.709.* See: Les Amis de Iannis Xenakis, *Iannis Xenakis Chronology,* https://iannis-xenakis.org/xen/bio/chrono_91-01.html.

[27] Xenakis, *Formalized Music*, p.178.

[28] B. Giannakopoulos, *Stochastic Music as Metaphor,* Institute of Sonology, The Hague, 2011, p.19.

nisms."[29] He specifically considered probability theory and stochastic laws as "veritable diamonds of contemporary thought"[30] and ideal compositional tools in his quest for the "*minimum of logical constraints* necessary for the construction of a musical process."[31] He used these laws of probability—particularly during the late 50s and 60s— as powerful methods of "enrichment of sonic processes."[32] The resulting pieces belong to the realm of a sonorous maximalism. They are usually dynamic, ever-changing, fast, brilliant. These bold orchestral masses of sounds are as imposing as the natural phenomena which inspired the composer, such as the "collisions of hail or rain with hard surfaces" or "the song of cicadas in a summer field."[33]

The same "maximalist" aesthetics and artistic visions were applied to DSS at first by Xenakis.[34] To him, the synthesis was not only complementing the use of traditional instruments: it was an attempt at creating a musical synthesis, thanks to which, "following [its] principles, the whole gamut of music past and to come [could] be approached."[35] And undeniably, Xenakis presented a new, unheard-of sonorous reality in his first stochastically synthesized piece *GENDY3.*

1.2.b) Minimum of logical constraints, finite computated malleability (Tenney/ Winter/Nezri)

I very much relate to Xenakis's interest in condensing (musical) processes to minimum logical constraint, i.e. computability.[36] However, I am interested in relating minimum logical constraints to the (limited) ways we perceive sound, in particular pitch and harmony. This position is inspired from James Tenney's perspective on composition, who was primarily interested in the question of how music is heard and proposing formal models of composition as answers to this question. Typically, composition was at times a means for Tenney investigate psychoacoustics[37] questions further, whether he was composing with a computer or not. Michael Winter's premise on music and pancomputionalism is also worth noting. If the composer also shows an interest in dealing with psychoacoustics in some of his works,[38] Winter significantly "[equates] the fundamental limits of

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[29] Dodig-Crnkovic, Gordana, *Alan Turing's Legacy: Info-Computational Philosophy of Nature,* 2013.

[30] Xenakis, *Formalized Music,* p.16.

[31] ibid, my emphasis.

[32] ibid, p.39, my emphasis.

[33] ibid, p.9.

[34] Let us say that Xenakis's compositional attitude became more "cautious" over time.

[35] Xenakis, *Formalized Music*, p.289.

[36] This term is not to be found in Xenakis's writings.

[37] See for example Tenney, James, *For Ann (rising)* (1969).

[38] See for example Winter, Michael, *Stream I* (2007).

knowledge with the fundamental limits of computation."[39] Interestingly, I believe that the acknowledgement of these limits seems to directly transpire in the sonorous renderings of Winter's pieces, which aesthetics tend to be usually "minimalist" or at least reduced to the essential. Similar asethetics are also found in the work of his predecessor, Tenney. In any case, it seems to me that both of their works point to a connection between the way they use computer to compose and their careful attitude to sounds, very different from Xenakis's. To me, they compose within the interval between formalization—if not some abstractions of mathematics, and the concrete limits of the human, physiological experience and comprehension of sound.

This leads me to try reflecting on Xenakis's idea about the potential of a musical synthesis for approaching "the whole gamut of music past and to come." It seems to me that this idea evokes the ability to create of an infinity of synthesized sounds, which exceed what we can currently imagine and know about sound, from a computer program. In a way, it could mean that one algorithm could compute any possible sound model, i.e. be a kind of universal Turing (and time) machine for sound. This reading of Xenakis seems to suggest that he aimed at creating with the GENDY algorithm a potential infinity (of sounds) from a finite (computer program)— corresponding to an insolvable, undecidable computational problem.

Even if it is clear that Xenakis was aware that DSS was in fact limited, this insolvable ideal of a musical synthesis, able to compute any possible sound, is interesting to think about—particularly in relation to *quantum indeterminacy*. It reminds that an indeterminate model used for computations, exemplified in DSS, is merely an *incomplete measure*[40] of quantum indeterminacy, which is irreducible and incomputable.[41] Thus the random sequences generated by computers depend on discreteness and linear interpolation. On the other hand, quantum randomness or stochastic quantum mechanics describe the omnipresent and continuous "uncertainty" of real phenomena, the lack of any discernible patterns or trends at a level which imply "both continuous and discrete computing."[42] Following Xenakis's musical synthesis ideal, one can dream of an "actual" quantum synthesizer, which computations would be both continuous and discrete, relying on a different algorithm all together. Yet, for now, it seems more reasonable to simply embrace and work with the limitations of our computers!

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[39] Winter, Michael, *Structural Metrics: An Epistemology,* University of California, Santa Barbara, 2010, p.6.

[40] Calude, Cristian S., *Incompleteness, Complexity, Randomness and Beyond,* University of Auckland, New Zealand, 2001.

[41] There is a correspondence between the uncertainty of quantum randomness in physics and to the undecidability and incompleteness of algorithmic randomness.

[42] Dodig-Crnkovic, Gordana, *Alan Turing's Legacy: Info-Computational Philosophy of Nature,* in *Computing Nature—Turing Centenary Perspective*, Springer, Berlin, Heidelberg, 2013, pp.115-123.

1.2.c) DSS' and possible compositional explorations today

One of the biggest changes in computers since the 90s has been the acceleration of the *latency time*, which expands in-between the execution of a synthesis algorithm and its transformation into (patent) sound. This transformation, consisting in the "conjunction of musical (symbolical) algorithm and media-technological (physically real) time operation,"[43] is what Wolfgang Ernst calls an *explicit sonification*. It is particularly crucial in the process of composing with non-linear synthesis like DSS: as latency precedes patency, conjecture precedes conjunction. Xenakis had to wait for his synthesis to be computed and hear its results, following a procedure which was not that far from the traditional score-making and realization of instrumental pieces. Composing with DSS today using the softwares SuperCollider or Max/MSP is a very different experience. DSS mathematical principles and processes have not changed but the speed for its explicit sonification has: DSS is now a real-time synthesis which parametrization can happen on-the-fly.

Stochastic synthesis can be used as a live instrument and its behavior can quickly be fixed into recordings suitable to spectral analysis. The latter also became a common technology, which very much changed our understanding of sound and acoustics. Spectral analysis makes some of the computational aspects of DSS and its indeterminacy explicit. It shows the way DSS' waveforms can sometimes repeat the same compressed sonorous information over time (*redundancy)*. The very basis of my compositional approach to DSS is actually based on spectral analysis, helping me to reveal what I think could be brought out as "musical" from DSS sound material. I mainly compose with waveforms that can be heard as a tone, with microscopic and barely perceivable stochastic modulations. I then use different kinds of pitch-noise continuums: as functions of amplitude modulation, frequency modulation, and/or additive spectrum. By doing so, I attempt to generate a specific kind of sonorous morphologies, imbued with determinism and redundancy,[44] while prompting unfigurable situations.

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[43] Ernst, *Sonic Time Machines—Explicit Sound Sirenic Voices and Explicit Sonicity,* Amsterdam University Press B.V., Amsterdam 2016, p.98.

[44] See sections on Xenakis' *GENDY3* and my works *once racing ceased,* and *for ábel*.

Chapter 2 : Stochastic amplitude modulation — Noisification

Section 1 presents morphologies non-generated by a computer, structured on a radical use of stochastic amplitude modulations and resulting in a perceptual saturation. Section 2 focuses on my attempt to formalize degrees of aural saturation while composing with stochastic synthesis amplitude random walks.

2.1 Unfigurable extremities of stochastic amplitude modulation — Noise and silence

I will endeavor to venture into the analysis of pieces leading to unfigurability through the use of noise and silence. Noise and silence are the two most extreme states of stochastic amplitude modulation, whereby all frequencies have an equal probability to appear and be given an equal intensity (be it zero). They are also perhaps the most extreme states of unfigurability. Noise and silence evoke an obviousness and patency of sound—or of the lack of it, which saturates one's perception in unintelligible sensations.

2.1.a) "White noise"[45] as a statistical model

Ensuing my broad understanding of composition, I extend Tenney's notion of structure to any artistic medium, as long as it is inscribed in time. The structural core of the two choreographic and musical pieces presented in this section is a statistical color: whitish.

Eiko & Koma's filmed, silent and outdoor butō[46] piece *Wallow*[47] appears deceptively simple at first glance. It can be summed up as two bodies slowly moving on a sandy beach, colliding into one another, until finally merging with the water. The piece's strength is "not necessarily apparent 'on the surface' of the [piece's morphology]."[48] Rather, *Wallow* is composed both in a removal and an amalgam of sensory stimuli which all evoke a kind of generic white noise. The color white becomes an intelligible sensation: saturating "random spots of light," or saturated "accumulation of information from several parts of the eye at the same time, beyond our voluntary control or ability

[45] "White noise" does not refer in this section to a specific signal (like sound), but the statistical model which it implies: a sequence of uncorrelated random variables with zero mean and finite variance. See Wikipedia, *White Noise,* https://en.wikipedia.org/wiki/White_noise

[46] Butō is an in-between theatre/dance movement born out of the unbearable darkness and dust of the aftermath of World War II. Its founders Tatsumi Hijikata and Kazuo Ohno shaped a dance created which themes are, to list a few: death and the dead, birth, the grotesque and monstrous, poetry, nature, the sublime, dust, Japanese traditions.

[47] Eiko & Koma, *WALLOW 這う*(1984), Media Dance, 2010, https://vimeo.com/9690716.

[48] Tenney, James, *META + HODOS,* Frog Peak Music, Hanover, New Hampshire, 2nd edition, 1986.

to learn."[49] The piece starts with the opening credits-like sentence: "This work was designed with no sound track." The dancers silently appear, along a faded scenery—a windy ivory beach, a gray sky, a drab sea. The whitish-ness of the scenery blends in with the dancers' jerky movements, reminding bodily stochastic amplitude modulations, oscillating "incoherently in a narrow band within which micro-intensities, singularities."[50] Through its uniform colorization, *Wallow* calls into question the "alledged inherent and self-evidentiary nature of bodily boundaries."[51] It blurs the spatial partition between the dancers' and their surroundings; and between our senses. It conveys "sensations to be picked up by the eye, not the ear; [and where] the eye become not only a kind of ear but also a kind of hand."[52] It manifests the vibrational, saturated and indefinite experience of white noise, which implicitly but intensely evoked in what is absent in the piece: the recognizable whitish mixed noise of wind, sea waves, and grains of sand.

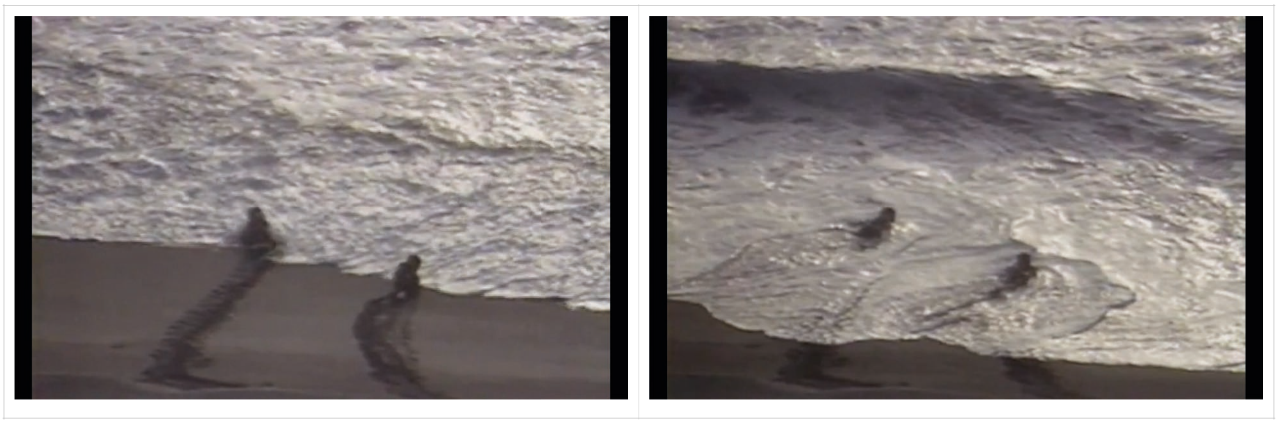

Fig 2: Final scene of Wallow (1984)

A different expression of this same structural, white noise is found in the work of Peter Ablinger and his series *Weiss/ Weisslich.* The latter declines the color white in all kinds of pieces and events, with a main research axis on white/ whitish noise (*Rauschen)*. For the composer, *Rauschen* corresponds to the suspension of the sonic world.[53] Ablinger considers noise as having uniformly distributed frequencies and equal intensities at every frequency, and thus "[containing] both the tones and the noises. It is the totality of all sounds and noises, their sum."[54] In the piece *Weiss/ Weisslich 18,* the composer placed 40 seconds-excerpts one after the other, of sustained blocks of noises, of 18 different kinds of trees he had recorded. The composer "found that the color of the

[49] Feyman, Richard P., *The Feynman Lectures on Physics* Vol.I, *Mechanisms of Seeing*, Basic Books, New Millennium Edition, 2010, 36-1.

