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Aesthetics and Poietics of Sound Material, Form and (absent) Body in Electronic Music: Conceptual Tools for the Computer Musician, and their Applications

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Aesthetics and Poietics of Sound Material, Form and (absent) Body in Electronic Music: Conceptual Tools for the Computer Musician, and their Applications

A dissertation submitted in partial satisfaction of the requirements for the degree
Doctor of Philosophy

in

Music

by

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The Dissertation of Johannes Regnier is approved, and it is acceptable in quality and form for publication on microfilm and electronically:

Chair

University of California San Diego

2019

DEDICATION

To Marit.

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ABSTRACT OF THE DISSERTATION

Aesthetics and Poietics of Sound Material, Form and (absent) Body in Electronic Music: Conceptual Tools for the Computer Musician, and their Applications

by

Johannes Regnier

Doctor of Philosophy in Music

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Professor Miller Puckette, Chair

The dissertation delineates several notions and conceptual tools of fundamental importance in our computer music practice, and proposes concrete applications of these concepts.

The first chapter is centered around the dialectic of matter and form, from the perspective of aesthetic philosophy, and afterward within the musical discourse.

In particular, we discuss the dualism empiricism vs. formalism, a prevalent binary opposition in computer music aesthetics. We generalize this dualism as the opposition signs vs. concepts. While acknowledging the pertinence of this opposition, both from the perspective of the aesthetics and the composition methods, we show that, in practice, the situation is more nuanced, and most computer music pieces exist somewhere on an axis drawn between pure empiricism and strict formalism. The following section discusses three compositional strategies to organize the sound material in a musical form: the form as a result of a process, sound transformations and morphological variations as structuring processes, and articulation of space as structuring element.

The second chapter is centered around the notions of performance, bodily presence and human agency in computer music. We show that the increasing use of electronics and digital technologies in musical practices has dislocated our notion of liveness and magnified the possible interactions with the sound material. We discuss the consequences of the absence of the body or of bodily gestures in computer music performances, and we establish a network of relationships between timbre, attribution of causality, inference of intention, and emergence of a virtual presence, that we consider are at the source of fruitful and creative ambiguities in computer music.

The third chapter presents our answers to these questions, in the form of six electronic music studies within a performance for dance, video and live electronics. These studies are based on a combination of direct interventions, improvisation and algorithmic processes. Several tools and techniques used in these pieces are presented, notably a modal synthesis model with morphing capabilities, a fractal-based algorithm to generate material at different time scales, a virtual analog extended model of the Xpander filter with morphing capabilities, and two reverberations able to generate abstract but cohesive spaces.

Introduction

Electronic and computer music practices seem, in many ways, to fundamentally reshape the rules and constraints that we usually find in the traditional musical practice (by traditional, we mean the Western musical practice, based on the note, and regarding the execution, on traditional acoustic instruments).

The increased and accelerated convergence between technology, techniques, and musical aesthetics and practices has defined new modes of composition, performance, and interaction, nowadays often via the computer. *Increased and accelerated*, because this aesthetics/technology convergence didn't occur just due to the advent of recording and digital techniques. It is not, of course, a phenomenon unique to the twentieth and twenty-first centuries. The invention of the movable-type printed press around 1439 allowed the mass production of printed sheet music. The technological innovations of the fortepiano in the late 18th and the piano (with cast iron frame) during the 19th century, replacing the harpsichord, allowed higher expressivity and louder sound, due to the increased tension of the strings and the key action mechanism. The valves for brass instruments in the 19th century expanded their usable range (Ahrens, 1996). All these technological innovations had a considerable influence on the ways to compose, perform, think, and listen to music. However, it is undeniable that the advent of the digital technologies has considerably reinforced and accelerated that convergence, and posed, in a relatively short period of time, new challenges for the composer and performer of electronic and computer music.