[50] Lepecki, André, *Limitrophies of the human,* in *Singularities—Dance in the Age of Performance*, Routledge, 2016, p.107.

[51] Feyman, Richard P., *The Feynman Lectures on Physics* Vol.I, ibid, 36-1.

[52] ibid.

[53] Ablinger, Peter, *Black Square and Bottle Rack: Noise and Noises,* in *Noise in and as Music,* Aaron Cassidy, Aaron Einbond, University of Huddersfield Press, 2013.

[54] ibid. In passing, this definition of white noise is not adopted by everyone, as some prefer to consider white noise as a single frequency moving as randomly as possible to all imaginable values at an intangibly high speed (like Clarence Barlow).

noise of specific trees is really *constant:* [for instance], the sound color of an (English) oak always sounds the same *irrespective of the force of the wind* (strong or weak = loud or soft)."[55] As it unfolds in an apparent accumulation of sonorous information, the piece also reveals how these noises are marked with persistent, distinct and somehow decipherable regularities. The trees' whitish noises seem presented in their respective, distinguishable probability distributions of stochastic amplitude modulations and average sonorous equilibrium. More precisely, the "constant" characteristics of their noises suggests that trees can be seen as successive stable harmonic timbres, more or less saturated depending on the wind.[56]

2.1.b) A first encounter with stokhos: "jidhe"

The body-movements solo piece *jidhe* played an important part in shaping my future research. I consider it to be my first, intuitive compositional encounter with stochasticism, at a time when I did not know much about stochastics, Eiko & Koma nor Ablinger.

jidhe refers to the Arabic translation of trunk or torso. I was sitting cross-legged throughout the entirety of this upper-body dance, so as to suppress the directional functions involved with the legs. The aim was to shed light on the smaller scale of torso- and arm-movements. In theory,[57] my movements were supposed to lack the ontological and formal aspects of traditional dance performances: macroscopy and expressivity. My main choreographic concern was to undergo different bodily states which would influence the direction and amplitude of my movements over time. Back then, I called this process going through different "spaces"—which correspond in retrospect to parametric/probability spaces. The latter consisted in the combinations of three main parameters:

- imaginary outer boundaries or barriers surrounding my body. These boundaries were mostly influencing the amplitude of my torso and arms movements on the sagittal plane.
- resistance, i.e., different kinds of relation to gravity. Resistance was more or less constraining the amplitude of my torso and arms movements, on the frontal plane.
- a specific value of pulses or points of juncture*,* traversing my otherwise continuous upper-body movements in a fixed period of time (ex: 3 pulses in 10 seconds). The value of pulses would change throughout the performance, contrary to the period of time in which they would occur.

Each of these parameters had variables which were gradually evolving in time and going through approximately five main types of probability spaces.[58] Within each of these determined sets of bodily movements parameters, I was repeatedly exploring their different possible bodily outcomes. The

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[55] See for more information on *Weiss/Weisslich 18* (1992/96) on https://ablinger.mur.at/ww18.html, my emphasis.

[56] This piece inspired me to write *Hommage to P.A.* for electronics and clarinet*,* in which the clarinet was playing the main frequency peaks of successive different blocks of granulated noises (based on stochastic synthesis).

[57] In practice, the performance ended up being much more macroscopic than microscopic, and perhaps figurative. Giving away these dance habits of expressive macro-movements is a real bodily and mental effort (See last section of the thesis). The rendering of the piece was therefore not very successful in my opinion.

[58] For example: I) large outer boundaries, strong resistance, 6 pulses in 10 seconds; II) small outer boundaries, strong resistance, 6 pulses every 10 seconds; III) large outer boundaries, no resistance, 4 pulses every 10 seconds, etc.

deterministic unfolding of these pre-defined spaces was structuring my otherwise random torso-movements. In brief, *jidhe* could be described as incorporating deterministic elements or pre-defined sets of parameters to bound the unfolding of a random process—which is the definition of a stochastic process.

I was hoping that my movements in *jidhe* could be perceived in their sonic qualities. After several attempts, I came to the conclusion that silence and noise were most suited for the piece, so as not to disturb the inaudible sonic qualities of my movements. No sound was to be heard at the beginning of the piece. Some white noise would gradually fade in, until abruptly falling into silence at the point where it began to be clearly audible. The two types of material, bodily and sonorous interacted with each other. The noise could seem affected and filtered by the irregularities of my bodily movements. Reciprocally, the abrupt change between noise and silence was influencing the perception of my uninterrupted movements, as if applying a different visual filtering to them. The two types of material were also converging towards one similar, intuitive notion of randomness, which I can now articulate as the basic structural element of the piece.

This previous description of *jidhe* might have sown the seeds of a comparison that the reader is now able to foresee. There is a coincidental correlation between the parameters used in *jidhe* and stochastic synthesis:[59] segmentation of one period/time duration into smaller chunks, construction of probabilistic motions out of simultaneous, two-dimensional random walks, presence of barriers for these random walks, breakpoints, (a kind of) interpolation.

Extended definition of stochastic synthesis:

- *following the abscissa of (t): a period T subdivided in n equal segments, and every time T is repeated, each segment on the time axis undergoes a stochastic alteration, compressed between two adequate elastic barriers;*
- *following the amplitude axis (a): a value is given to each extremity of the n-preceding segments, these values form a polygon inscribed or enveloping a sine wave, or a rectangular form, or a form born of a stochastic function, or even a polygon flattened at the zero level, and the ordinates of these n summits undergo a stochastic alteration at each repetition, compressed between two adequate elastic barriers;*
- *the resulting formation of a waveform thanks to the linear interpolation of these pairs of time and amplitude values at each segments (so-called breakpoints).*
- *the repetition of these waveforms formation over time.*

[60]

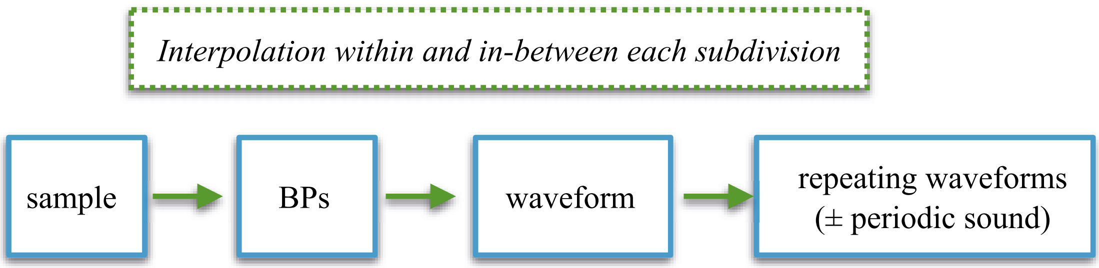
[59] Of course, I do not mean there is any complete equivalence between both.

[60] Xenakis, *Formalized Music,* p.290.

2.2 Stochastic amplitude modulation and *Harmonic perception*

For the rest of the thesis, I will focus on the version stochastic synthesis designed by Xenakis in 1977, using first order-random walks—rather than the GENDY algorithm from the late 80s, using second-order random walks (as explained in *Formalized Music*).

Stochastic synthesis is based on the repetition of varying polygonal shapes (waveforms) which share the same set of parameters. A polygonal shape is a collection of straight lines connected at their end points. These end points correspond to the synthesis *breakpoints* (BPs): one breakpoint is the junction between one amplitude value and one time value. BPs are as numerous as the number of slices in the waveform. In every cycle, the synthesis BPs are connected by the interpolation of samples in-between each of them. The temporal layers and their respective interpolations involved in stochastic synthesis can be represented and simplified as follows:



The polygon/waveform shape varies whenever breakpoints are being displaced in the time and/or amplitude dimensions. These displacements are non-linear and follow random walks, happening independently on the time and amplitude dimensions. As Hoffmann explains it, "there are 2-times-the-number-of-breakpoints random walks active for the deformation of a single wave form over time."[61] These random walks can follow the same or different probability distribution.

The piece *once racing ceased, the old 166 renumbered* centers on the synthesis' random walks on the amplitude dimension. It consists of a 7'00" long gradual pitch-to-noise continuum, focused on one single synthesized pitch (at 466.16 Hz), the layering of different stochastic synthesizers and sine waves, and the intensification of the synthesis stochastic amplitude modulations.

2.2.a) Harmonic perception and Indigestibility (structure)

[61] Hoffman, Peter, *Models of Sound* in *Music Out of Nothing,* p.128.

Through preparing the piece, I became more interested in the question of pitch and the ability to detect amplitude modulations (AM) in the partials of one single tone.[62] To simplify some basics of psychoacoustics, subtle AMs are more difficult to perceive than frequency modulations (FMs).[63] Our hearing organ can for example only grasp individual changes in amplitude in each harmonic of a compound tone only up to its 8th harmonic. Stochastic synthesis is an interesting tool to delve into these questions as it can generate extremely precise and subtle stochastic AMs for each of its individual partials. The boundaries of its random walks' spaces on the amplitude axis affect more or less the perception of a given synthesized tone. Thus my general aim in the piece was to decipher the synthesis most stable, periodic state, to find ways to enhance its partials, and later on to obscure its periodicity through stochastic amplitude modulations (SAMs).

i) Stochastic synthesis & harmonic perception

Tenney's notion of *harmonic perception*[64] was at the basis of my approach to SAM.[65] Tenney was influenced by "Gestalt psychology [which] tries to understand the perceptual mechanism of gestalt formation; how several objects may or may not be perceived as one."[66] Unlike *contour perception*, concerned with musical macro-gestures, harmonic perception is linked to the understanding by one listener of the periodicities of two or more stable tones and their interactions. "By harmonic perception [Tenney means] the perception of varying relations between tones of definite pitch and of varying qualities or conditions that arise when two or more tones are heard together— either simultaneously or successively."[67] Harmonic perception can consist in observing the perceptual similarities and dissimilarities between two tones played by the same instrument or between two instruments playing the same pitch. Additionally, harmonic perception articulates the connection between detailed perception and time. The ability to hear heightened details and variations in pitched sounds asks for time, that is: sustained tones. The latter are needed for pitch information to permeate and persist in the listener's short-term memory.

Because of its wide possibilities of modulations and potentially indefinite durations, stochastic synthesis can be a great instrument to study through the lens of harmonic perception. Two additional conditions are needed:

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[62] In passing, I realized that AM, and specifically stochastic AM has been a topic of interest for Tenney, see James Tenney, *Computer Music Experiences, 1961-1964,* http://plainsound.org/JTwork.html .

[63] See Chapter II for FM.

[64] See Tenney, James, in *From Scratch,* "John Cage and the Theory of Harmony," pp.281- 304, and *The Several Dimensions of Pitch,* pp.369-382.

[65] And stochastic FM (See Chapter 3).

[66] Winter, *Michael, Meta+phenomenology: Primer Towards a Phenomenology Formally Based on Algorithmic Information Theory and Metabiology,* in *Unravelling Complexity:The Life and Work of Gregory Chaitin,* World Scientific Publishing Company, 2020, p.320.

[67] Tenney, James, *From Scratch*, Chapter *Toward a Quantitative Theory of Harmony,* p. 236.

- Stable pitch and sufficiently slow stochastic modulations:

The ideal configuration is when a stochastic synthesizer produces a sustained, fixed pitch with relatively stable partials and sufficiently slow modulations. The synthesis can evoke the sound of formant structures thanks to the combination of its spectral peaks and dips and the irregular frequency and amplitude fluctuations, deviating from these peaks and dips.

- The incorporation of transparent signals or sounds of unvarying pitch, like sine waves

A tactic found to focus the listener's attention on the synthesis' sonorous details was to mix it with transparent sounds. On their own, stochastic synthesis modulations tend to be perceived either as too stable, inducing a too clearly periodic/tonal percept; or too unstable and complex to convey any periodicity at all. By playing sine waves at the synthesizer's peak and dip frequencies, I started engaging with thresholds of perceptibility of stochastic AMs and FMs. Besides getting even closer to a voice's sonorous characteristics, this method allowed me to create a certain transduction of tonal percepts, where for example certain partials of stochastic synthesis could be perceptually replaced by pure, periodic sine waves, while evolving into more unstable and complex oscillations (SAM/SFM).

ii) Stochastic synthesis' tuning: Constant Q-system (numBPs), and Indigestibility

To understand the "harmonico-perceptual" potential of stochastic synthesis, the breakpoint positions were fixed on the time axis. So as to generate a stable pitch, the frequency-barriers were made equal to each other (no space for the frequency random walks to occur). From this configuration, "the injection of periodicities in (t)" are the most explicit. Periodicity is traceable in stochastic synthesis. Its random walks steps on the amplitude and frequency dimensions are meeting at the same time as breakpoints or *BPs*. In other words, stochastic waveforms are split into small chunks according to a specific segmentation or value of *BPs* which I call *numBPs*. For simplifying the analysis to its outmost, I decided to freeze the synthesis' duration modulation, meaning that the numBPs were equally spaced. The following paragraphs are valid only with this specific parametrization (numBPs equally spaced and no frequency random walk)—also used in my piece *once racing ceased* as explained later.

In this context, each numBPs (or slicing of the waveform) corresponds to a specific series of spectrum's frequencies. Stochastic synthesis becomes similar to a so-called *constant Q-system* where its quality (*Q)* factor, which indicates a resonator's bandwidth relative to its center frequency, is constant. Thus stochastic synthesizers' spectra become numBPs-dependent but pitch-independent. The spectral information they carry remain unchanged for each individual numBPs values, independently of their center-frequency (the mean between their minimal and maximal frequency-barriers) and whether their frequency-barriers are comprised in a narrow frequency range, or dispersed.

To put it another way, the numBPs allows to have a certain control over the spectral centroid of stochastic synthesis' waveforms. According to the composer Clarence Barlow, the spectral centroid is "the 'centre of mass' of a sound's spectrum, usually associated with the "brightness" of the sound. It is calculated as the average of the spectrum's frequencies, each multiplied by its own loudness."[68] So the higher the numBPs (or the smaller the slices in the waveforms) combined with no or very small frequency variations, the more the signal will comprise high partials, and the brighter it will sound. In particular, if linear interpolation is used between a synthesizer's BPs, the high frequency partials' overall energy will get stronger whereas their lower partials will get weaker.[69] On the other hand, a synthesizer with fewer BPs will have fewer main spectrum's frequencies, but more energy condensed on these peaks.

Again, when the maximum and minimum frequencies are equal and the numBPs share the same proportion in duration, the values of BPs appeals to spectral serial behavior. Synthesizers with different numBPs can share the same overtones if their numBPs are numerically related. This is an interesting point of junction between the computations of the synthesis and their tuning consequences or perceived degrees of consonance. Stochastic synthesis numBPs' parameters can be connected with Barlow's '*indigestibility*' function.[70] Without going into too much detail, this function was initially destined to be used in the calculations of what Barlow calls the harmonicity of intervallic relationships. The *indigestibility* function calculates coefficients based on the simplicity and the divisibility of natural numbers. It results in the following table:

$$\xi(N) = 2\sum_{r=1}^{\infty}\left\{\frac{n_r(p_r - 1)^2}{p_r}\right\}$$

where

$N = \prod_{r=1}^{\infty} p_r^{n_r}$;

p is a prime; and

n is a natural number.

N	$\xi(N)$
1	0,000000
2	1,000000
3	2,666667
4	2,000000
5	6,400000
6	3,666667
7	10,285714
8	3,000000
9	5,333333
10	7,400000
11	18,181818
12	4,666667
13	22,153846
14	11,285714
15	9,066667
16	4,000000

Fig 3a & 3b: table of Indigestibility values from numbers 1 to 16, and mathematical formula

The numbers 1, 2, 3, 4, 8, 16 are very digestible, contrary to 7, 11, 13, 14. This table can be related to the (aural) complexity of a stochastically synthesized sound, depending on its numBPs.

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[68] See Barlow, Clarence. "Glossary of Terms with Respect to Intonation". In *KunstMUSIK,* No. 17, Cologne, Germany, 2015.

[69] If considered as an issue, using different types of interpolation curves can attenuate this brilliance. They act like low-pass filters that smooth out (i.e.,: approximate) the discontinuities of the synthesis' computations and replace its zeros. Special thanks to Peter Pabon for letting me know this important piece of information— as well as the explanations on stochastic synthesis being a constant Q-system.

[70] See Barlow, Clarence, *On Musiquantics*, Royal Conservatory The Hague, 2003; and Rodriguez, Mauricio, *Harmonic Generation based on Harmonicity Weightings,* CCRMA & CCARH, Stanford University, 2013.

During my preparations of the piece, my hearing was for instance intuitively drawn towards synthesizers set with very digestible numBPs, such as 8, 10, 12, 16, which could be smoothly layered together. On the opposite, the sole unison of three synthesizers with numBPs respectively equal to 7, 11, 13 sounded dissonant and mistuned. Hence, I believe a *spectral indigestibility of a compound tone* was at work during my intuitive parametrization of stochastic synthesizers. These coefficients hint at how stochastic synthesizers with different BPs can be harmonically related and coherently tuned together (if such a coherence is looked for).

While composing *once racing ceased…,* I did not know about Barlow's function, nor the low-pass-filtering effects of interpolation. The numBPs value of my main synthesizer was equal to 15, the frequency minimal and maximal barriers both equal to 466.16 Hz, and the interpolation used was linear. The resulting signal had strong partials up to 9000 Hz with a lot of energy dispersed throughout frequency peaks comprised between 1800 and 4800 Hz. In order to compensate for this brilliance and get more energy on lower frequency peaks, I mixed it with additional synthesizers with smaller numBPs: 3 and 5—which are numerically related to 15. This procedure had two purposes. First, mixing these synthesizers together intensified the persistence of the 466.16 Hz pitch and its octaves, since my synthesizers shared and repeated some of their spectral information. Secondly, mixing these synthesizers together allowed me to get different variations in SAMs.

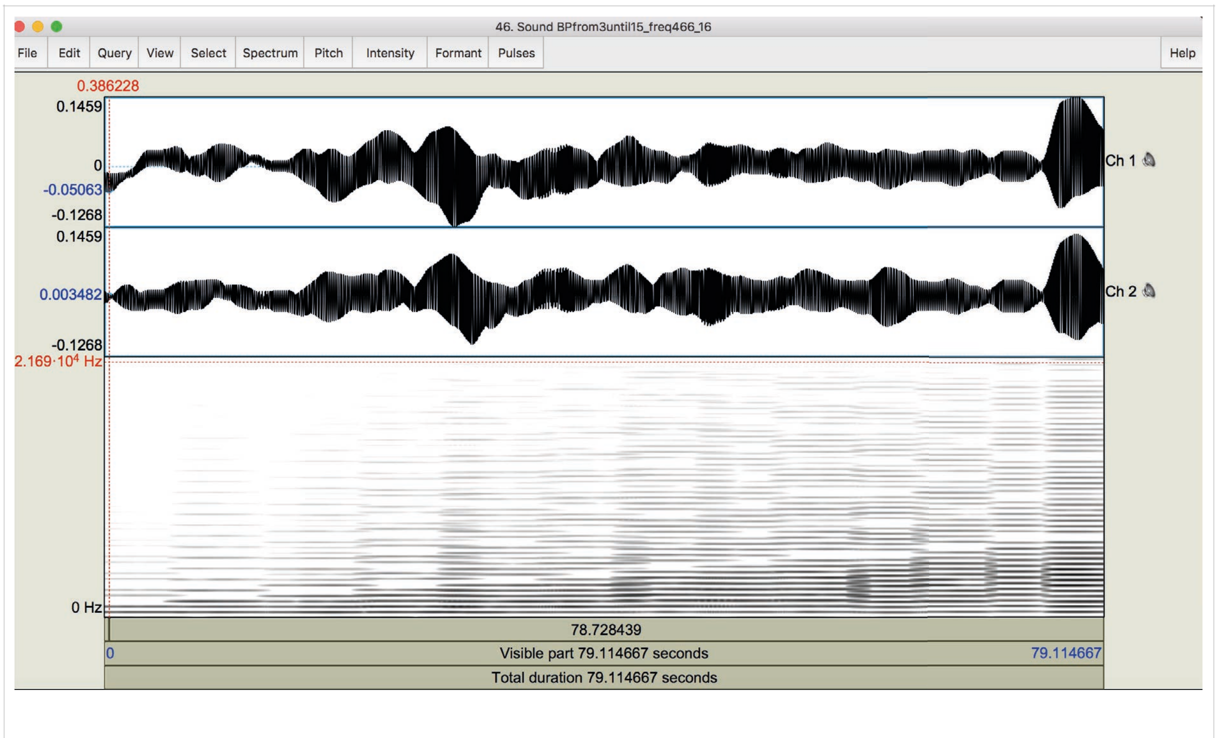


Fig 4a: Spectrum of one single stochastic synthesizer, playing a steading tone (minimal frequency-barrier = maximal frequency-barrier = 466.16 Hz), numBPs equally spaced, starting from 3 BPs up to 15 BPs.

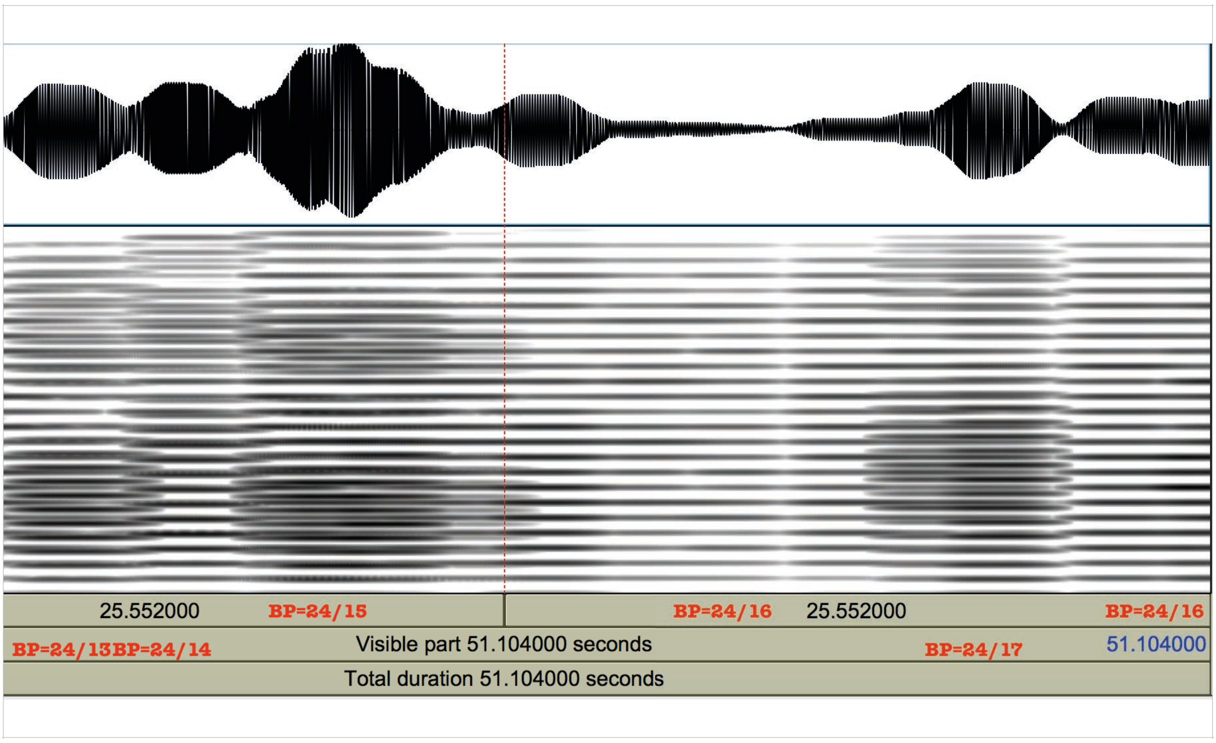


Fig 4b: Spectrum of two stochastic synthesizers, playing a steading tone (minimal frequency-barrier = maximal frequency-barrier = 466.16 Hz), numBPs equally spaced but each synthesizer having a different numBPs (indicated in red). Notice the matching of the partials for numBPs=24 and 16, instead of numBPs= 24 and 13, 14, 15, or 17.