While the fundamental principles and difficulties that computer music composers are facing remain similar to those of the traditional composer, digital technologies markedly exacerbated some of them. And among those, one is, in our opinion, central: the question of the articulation of the sound material in a musical form, either during a composition process, or on stage, during a performance. Two aspects arise from this problematic. First, the questions of material, structure and form (we will distinguish between these three notions in this dissertation). Indeed, as pointed out by Curtis Roads, the possibilities of sound transformations and manipulations, and the open and heterogeneous nature of the sound object have drastically expanded the "*possibilities of musical form*" (Roads 2015). It led to a proliferation of new forms, often unique and singular, and raised new challenges for the composer regarding the organization of sounds. The replacement of symbols (the notes) by the sound object magnified the dualism material/form, and changed the way we listen, by emphasizing the meaning of sound itself (Demers 2010). The sound object —not only the sound object as defined by Pierre Schaeffer, but the sound object in a broader sense, as compositional element, as an ensemble of characteristics, functions and potentialities, all possibly time-varying—, not only opened a whole new range of possibilities, allowing to compose the sound itself, as it is commonly admitted, but also reshaped the ontological statuses of material and form. The boundaries between them are blurred and fluid. In other words, it is possible to cross more easily such boundaries, and to consider them at an operative level, as a compositional parameter. Several questions stem from this assessment: the question of formalism, of course; the question of the form as a result of a process; and the question of the material as a space of potentialities, containing its own possibilities of structuration. There is no question however, in this dissertation, of claiming the disappearance of categories and the complete unity of material and form: we will show that ontological and phenomenological differences, of course, exist. Furthermore, to consider and think categories and hierarchies is a proven, if not necessary, way to carry out and develop our compositional work.

If we have devoted, in the first chapter of this dissertation, an important portion of our work to these questions, it is precisely because of the questions that we are facing in our own compositional and performative practices. While it often seems to us that creating the sound material is, within the whole composition process, a phase full of promises, open, and, we would like to add, relatively simple, it is the structuring phase as such, when it comes to exploit the potentialities of this sound material, and to create a global coherence, that puts the whole edifice at risk of collapsing. This dichotomy maybe originates from our background and experience as sound engineer and sound designer, but we nevertheless believe it is a shared concern among most electronic music composers.

Second central aspect: the question of interactions and bodily presence during a performance of electronic music, and their inevitable corollary, that we call the *dislocation of liveness*. Undeniably, the advent of recording techniques, and the ever-increasing use of electronics in music, had (and of course still has) a considerable impact on musical practices, and profoundly changed our notion of liveness in music. Several new interrelated questions stem from this assessment, that we will discuss in the second chapter: the question of the (in)visible presence of the performer during a performance of electronic music; the attribution of causality and its relationship with the time-varying behavior of sound morphologies, and their immediate consequences, the process of expectation and the emergence of a narration; and lastly, we will discuss the notion of a "present absence", that is, the emergence of a virtual presence during the performance of electronic music, a concept that appears under different names (named *reactive presence* by Jean-Claude Risset, *living presence* by Simon Emmerson, or *virtual persona* by Paul Sanden). The growing importance of these questions in our own practice as computer musician, is, we believe, the fertile ground of our electronic explorations of the physicality of the sound material, and its potential ambiguity.

To support our arguments, we refer to the works and writings of several electronic composers, in particular Chowning, Xenakis, Roads, and Vaggione, as well as composers from "popular" electronic music and electronica. We also regularly refer, throughout this work, to domains adjacent to music, notably phenomenology, and aesthetic philosophy. We are however not "doing" philosophy; we are instead building and discussing the conceptual tools of our approach to composition and performance in electronic music.

Lastly, to illustrate our positions, a performance combining dance, live electronics, and video advances some possible answers to the questions we mentioned above. These answers should be considered within an aesthetic context and are individual and, therefore, inevitably subjective answers to general questions. We hope nevertheless to give insights into our inspirations, aspirations and explorations. This performance, its context, the techniques and the computer music tools developed and used for it, will be discussed in the last chapter.