<u>2.2.b) Harmonically consistent densification of space (morphology)</u>

The morphology of *once racing ceased…* builds up in a general textural ambiguity and densification of harmonic space: from pure pitch, to tuned noise and broadband noise.

The type of noisification follows from the sole widening of the amplitude random walks space of the synthesizers. Their numBPs are equally spaced in duration and their minimal and maximal frequency-boundaries are both equal to 466.16 Hz from the beginning of the piece and are left unchanged throughout. The initial, pure periodicity of the stochastic synthesizers is gradually being muddied through more and more frequency spectra amplitude jumps. Aurally, the sole manipulation of the random walks on the amplitude axis results in broad-band noises, which are harmonically coherent: their relation to 466.16 Hz remains identifiable. Yet SAMs are numBPs-dependent too: the smaller the numBPs is, the noisier a same value of SAM will sound in comparison to a bigger numBPs. Using synthesizers with different numBPs was therefore an efficient method to layer different variations and degrees of noisification in the piece.

The piece also works through harmonic densification and expansion, which operates through SAM and the addition of sine waves. *once racing ceased…* starts with the introduction of sustained sine waves meant to interfere with or reinforce the amplitude scatter in the synthesis partials. Progressively other sine waves justly tuned with 466.16 Hz (mainly thirds, fifths and sevenths) gradually fill the spectral dips or missing harmonics of the synthesizers, creating an internal melodic line, without it being on the foreground of the piece.

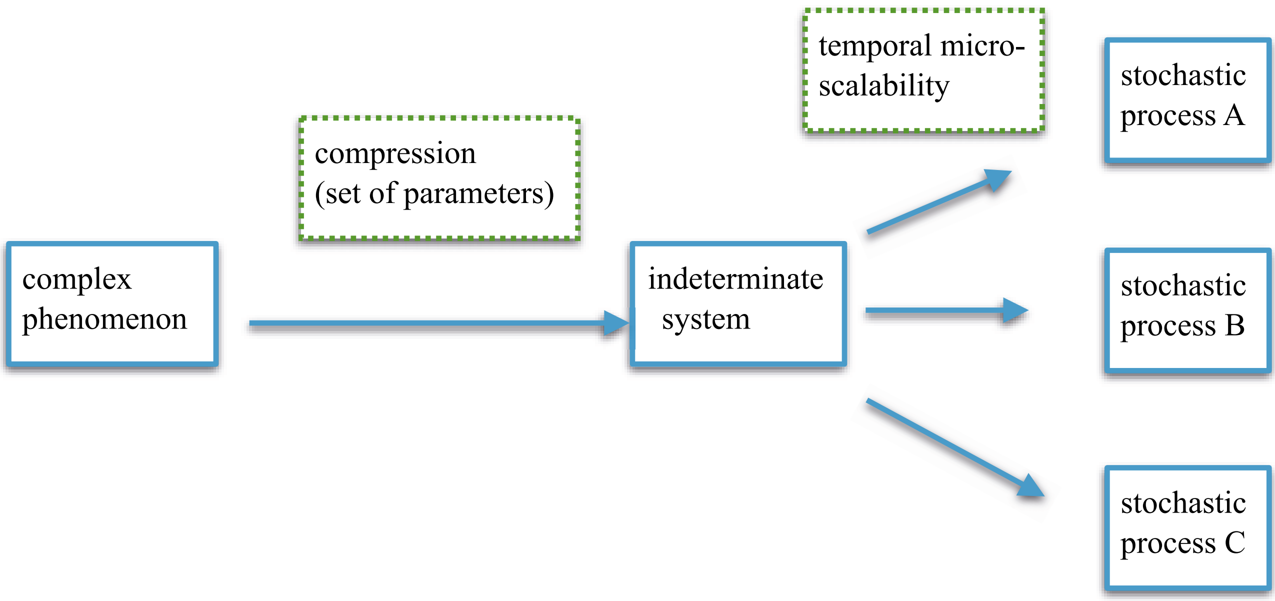
This densification of harmonic space is very much linked to the other important consideration in the piece: its acoustic spatial composition**,** i.e., the distribution of its sustained sounds in space. Dealing with this spatial composition amounted to delineate and spread formant-like mixtures of stochastic synthesizers and sine waves on each loudspeaker. My goal was to smooth the possible appearance and densification of standing waves patterns created by the accumulation of frequencies based on the same fundamental pitch. *once racing ceased…* exists in several versions (for 2, 4, and 8 channels). This is most effective as an 8-channel version, in which, the harmonic relationships and frequency bands (potentially contiguous) are spread out, the multiple layers of interfering waveforms having more space to permeate one's hearing. Conversely, the rough bouncing of the piece on a stereo version and its flattening greatly affects its harmonico-perceptual feature. This mistake made me realize the intricate and inseparable relation between the abstract spatio-temporal composition of sound and the materiality of sound. Composing sounds was not anymore about composing "in" space, but perhaps composing space itself. Harmonic perception considerations thus became entangled with the composition of sound, from the very start.

Chapter 3 : Stochastic frequency modulation — Temporal scalability

The question of temporal scalability of musical structures is a traditional one. It has been mainly presented through the idea of interchangeability of macro- and micro-musical times. In this last chapter, I will solely examine the notion of micro-temporal scalability of stochastic processes.

Scalability is centered on relations of (spatio-)temporal proportions or distance-measures. It depends primarily on compression, i.e., the reduction of the complex temporal structure of a given phenomenon (sound or else) to a finite set of control parameters. Hence, temporal scalability is the possibility of temporal dilation or contraction of compressed temporal structures. It is appropriately represented through maps and their metrical properties. Within such maps, scaling corresponds to the multiplication or division of a given vector (or distance-measure) by a ratio (a scalar), without changing its direction.

Indeterminate computational systems are per definition compressed. The stochastic processes indeterminate systems generate are therefore compressible, and thus theoretically scalable in time. In my compositions, I have attempted to design maps for representing different micro-temporal scales of stochastic processes based on one unique indeterminate system or set of parameters. Such map allowed me to explore the perceptual effects of scaling these stochastic processes in time. Since stochastic processes can result in morphologies which challenge our perception, I was curious to see if contracting or expanding them in time would effect our perception.



By no means do I imply that the scalability of temporal stochastic processes involves a scalability of unfigurability —the first is quantifiable, the second is not: unfigurability remains a situation, prompted by an problem in perception and charged with subjectivity. Nevertheless, I find this point of irreconcilable friction intriguing. Psychoacoustics improved our understanding of how or when such problems in perception can occur, particularly through the use of compressed representation of sounds, maps and thresholds, all imbued with scalability/quantifiability. Models of so-called perceptual vagueness, which attempt to measure the imperfect discrimination of percepts in one's mind, are exemplary of such developments:[71]

> Judgements involving vague predicates involve a two-stage mental mechanism: first, *mapping a stimulus* (e.g. some magnitude of height, brightness, loudness, or other) *onto an inner scale of magnitude*, which provides a mental representation of that magnitude with some approximation; second, comparing that representation to a distinguished value, which can be understood as a *threshold value* for mental representations to be categorized in a certain way.[72]

The compressed representations of complex temporal structures (like sounds, or bodily movements) and their mapping influenced my ways of thinking and analyzing. I started developing a way to organize dynamical systems on maps or lattices. I was aiming at composing temporal scales of random processes, whether their realizations were generated by a computer or not. I was also curious in investigating the mixing the two "types" of random processes to get micro-temporal differences between them and perhaps specific kinds of perceptual effects.

Section 1 describes the piece *for ábel* which relates to the question of perceptibility of stochastic synthesis' random walk occurring on the time/frequency axis, in combination with clarinet tones. Pitch has evidently a central role in this section. Section 2 introduces comparative studies of pairs of (musical and choreographic) pieces based on stochastic processes and which are, in my opinion, unfigurable, borderline cases. They present different morphologies, but such strong structural and computational similarities that they may be analyzable in terms of temporal scalability.

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[71] They remind Hennix's wish to establish a borderline cases' grammar "governing these disembodied sound wave maps."

[72] Dietz, Richard, *Vagueness and probabilities: Introduction,* University of Tokyo, 2017. That said, this "inner scale" escapes provability and remains uncertain.

3.1 Combining computed and non-computed micro-stochasticisms

for ábel is a piece for clarinet, stochastic synthesis and sine waves, circling around 362 Hz. More precisely, the gravitational center of the piece is a unique *reference sonority*: G played on the clarinet without using any particular breathing or extended techniques. The main investigation behind the piece is to bring this reference sonority in and out of a perceptual focus, as well as scattering its localization in acoustic space.

To contrast with the general indiscernibility of the two sound sources, the composition is made from the probabilistic unfolding of successive sound blocks. Each of these blocks operate various subtle sonorous deformations to the reference sonority. Rather than thinking these deformations in terms of changes in 'timbre,' they were treated as stochastic frequency modulations (SFMs) of a single tone. I approached the piece compositional process through the lens of perceptual map and thresholds, especially for the composition of the synthesis SFM.
Still not daring to work with the duration modulation of the synthesis, I preferred to continue using numBPs equally spaced. In this configuration, I was interested in investigating the average behaviors of the synthesizers over time when modulated on the frequency axis and play with degrees of pitch-identity through time.

3.1.a) Perceptual vagueness and Harmonic space

Thinking in terms of perceptual map and thresholds meant roughly establishing a self-made, controllable model of perceptual vagueness on the level of pitch, based on James Tenney's *harmonic space*. Harmonic space is one example among the many models of pitch-maps,[73] built in relation to the perceptual notions of consonance and dissonance. This non-dogmatic, simple compositional and mathematical construct is particularly suitable to a computer program. An instance of harmonic space is built from one value (a foundational frequency), and ratios of natural numbers. It evokes not so much a premeditated trajectory, but a field made of interconnected and intersecting lattices, corresponding to vectors, or *harmonic distances*. The latter describe the trajectory of two frequencies belonging to the same harmonic space. Harmonic distances are calculated by multiplying one of these frequency values by the ratio(s) needed to arrive at the second frequency value.

[73] See Clarence Barlow's concept of *indigestibility/ harmonicity*, Catherine Christer Hennix's *Brouwer's Lattices,* etc.

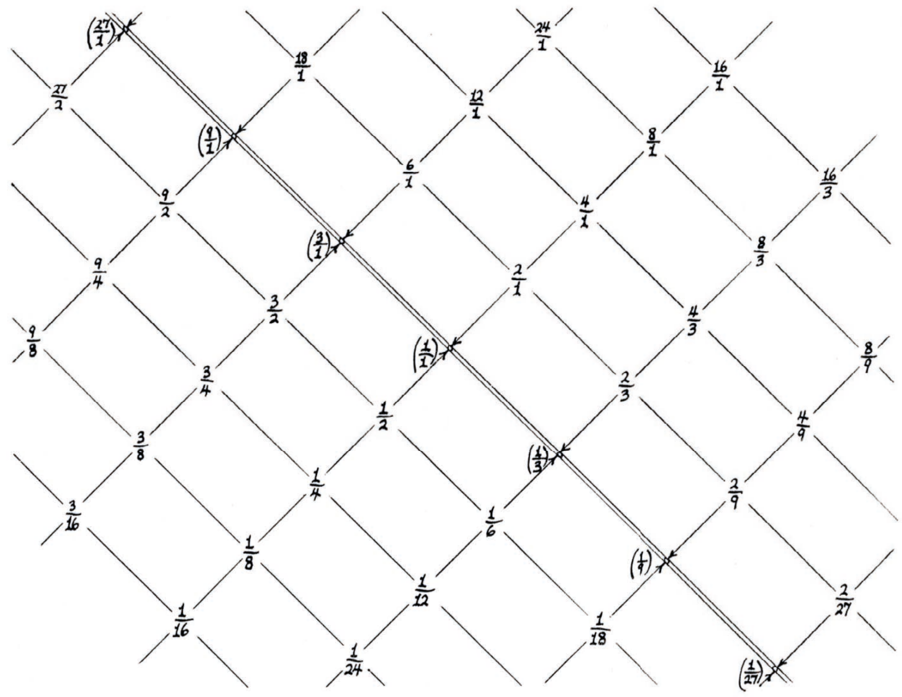

Figure 2. The 2,3 plane of harmonic space, showing the pitch-class projection axis.

Fig 5: One of Tenney's drawings of harmonic space

Harmonic space and distances are considered by Tenney as useful (and incomplete) indicators of degrees of perceived consonance or dissonance when several tones belonging to one harmonic space are played together. To combine Tenney's harmonic space and Barlow's indigestible function, the smaller and more divisible (digestible) is the ratio to describe the distance between two frequency values, the more consonant the two corresponding simultaneous tones should sound like. The bigger and indivisible (indigestible) is the ratio to describe the distance between two frequency values, the more dissonant the two corresponding tones will be when played together.[74] Harmonic space and distances are helpful to simplify the calculations of perceptual thresholds such as the critical bandwidth. As a reminder, the critical bandwidth is the smallest frequency difference between two partials or tones such that each can still be heard separately.

In the piece *for ábel*, I was interested in composing mixtures of pitch and noise as "measures of blurriness" in a harmonic space. It meant sticking to a metrical mode of thinking sounds and their organization. Harmonic space allowed me to articulate two simultaneous perceptual thresholds:

- 1) the perception of the individual variations of one independent sound source, especially in pitch but also in loudness and duration. This first threshold can be put in parallel with the notion of just noticeable difference (JND). In particular, by using equally spaced numBPs and treating the frequency-barriers as harmonic distances, I could deal with the sound of one single synthesizer

[74] The same scheme is applicable to the relation between two "non-fundamental" tones, as long as they belong to the same harmonic space.

through the lens of harmonic space. Naturally, I was not expecting these harmonic distances (meaning: the minimal and maximal frequency barriers) to be "heard" in the synthesis. Rather, harmonic distances were making it clearer to control the synthesis' frequency fluctuations within very precise intervals.

- 2) the simultaneous mixture of two or more sound sources which are perceptually more or less indistinguishable, or heard as one single pitched-tone. This second threshold echoes to the notion of critical bandwidth.

i) First compositional steps: clarinet-multiphonics and SFM

The first compositional steps consisted in listening and analyzing clarinet-multiphonics recordings, modeling a stochastic synthesizer that would approach the sound of a clarinet, so as to finally relate the perceptual effects of SFM to the clarinet-multiphonics sounds.

I first listened to my clarinetist friend Ábel playing the same G at 362 Hz, using different fingerings, breathing and multiphonics techniques.[75] I assimilated the different levels of stability, amplitude and sustainability of these variations in sounds, and specifically their microtonal modulations to a kind of SFM. The analyses of these recordings showed that certain multiphonics were more prone to destabilize the steadiness of the tone, others introduced noise, or led to dense overtones structure. This collection of varying Gs became the main material for the piece.

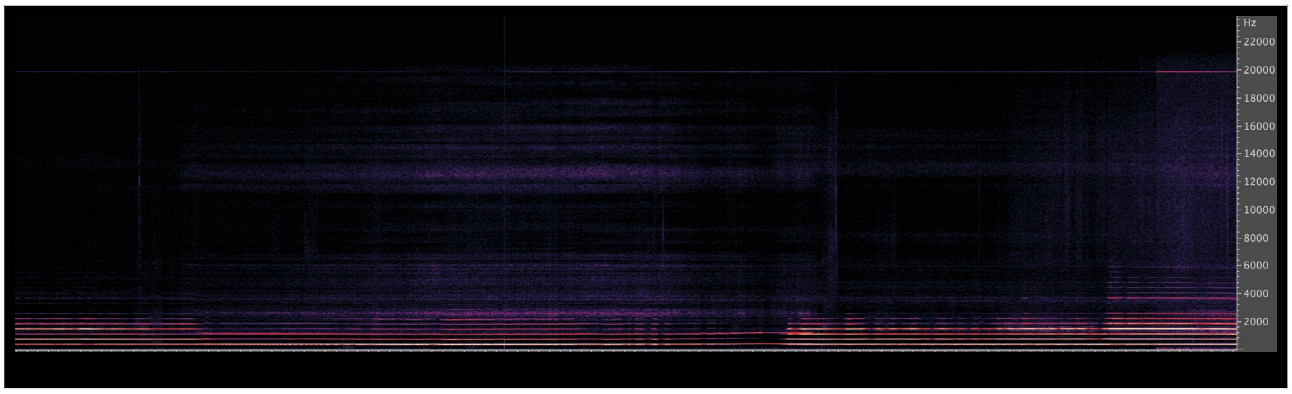

Fig 6a: Spectral analysis of clarinet playing the same G with different fingerings (see recording '1_ClarineRecs mix')

With this in mind, I returned to stochastic synthesis and concentrated on its SFMs, i.e., the random walks which operate on the time/frequency axis. To have the most explicit aural understanding of these specific stochastic deformations of the waveforms, I set the synthesis AM to zero, its number of breakpoints (numBPs) to 7 and its frequency-barriers to 362 Hz. By doing so, the synthesis sound was closest to the spectral scope and richness of the clarinet's reference sonority. Then,

[75] Prior to the piece, I was already interested in clarinet-multiphonics techniques and had read Jack Yi Jing Liang's thesis *Clarinet Multiphonics: A Catalog and Analysis of Their Production Strategies,* Arizona State University, 2018. Following this reading, I asked Ábel to work with specific fingerings of G which multiphonics were supposedly more stable. See sound file *recording 1_ClarineRecs mix.wav*.

I opened the synthesis frequency-barriers from a frequency-band of 15 Hz, up to 200 Hz (362 Hz being the center-frequency), so as to perceive its SFM fluctuations Finally, I triggered one synthesizer after the other in each of these bands, generating different random walks and varying, more or less stable stochastic modulations of one unique pitch.

I was intrigued and willing to work with the perceptibility of these microscopic variations. SFMs correspond to different sonorous behaviors of the same redundant computational system. Their different statistical properties can be averaged and perceived through time (*ergodicity*):

- 1) relative equilibrium and perception of one single pitch:
  - the perceptibility of one (almost) unified and stable pitch,
  - the perceptibility of microscopic variations of one pitch (tremolo);
- 2) relative instability and perception of micro-sequences of pitches:
  - the perceptibility of a sequence of very close pitches (micro-interval);
  - the perceptibility of a (broader) sequence of randomly varying pitch.
- 3) perceptual differentiation of the synthesis successive behaviors (macro-sequence).

The first two relate to the morphology of individual synthesizers sounds and the temporal scaling of each of these stochastic, redundant FM processes. The last one concerns the comparison between each of the blocks.

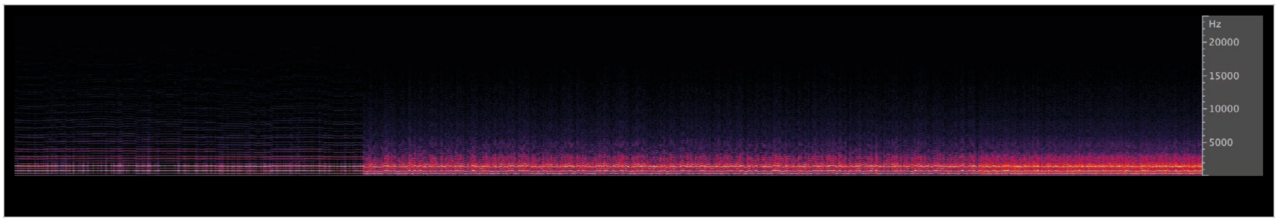

Fig 6b: three successive behaviors of one single stochastic synthesizer, fixed amplitude (maquette "for ábel" — see recording '8iterationsSST_362Hz')

ii) SFM as a source of stable sets of pitches

First and unsurprisingly, the whole spectrum of the synthesizer (fundamental + overtones) is modulated in the exact same way through time: the same SFM is replicated on each partials of the synthesizer. Secondly, as a consequence of its implementation and the absence of interpolation between the durations of the BPs in its waveforms, the synthesis' SFM always results in a finite number of values, of possible steps to 'walk onto' which are repeated over time. Once a stochastic synthesizer which is not interpolated has been triggered, the frequency values where its steps occur are fixed. In brief, specifically for high frequency register, the synthesis SFMs are translated as stable, limited, unchanging sets of pitches.

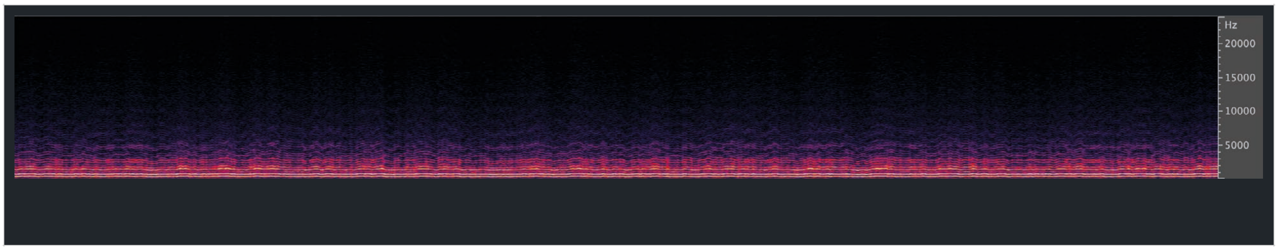

Fig 7a: one stochastic synthesizer's behavior—unchanging scale through time.

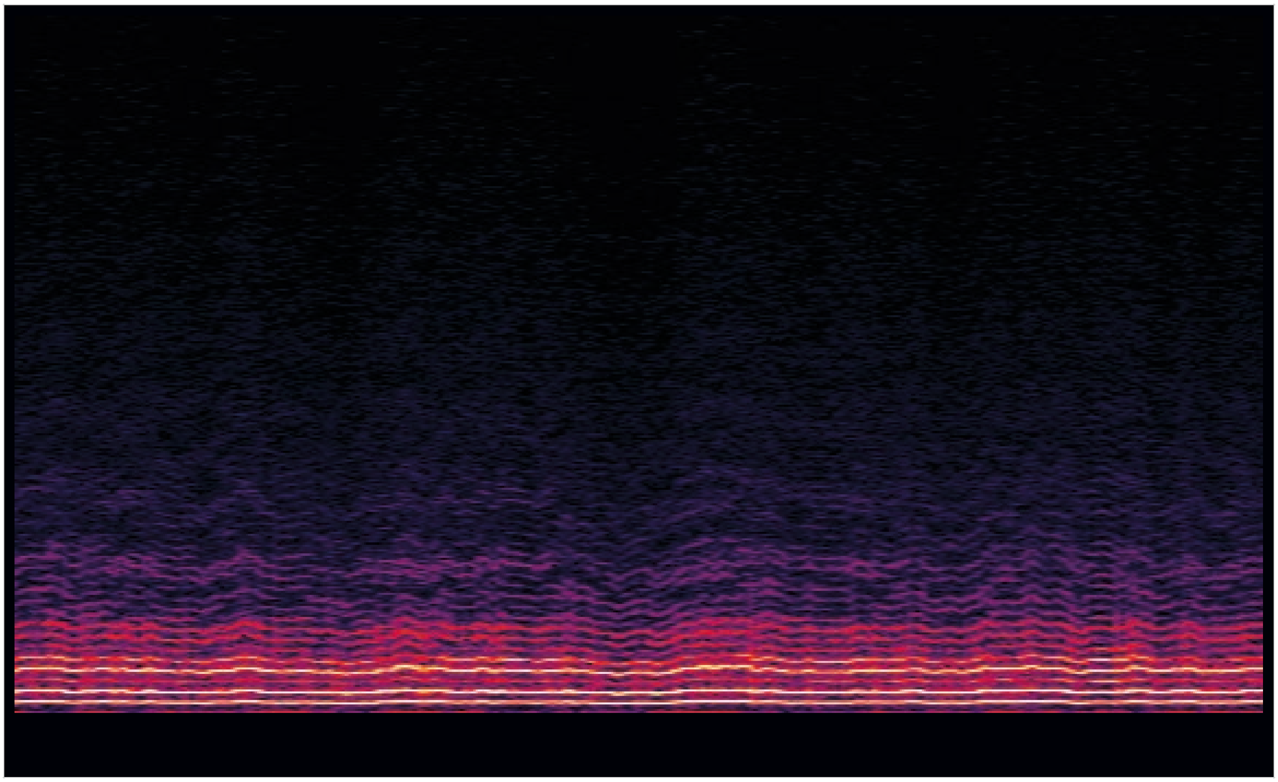

Fig 7b: Zooming in of Fig 5a

These emerging discernible pitch sets are a remarkable feature of stochastic synthesis. They result from a combination of multiple factors, mainly: absence of interpolation of durations, numBPs—the speed of modulations in relation to the distance between the frequency-barrier making them more clearly audible as well. In *for ábel,* the SFMs consist in very slight deviations from an original, fixed pitch. They are obtained through combining the medium height of the mean frequency (362 Hz), a low numBPs, the relative slowness of stochastic modulations, and reduced distances of between the frequency-barriers.