Thus, this work can be considered as an analytical and ontological study of our approach on composition and performance of electronic music. It is articulated from the point of view of the *sender*, the composer or performer, that is, following the musical semiology of Nattiez, and the tripartite model of Molino (Nattiez 1990), from a *poietic* point of view: it is about the attempt to put into words our musical concepts and creative processes. The challenges we faced to structure this dissertation reflect those we face to structure our music: both are the mirror of our interrogations. We believe, or we hope, that these words will shape our musical thought, at least as much as our musical thought is shaping our words.

1. Poietics of sonic structures

1.1 Ontology of matter, form, and structure

1.1.1. The dialectic of matter and form: prolegomena

> The distinction between matter and form is the conceptual scheme deployed in the greatest variety of ways by all art theory and aesthetics. […] Form and content are the commonplace concepts under which anything and everything can be subsumed. If one correlates form with the rational and matter with the irrational, if, moreover, one takes the rational to be the logical and the irrational the illogical, and if, finally, one couples the conceptual duality between form and matter into the subject-object relation, then one has at one's disposal a conceptual mechanism that nothing can resist. (Heidegger 2002).

Before addressing the questions related to musical aesthetics, formal principles, formalism, organization of sound material and form articulation, it seems necessary to precisely define the notions of form and matter, first from an ontological point of view, and second within the musical discourse.

The dialectics matter/form is a pivotal concept of Western art and aesthetic philosophy and has become today a rather trivial and obvious opposition. Aristotle, in particular, systematized a substance theory, in other words, an ontology, based on a fundamentally dualist nature. Aristotle defined the concept of substance, the *being*, as a complex of form and matter. The matter is what constitutes the form, and the form the way this matter is organized and structured to constitute the object, with certain characteristics and functions, thus an object that becomes part of the sensible world: a perceptible and intelligible object.

> We call the matter the substrate; in another, the shape; and in a third, the combination of the two. By matter I mean, for instance, bronze; by shape, the arrangement of the form; and by the combination of the two, the concrete thing: the statue. (Aristotle 1989)

Heidegger emphasized the limits of the fundamentally utilitarian nature of the pair matter/form in Aristotle's philosophy:

> Matter and form are determinations of beings which find their true home in the essential nature of equipment. This name designates what is manufactured expressly for use and usage. Matter and form are in no way original determinations belonging to the thingness of the mere thing. (Heidegger 2002)

By *mere thing*, Heidegger designates what is left of the thing once free from any character of serviceability, that is, potentially, a work of art. However, Heidegger is above all concerned with the fundamental ontological status of the work of art. The emphasis on the *usage* in the conceptual pair matter/form in Aristotle remains relevant when considering the processes and procedures of production (the poietics) in computer and electronic music, that is, how a work is composed, which strategies to organize sonic matter, and to articulate the musical form were used.

Moreover, two aspects of the Aristotelian theory of substance seem to us extremely pertinent when considering the organization of sonic matter in a musical form. First, that matter is relative: "*Again, matter is a relative thing—for different forms there is different matter*." (Aristotle 1991). Aristotle stresses that matter is relative to an *end* and a *function*, and therefore, that a form could be considered as the matter of a subsequent form. This fundamental notion of Western philosophy will indeed lead to several analogies in a compositional context, obviously as regards to self-similarity for instance, but also, more generally, as regards to the composition at different time scales. Adorno observed:

> Material, by contrast, is what artists work with: It is the sum of all that is available to them, including words, colors, sounds, associations of every sort and every technique ever developed. To this extent, forms too can become material; it is everything that artists encounter about which they must make a decision. (Adorno 2002)

James Tenney, more radically, proclaims that "*it is no longer necessary to treat form and content as fundamentally different things*" (Tenney 2015).

This leads us directly to the second aspect: Aristotle elaborates, from the concepts of matter and forms, the concepts of *potentiality* and *actuality*, and thus, a theory of process and becoming. The *ousia*, the substance in Aristotle's philosophy, unfolds from the possible - potentiality- to the real - actuality-. Matter is being given a potential, and, when actualized, becomes form.