<u>*3.1.b) Micro-scalability of SFM in harmonic space*</u>

i) Organization of SFM in harmonic space — Frequency-barriers as intervals

To control, order or compose the redundancy (and eventually perceptibility) of these sets of pitches, I opted for a rigid definition of the synthesis parameter of minimal and maximal frequency-barriers. I was aiming at extending harmony-related concepts to the most microscopic temporal level: the sample level. The pitched random walk spaces were seen as "sub-harmonic spaces" within a larger harmonic space, built in a Tenney's simplified fashion from the frequency 362 Hz. The minimal and maximal frequency-barriers are thus composed as intervals within this harmonic space, or harmonic-distances between two tones, through ratios of natural numbers. The mean around which these ratios are deployed is static and corresponds to 362 Hz, which remains the harmonic center of gravity of the piece. The sequencing of these ratios give rise to successive scaled spaces for the pitch stochastic processes to unfold. This particular way of thinking is for me an expression of (spatio-)temporal scalability of stochastic processes.

These scaled spaces act like frames of perceptual focus/refocus around a unique tonal center. The different distances between the two frequency-barrier values were always kept intentionally small, so as to go bellow or beyond what can be considered as a critical bandwidth. By convoking this notion in the parametrization of the frequency-barriers of the synthesis, I was aiming at generating pitch sets in my synthesizers, which could ambiguously revolve around this critical bandwidth.

ii) Simultaneous stochastic synthesizers, micro-temporal scalability

My compositional plan consisted in generating successive blocks of simultaneous synthesizers. Each block would imply a different set of parameters, applicable to the simultaneous synthesizers. Within each block, the synthesizers would result in different versions of their shared parametrization, i.e., slightly different pitch sets.

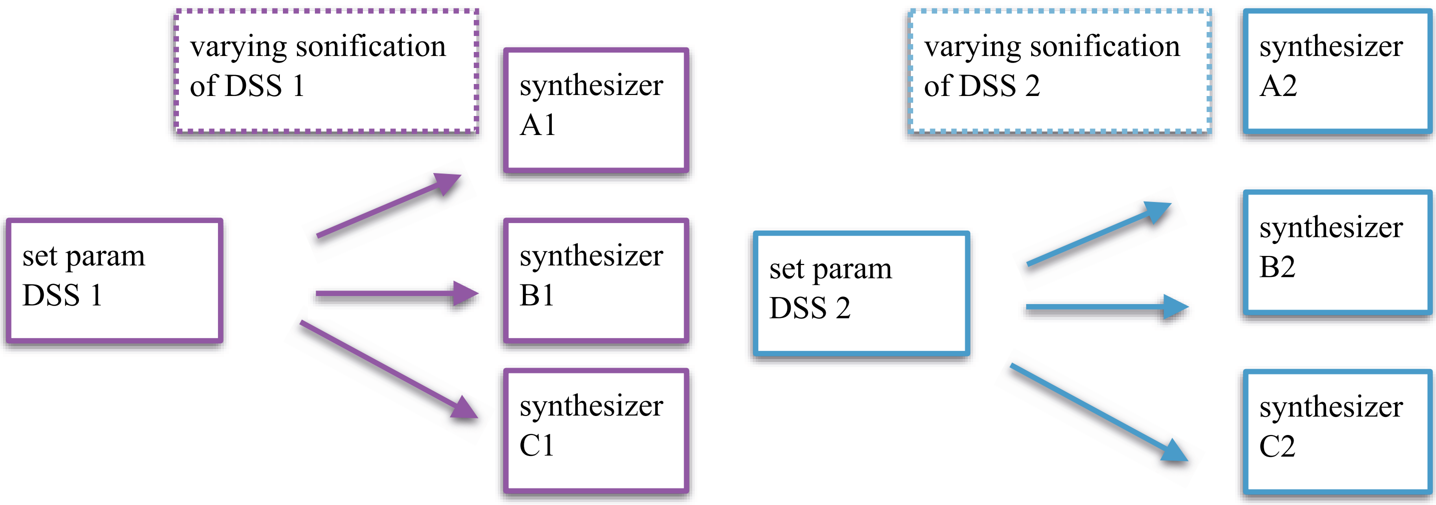

Fig 8 : Schemes of 2 successive synthesized blocks (DSS 1 and DSS 2).
[In the piece, the differences between such sets of parameters are very subtle. The scalability of the stochastic processes they entail is therefore occurring on a microscopic level.]

In my first attempt, I used a completely randomized sequencing of harmonic distances for the frequency random walk spaces. The synthesizers' sounds were becoming statistically homogeneous after a while. Their unfolding was too ergodic: although everything was changing, everything remained the same.[76] Therefore, the pairs of frequency-barriers were randomly generated and sequentially organized from successive and precise ranges of natural numbers, changing according to a superimposed and determined parameter, mixing indigestibility and pitch-distances. Once more, the two concepts of indigestibility and harmonic distances were mostly used as way to organize the sound material in the piece, rather than to be conveyed in the listening of the piece (and in particular its stochastically synthesized sounds). The general unfolding of the piece follows the below straightforward procedure:

a) from more indigestible coefficients (intervallic ratios closer to 362 Hz in frequency, but more harmonically distant);
b) towards more digestible coefficients (intervallic ratios more distant from 362 Hz in frequency, but harmonically closer).

ex 1 (limiting-case of step a): ratio 26:27

- 362*(27-1)/27= 348.6 Hz for the minimal frequency-barrier;
- 362*(27+1)/27= 375.407 Hz for the maximal frequency-barrier,

making a difference of ±13.4 Hz from 362 Hz.

ex 2 (limiting-case of step b) : ratio 10:15

- 362*(15-5)/15= 241.3333 Hz for the minimal frequency-barrier;
- 362*(15+5)/15= 482.666 Hz for the maximal frequency-barrier,

making a difference of ±120 Hz from 362 Hz.

3.1.c) Macro-structure and alternation between indiscernibility and differentiation

The piece's macro-structure is based on a constant perceptual process of alternation between

- the indiscernibility between the electronics and the clarinet,
- the differentiation between the two sound sources,
- and the differentiation between the successive variations happening within each of them.

The question of indiscernibility or differentiation between two simultaneous or successive sound sources must be understood in a broader context than simply pitch. It refers to what Tenney calls a "multidimensional psychological or perceptual space,"[77] which dimensions are "the several parameter involved in the perception and description of any sound, i.e., time, pitch and intensity."[78] Each of these parameters could be represented in respective maps and gathered in a larger "perceptual space". Perceiving differences between two sounds therefore depends on the combined magnitude of changes happening in each of parameters or dimensions.

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[76] This was also a consequence of the setting of the other parameters (loudness, durations) and not using additional UGens or envelopes.

[77] Tenney, James, *Hierarchical Temporal Gestalt Perception: A Metric Space Model (with Larry Polansky),* 1978, in *From Scratch —Writings in Music Theory,* pp.201- 233.

[78] ibid.

Evidently pitch but also loudness are the main parameters contributing to the blending and balancing between the sound sources in acoustic space.[79] Several sine waves play a tone which frequency is either equal to 362 Hz and its octaves (reinforcing the reference sonority); or to the stochastic synthesizer's minimal and maximal frequency-barriers. They also followed the same determinate amplitude curve as the synthesis: from mezzo-piano, to pianissimo, to piano. The clarinet only plays Gs,[80] and its loudness curve counterbalances the electronics' one: from pianissimo, to mezzo-piano, to piano. It starts from soft dynamics, long overall attacks, and fades out in a similar fashion, so as to discreetly appear 'through' the electronics. But by introducing multiphonics and air noise, the clarinet adds new pitch information, and potentially disrupts, as multiphonics involve a certain fragility in pitch and/or unstable loudness.

Differentiation mostly happened through changes in amplitudes and the temporal agencement of the sound sources.

The first tactic used to create rhythmical disjunctions was to set very short attacks and decays between the electronics' successive blocks. These abrupt changes were triggered according to an independent random sequence,[81] timed differently from other changes happening in the electronics. It intensified an unpredictable of their unfolding and mixture with the clarinet part.

A time unit of reference of ±40 seconds was shared among the electronics and the clarinet to trigger a new change in pitch. If this time unit will not necessarily be perceived as a regular measure, as a gradual desynchronization progressively unfolds between the clarinet and the electronics. For the latter, the time unit is changed every minutes. It is shortened until the middle of the piece, and back to 40 seconds at the end of the piece, following another sequence based on ratios.[82] As for the clarinet, this time unit remains unchanged but potentially contains silences, depending on the performer's preparations.[83]

Writing the piece and its explanations were challenging and convoluted processes. On aspect of this process strikes me the most. It is as if the notion of temporal scalability discovered through the setting of the synthesis' random walk spaces had spread from the conception and structure of the composition. The piece seems scalable. This is made possible because it is generated by a computer program in combination with an open score. Theoretically, it could be adapted to any other pitch playable with a clarinet, or any other pitch played by another instrument. It could also be made longer or shorter in time. In brief: the (input) variables of the piece could be modified without

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[79] Similarly as the stereo bounce of *once racing ceased…,* the recording of the piece unfortunately flattens the subtlety of the interactions between the clarinet and the electronics.

[80] See score in Appendix 2.

[81] Random sequencing from the following list: [25, 23, 7, 15, 5, 5, 10, 30]. Summed together, these values correspond to 3*40s (time unit of reference).

[82] The ratios used in this sequence are: (1), (4/5), (7/5), (8/5), multiplying the time unit of 40 seconds.

[83] See Appendix 2.

affecting the piece's structure—which seems expressible in terms of computability.[84] Thus I would be curious to see how this unique structure could give rise to different versions, or morphologies, with perhaps different perceptual (unfigurable?) effects. I will move towards this specific question in the following and last section.

3.2 Comparing computed and non-computed micro-stochasticisms: scalable unfigurability?

This section is more speculative. I will compare unfigurable pieces presenting microscopic contingencies: micro-stochasticisms created by a computer program or related to the performance of a piece. Either way, these stochasticisms are structuring the pieces which can somehow all be expressed in terms of computability. In passing, the documentation of the works mentioned is limited (sometimes, non-existent), making my remarks even more subjective.

3.2.a) Sonorous micro-stochasticisms

I discovered Chiyoko Szlavnics's piece *Gradients of Detail* (2005-6) a year after having listened to Xenakis's *GENDY3* (1991) for the first time. Even if the two pieces are radically different, the first being static, slow, and arranged for acoustic instruments, the second being very fast, dynamic, brilliant, electronic, I found them similarly unfigurable. I suspected they shared structural features, partially undetectable to the ears. These were revealed when analyzing their spectrograms. It seems to me that the two pieces could be said to be two morphological versions of one similar structure differently scaled in time. Szlavnics' *Gradients of Detail* would be roughly stretched 10 times more than *GENDY3.*

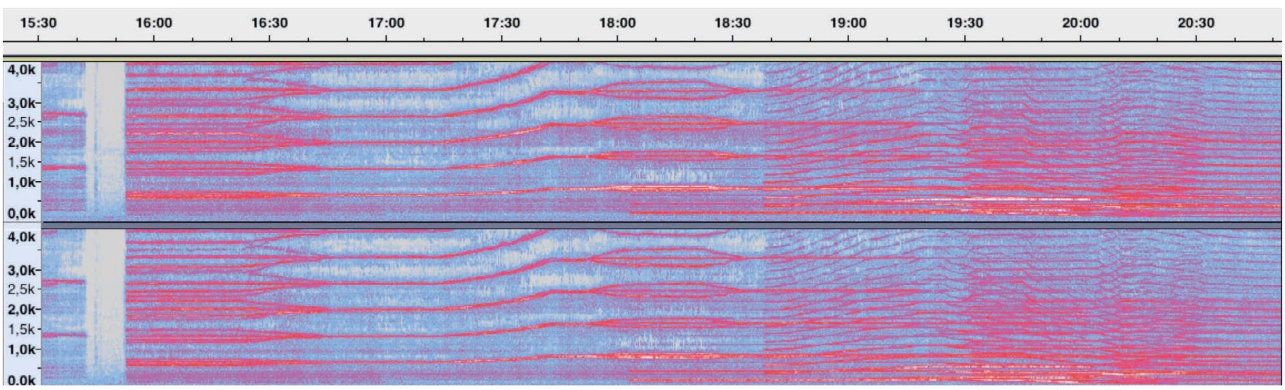

Fig 9a : Spectrogram of Szlavnics' "Gradients of Detail" (15'30"—20'30")

[84] See Winter, Michael, *Relativity and Scalability with Respect to Sound and Silence*, in *M. Word Events: Perspectives on Verbal Notation,* editors Lely, J. and Saunders, M. Bloomsbury. 2012, p.397: "the concept of scaling a piece without disturbing its structure can be expressed in terms of computability".

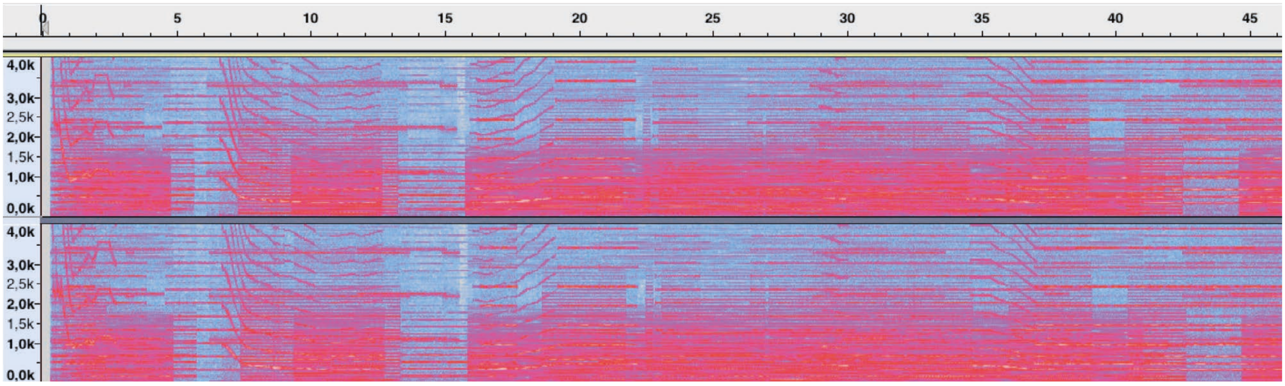

Fig 9b : Spectrogram of Xenakis "GENDY3" (0'00"—0'45")

My first proposition is that linear interpolation and a discrete formalism are at the very core of the two pieces. The connectivity of sonorous elements in the two pieces depend on lines and points. Linearly interpolated breakpoints are present in *GENDY3* for the generation of sound, on a microscopic level. Linearly interpolated breakpoints are also present in Szlavnics' piece for the generation of her score, on a macroscopic level. Her compositional process starts from intuitive hand drawings, which complex curvatures and irregularities are later on compressed into a computer program. The latter quantizes her drawings into straight, segmented lines and points interpolated between each other, becoming suitable for music notation.

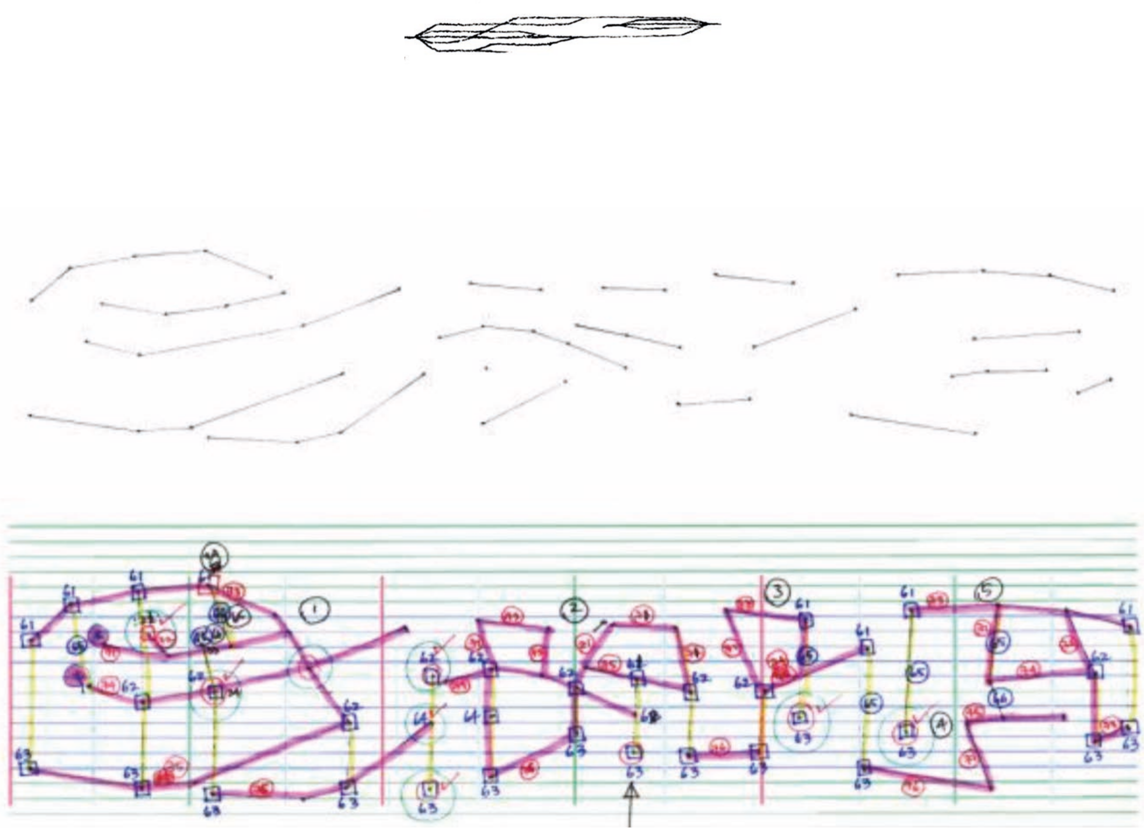

Fig 9c and 9d: Example of a drawing for "Gradients of Detail" and for a process of translation of Szlavnics' Untitled piece (2004)

My second proposition is that the composition of the relationships between the sonorous elements of the piece (be it relations between the synthesis' partials in *GENDY3* or the harmonic relationships between the strings in *Gradients of Detail*) is imbued with computations, particularly on the level of pitch. As a former student of Tenney, Szlavnics understand "ratios as being a network of interrelated pitches connected to each other through direct […] or indirect […] mathematical relationships".[85] On such basis, the degree of precision with which to translate and orchestrate these drawings is particularly high. Both Xenakis and Szlavnics's pieces work as sonification of computed, mathematical datas, and are based on discrete structures. And I wonder if such a structural discreteness does not correspond to a particular kind of aesthetics—perhaps, a particular kind of aesthetic experience. I believe that the two pieces' computations and compression generate structural similarities between them and invite for an attentive, detailed listening to sounds.

It could be argued that such similar discrete structures, found in Szlavnics's score and *GENDY3*'s waveforms, could be interchangeable, and result in interchangeable morphologies, and perhaps interchangeable unfigurabilities. I do not think so. Rather, in their respective morphologies, the two pieces present two different, irreconcilable types of non-linearity:

- a computed random non-linearity (*GENDY3)*— which allows its sonorous realization to be identically reproduced;
- a non-computed random non-linearity (*Gradients of Detail)* due to the acoustic instrumentation of the piece, the combination of the strings' vibrations and the whole complexity they entail. Their vibrational complexity make each sonorous realization of the piece unique. This aspect echoes to the more traditional and procedural notion of indeterminacy.

What I meant to evoke here is perhaps a question. I keep wondering how such a possibility to associate in listening, to hear similarities between two pieces which are so radically different can even exist. I wonder if one can develop a cognitive ability to decipher the presence of this specific kind of formalism or computational discreteness within different spatio-temporal scales (the microscopic one in *GENDY3* and the macroscopic one in *Gradients of Detail)*. The question is in fact much broader than a discussion on micro-stochasticism and I feel as though this may be an impassable wall. I will therefore get back to the essential idea of this thesis (symbolized in its title's slash): the computational notion of indeterminacy is distinct from unfigurability. Unfigurability can be experienced and explored through the lens of computations but cannot be explained.

> … because the incomputable is this element of undecidability […] that is logically inscribed into every computation, something in computation remains unknown and, ultimately, beyond representation.[86]

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[85] Szlavnics, Chiyoko, *Opening Ears: The Intimacy of the Detail of Sound*, Filigrane, Issue #44 Editions Delatour France, Paris, 2006.

[86] Fazi, Beatrice, *Digital Aesthetics: The Discrete and the Continuous,* Theory, Culture & Society Vol. 36, University of Sussex, 2019.

3.2.b) Choreographic micro-stochasticism?

These very last paragraphs will present personal views on choreography.

It is striking to notice that the question of the agencement of microscopically-scaled motions has not fully reached this field yet. Choreography, which constantly faces the question of the body organizing its passage through time and space, seems hermetic or resistant to think through such a microscopic scalability or spatio-temporal microscopy of body-movements. Strikingly, when the pioneer, contemporary dance choreographer Anne Teresa De Keersmaeker was asked (in 2017) what the micro-movements of dance could be, she pensively answered that they were still to be invented.[87] This answer shows the general state of affairs in choreography and the difficulty to get rid of dance's premises: prescribed motions, patent displacement and mobility, extreme motricity and technicality, habitual uniformity of bodies' movements. It is also surprising since it makes no mention of Steve Paxton's *Small Dances,* choreographed 40 years before (1977).

In *Small Dances,* one or more dancers are standing in stillness (and silence). They observe and offer to the view of the audience the effects of gravity on their bodies: their constant micro-movements and adjustments to gravity— unpredictable, random, reflexing actions specifically around the spines and joints. The piece presents a kind of topographical map of a body's oscillations, or quite literally: *standing waves*. It is also a compressed, scalable piece per excellence: its structure (reducing the body's complex motions to a sole, vertical line) remains unchanged, whether it is performed for short or extended periods of time.

The richness of *Small Dances*' discovery contrasts with the limited compositional impact they had on contemporary choreographers. The piece still seems under-explored as a starting point for a new generations of works and, perhaps, a different ontology for body-movements focused of non-active movements as the main choreographic material. These works would be less based on this traditional principled expansion of movement in space, but rather on the composed subtraction, rarefaction, reduction of movement in space and, most likely, its extension in time. To sum up, I am looking forward to see (and work towards) a translation of Tenney's harmonic perception and space to the choreographic field. Developing new tactics of attention to enhance microscopic body-movements, informed with mathematical structures and metric spaces[88]—something like variable, abstract, microscopic dances, is a promising area of exploration.

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[87] The Museum of Modern Art, *Anne Teresa de Keersmaeker in conversation with Kathy Halbreich*, MoMA Live, 2017, https://youtu.be/6bYMOFuuNXc?t=2840 , around 46'30"- 56'00". Halbreich mentions "the internal microscopic structure of sound as a model for the macroscopic ensemble of harmonies" in Gérard Grisey's *Vortex Temporum,* and asks: "What would be the microscopic structure of dance?". De Keersmaeker answers, after silences and hesitation: "This aspect, how [Grisey] works with micro-intervals, is work that is still to be done."

[88] Mathematical concepts are already explored in dance though (Rudolf Laban, Noa Eshkhol, Hiroaki Umeda, etc).

This might only be done by artists who are less preoccupied with dance and rather focus on body-movements. Paxton recently stated: "I am perfectly willing to eliminate the word dance from language [but] I don't think we can do without the word movement".[89] The composer Robert Blatt inscribes himself in such lineage with his piece *All Together Now* (2015).[90] The piece seems to come from a witticism based on the multiple meanings of the word pitch: pitch as tone height, and also as the verb to sway, to roll—to wallow. The fixed soundtrack evokes straightforwardly tone heights, through the gradual apparition of sine waves in a completely stable, justly tuned, dense harmonic space. As for the bodily aspect of the piece, a main performer and invited members of the audience follow a score unfolding on a screen in front of them. The score indicates degrees of yawing, rolling, and pitching for the head and torso. By compressing upper-body motions to quantized, numerical degrees, *All Together Now* produces a very complex and precise choreography, as challenging to perform as it is interesting to watch. It reminds of the actual bodily experience of standing waves (where someone would move his or her head, only to find nodes or phase-cancellation points in space).