> The proximate matter and the shape are one and the same; the one existing potentially, and the other actually. Therefore, to ask the cause of their unity is like asking the cause of unity in general; for each individual thing is one, and the potential and the actual are in a sense one. Thus there is no cause other than whatever initiates the development from potentiality to actuality. (Aristotle 1989)

We will see further in section (1.2.2) how this actualization of matter, and its corollary, the form as a result of a process, echoed in the works of composers such as Cage or Xenakis, among many others.

1.1.2. Form and matter in Music

Given these definitions and interrelations between matter and form, it is now pertinent to discuss what we consider is at the source of the difficulties - and the richness - of this dualism in a musical context. Contrary to the domain of the plastic arts, where there is an obvious disjunction between matter and form, we have to deal in music with a continuum, in regards to their ontological status. Schaeffer points out that "*there is, in music, a curious common border between matter and form*" (Schaeffer 2012). Moreover, the nature of this continuum turned out to be of a crucial importance since the advent of computer and digital techniques in music.

Indeed, we perceive sound material and form within the same flow of time. The sound phenomenon is, by its very nature, a temporal phenomenon, meaning that the act of hearing differs profoundly from the visual perception. Therefore, while it is possible to examine an object more closely and even to "step back" in order to gain greater perspective, it is not possible to achieve the same overview in the world of sound (Regnier 2015): there is "*no possibility of hindsight*" (Chion 2010).

It is clear however, that, during listening, segregation occurs, allowing us to perceive a work in several hierarchical levels, and therefore, to distinguish between material and form. In a traditional musical context (that is, with traditional instruments), the disjunction mentioned above occurs predominantly by recognition of the instruments (the material). Furthermore, the identification of musical phrases, sections, or forms is reinforced by the phrasing and the visible movements of the interprets (in the context of a live performance, to which we are spectators). But in the case of computer and electronic music, instead of composing for a finite set of instruments, one composes with the instruments themselves. The sound material is malleable, and part of the composition process. Therefore, the range of possible sounds is boundless: some sounds can be fully recognizable, some others will resist any attempt at identification. Sounds can be transformed from recognizable to unrecognizable, and vice versa. Thus, sources or material recognition in computer and electronic music can be often ambiguous, and sometimes impossible. This ambiguity is the fertile ground of computer and electronic music, and what constitutes one of its pivotal attractions. But at what level, then, do we perceive this divide between material and form, between sound events and larger forms?

James Tenney argues that this is a matter of temporal scales of perception and Gestalt. Deeply influenced by phenomenology and Gestalt Theory, Tenney introduces the concept of *Temporal Gestalt units* (TGs), to designate these different time-spans, that is, different temporal perceptual categories, cohesive and clearly separated from each other (Tenney, Polansky, 1980). Tenney observes that "*formal properties at one hierarchical level become the "content" of formal units at the next* higher *level* " (Tenney 2015). He adopts here the Aristotelian view of the dualism matter/form that we mentioned previously: matter is relative to an end and purpose.

Tenney proposes several hierarchically organized TGs:

- At the lowest level, the *Element*: "*a TG which is not temporally divisible, in perception, into smaller TGs* ". An element would be then the equivalent of a sound atom, an indivisible element as defined by early Greek philosophers, such as Leucippus, the founder of atomism, and Democritus and Epicurus, who saw the universe as a discontinuous space comprised of indivisible atoms.
- *Clang*: a cohesive succession of several elements
- *Sequence*: a cohesive succession of several Clangs
- *Segment*: a cohesive succession of several sequences
- *Section*: a cohesive succession of several segments
- And finally, at the highest level, the TG is nothing else than the piece itself, even if Tenney doesn't exclude the possibility of higher level TGs, such as the succession of different pieces during a concert, or on a record.