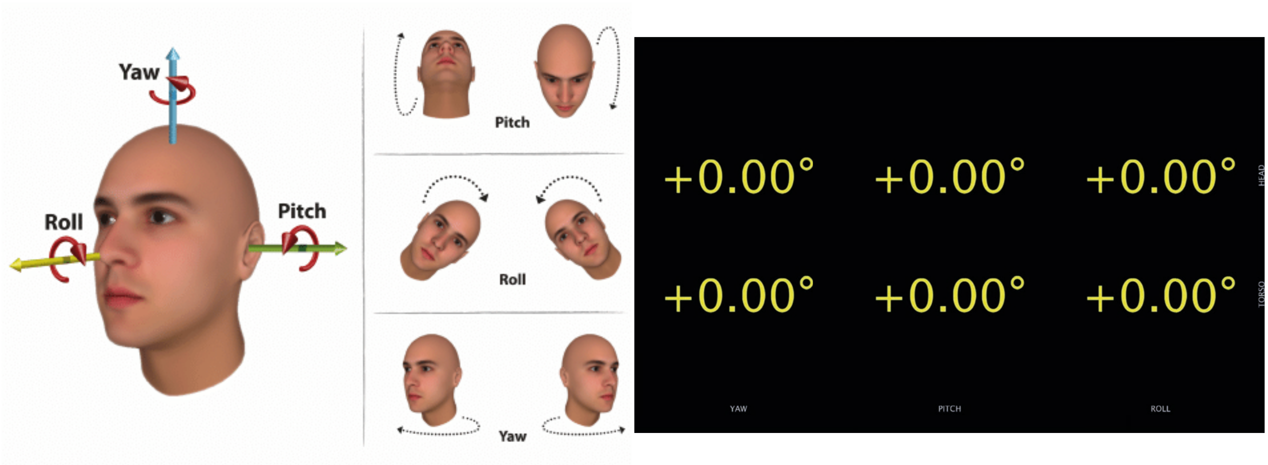

Fig 10a & 10b: A reminder of the actions of yawing, rolling and pitching; and a screenshot of the score at the beginning of the piece

The score follows individual random processes in generating these degrees values for pitching, rolling and yawing for both the head and torso. These values seem proportional to one another, and never exceed the possibilities of the body. An additional layer of stochasticism follows from two elements. First, the score is so difficult to perform that even the main performer of the piece must deviate from it. So the necessarily imprecise translation of the score into bodily movements creates a certain unpredictability. Moreover, since they follow the score for the first time, the audience members end up being more or less forced to mimic the main performer, creating additional deviations and imprecisions.

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[89] Culturgest, *Steve Paxton conference at Culturgest [Lisbon, Portugal, 2019]*, 2019: https://www.youtube.com/watch?v=iX8A-ELSJk8 1 hour and 50'45".

[90] WEISSLICH, *Robert Blatt - All Together Now [w/score] | WEISSLICH 4 31.10.15*, 2015, https://www.youtube.com/watch?v=BcTGtpsYLns.

This piece seems very important in its effort to compress bodily motions to a "minimal logical constraints," extremely precise proportional relations and subjected to stochastic processes. It denotes the possibility of expanding computational concepts to scores and strategies in the choreographic field—even if the result is doomed to remain imprecise, and unfigurable.

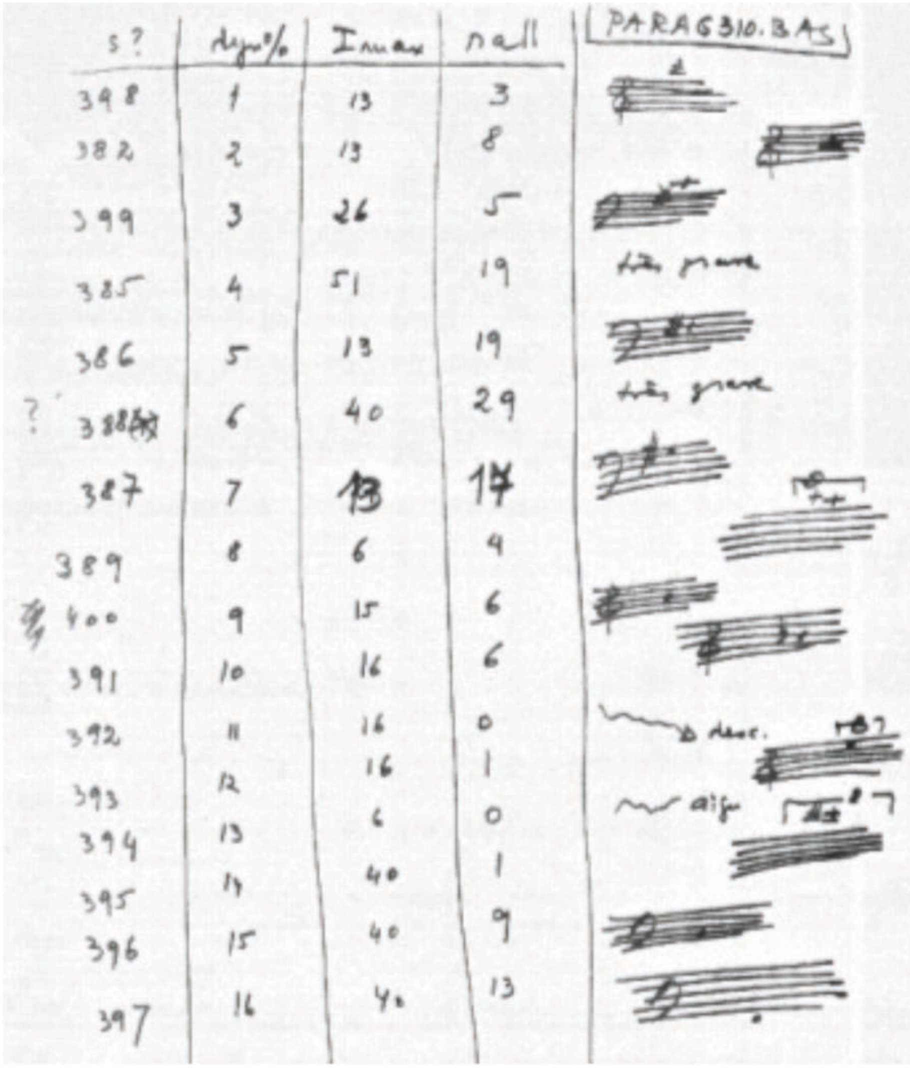
Fig 10c: Screenshots of 'All Together Now'

Conclusion

This thesis gave me a precious opportunity to reflect on, process and articulate the numerous and eclectic compositional ideas that I have gathered over the last four years. Getting a better understanding of the notions of structure, morphology, and indeterminacy set very necessary grounds to revise my views on composition and enlarge its scope. It provided me an interpretative lens for analyzing artworks which seemed hermetic to analysis initially. These compositional tools should be developed further in the future. I particularly intend to deepen my understanding of computability theory, which concepts could only be briefly touched on in the context of this research.

At the same time, I realize I have embraced a contradictory or paradoxical attitude in my willingness to give as much importance to the theoretical clarification of certain concepts or organizational maps; and to the "real" unfigurability, obscurity, unverifiability of subjective, human experience in face of music, and art in general.

Appendix 1 — A sheet from Xenakis' sketchbook



"A sheet from Xenakis' sketchbook at CEMAMu, documenting the pitch parameters used for the first section of GENDY3. In GENDY3, only tracks 1, 3, 5, 9, 13, 14, and 16 are sounding, all others being muted." (Source: Hoffmann, Peter, Music Out of Nothing?, p.251)

Appendix 2 — Score of *for ábel*

for ábel (2020)
for clarinet & electronics

General Description
The main investigation of this piece is to revolving around a 'reference sonority' (pitch): 363 Hz (G), both for the electronics' (sine waves and stochastic synthesizers) and clarinet parts.

Description of the Electronics
The electronics consist in successive blocks of sounds. While circling around 362 Hz, their amplitude and panning are randomized. The overall amplitude of the electronics is statistically described as:

1. ppp-mp
2. pp-mp
3. p-mp
4. ppp-p
5. ppp-pp
6. pppp-pp
7. ppp-p
8. pp-p

The only determined material of the electronics is the trajectory of one sine waves along the octaves of 362 Hz:

1. 1089Hz (± 0'00" 0'40")
2. 724 Hz (± 0'40" 1'20")
3. 362 Hz (± 1'20" 2'00")
4. 181Hz (± 2'00" 2'40")
5. 90.5Hz (± 2'40" 3'20")
6. 181Hz (± 3'20" 4'00")
7. 362Hz, (± 4'00" 4'40")
8. 724Hz, (± 4'40" 5'20")
9. 1089Hz. (± 5'20" 6'00")

Stochastic synthesizers' frequency modulation is affected and reset every ±40". Their frequency-barriers vary up to 241 Hz (2/3 from 362 Hz) as a minimum frequency-barrier and 483 Hz (4/3 from 362 Hz) as a maximal frequency barrier, and are symmetrical according to a center frequency equal to 362 Hz.

Preparations for the performer: 8 iterations of Gs.

<u>Temporal considerations:</u>

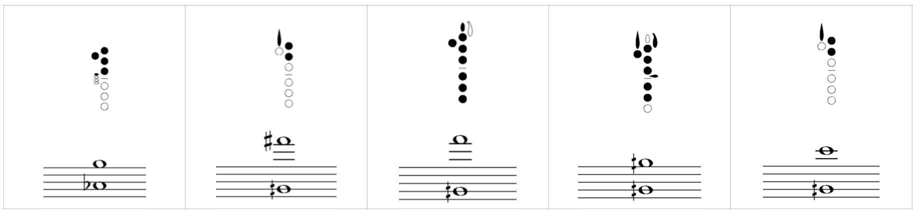
- the clarinet should play between 0'20" after the beginning of the electronics, until 4"40",
- 8 iterations lasting more or less 30" (±10"), eventual breathing and silences included.
- Circular breathing can be used, but it should be as discrete as possible, never forceful, and changes in the sustained sonorous material should be heard every ± 30 secs.

<u>Amplitude:</u> set for each iteration according to the following statistical shape mirroring the electronics':

1. pppp-pp
2. ppp-pp
3. ppp-p
4. pp-mp
5. p-mp
6. pp-mp
7. ppp-p
8. ppp-p

<u>Clarinet techniques</u>
All techniques can be used to give these different shades to the pitch 362Hz, as long as they remain in the field of your instrument. They should never forced or sound forceful. Different techniques that could be used are:

- playing 362 Hz as a fundamental.
- playing 362 Hz as a fundamental, adding various (subtle) degrees of air noise.
- micro tonal deviations from the fundamental, adding various (subtle) degrees of beatings with the electronics.
- multiphonics, with G as a fundamental. Multiphonics should be brushed, skimmed, never loud, as steady as possible. They can also not sound at all (only pitch heard would be then G). Ex:

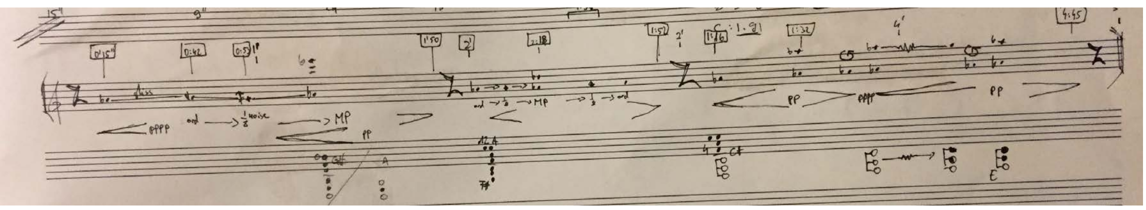


With consideration to the description of the electronics or not, should be set in advance:

a) the 8 iterations and variations of sonorous material revolving around G tuned to 362 Hz;
b) the durations of each block where clarinet is playing, which should be manageable for the player. For instance, playing 4'00" of circular breathing is a possibility only if the player can hold it for so long, otherwise this option should be dismissed. Fixing appropriate durations, according to the techniques, the sound material used and the abilities of the player, is the most essential step of the preparations.

It is required to fix these durations and materials on a written score. No improvisation.
On the overall: soft, clear, determined, never forceful nor expressive.

Set up
Preferably: no amplification of the clarinet. 2 speakers, pretty close to the clarinet so that the two sources of sound (acoustic and electronic) may blend together   experiment with the placement of the speakers in the space.



Example of a final clarinet's score, prepared by Ábel Fazekas (2020)

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