Furthermore, Tenney introduces the two decisive factors for cohesion and segregation: temporal proximity and similarity, pointing out that "*relative temporal proximity* [and] *relative similarities of TGs at a given hierarchical level will tend to group them, perceptually, into a TG at the next higher level*" (Tenney 1988). These two factors are not only descriptive, but are also operational, both with regard to perception and analysis -how to detect the boundaries between different TGs- and to compositional procedures, for the formation of TGs. He elaborates then a Gestalt-based metric space model, whose fundamental hypothesis is as follows:

> A new TG at the next higher level will be initiated in perception whenever a TG occurs whose disjunction (with respect to the previous TG at the same hierarchical level) is greater than those immediately preceding and following it. (Tenney and Polansky, 1980)

Thus, according to Tenney, the perception of the form, as an assembly or a succession of elements from a lower level, resides essentially in the perception of differences between these elements. Tenney and Polansky propose then a music analysis program, allowing prediction of the boundaries between TGs, and consequently able to partition a composition in its multiple TGs, over several hierarchical levels: clangs, sequences, segments etc. Even if Tenney's model consider only a rather limited set of parameters - time, pitch and intensity- and doesn't consider higher level musical factors such as harmony, musical motives and their relationships, or higher-level psychological factors such as expectation or emotions, it is nonetheless able to successfully segment a piece in several hierarchical time units, as shown by the results of the program on three pieces: Varèse's *Density 21.5*; Webern's Concerto, Op. 24, 2nd movement; and Debussy's *Syrinx*.

In a similar manner, Diana Deutsch (Deutsch 2013) proposes *grouping cues* used by the listener to sort tones or sequences of tones into groupings. Some of these cues are similar to Tenney's cohesion factors, such as pitch proximity – linkage between tones that are close in pitch, segregation between those further apart -; temporal proximity; amplitude and amplitude modulation; timbre similarity – she names it *sound quality* -. Deutsch also discusses higher-level factors such as memory or attention. Stephen McAdams (McAdams 1987) also emphasizes the attention and memory as crucial factors in the perception of musical structures and forms, distinguishing between *episodic musical memory* (identification of multiple episodes, themes or musical phrases that constitute a piece) and *semantic musical memory*, the memory related to a global meaning, that plays a central role in the process of expectation. McAdams stresses, in addition, the importance of phrasing in music, that strengthens structure recognition.

1.1.3. Form and structure: disambiguation

If we want to give more attention to the interrelations between form and material in music, a distinction between the notions of form and structure is pertinent. The difference is not always apparent, and both terms are often being interchanged, or used ambiguously in the music field.

Form in music admits a broad range of non-exclusive definitions (Manoury 2017):

- In a restricted sense, the form can be considered as a standard arrangement of sections, motives, patterns. Such standard forms can be, for instance: scherzo, songs (form ABA, verse/chorus), lied, rondo (form ABACA...), the sonata form etc.
- The form can be based on a composition procedure: for instance, repetitions (canon, fugue), theme, and variations (chaconne, passacaglia).
- Lastly, as stated by Schoenberg, the form is simply the "*disposition of the material for the construction and development of musical ideas*" (Schoenberg 1983). It is the temporal organization of musical events. That is, it is defined by the order of events along the timeline. Tenney's model relies on that definition.

As the first definition is of a limited interest in the context of computer music, we will focus primarily on the two others, that is, we will consider the form both as the organization in time of the sound events and as a result of a procedure of composition.

As a matter of fact, the possibilities offered by computer music techniques have considerably expanded the range of possible forms. In most cases, a new computer music piece will exhibit a new form, its own singular form. This is not without posing problems: the confirmation bias, and the processes of expectation and recognition play a central role in regards to the apprehension of the musical form. If it is easy to recognize an ABA form, or a rondo, it is more delicate to apprehend a radically new form. Busoni, mentor of Varèse, said: "*Is it not singular, to demand of a composer originality in all things, and to forbid it as regards form? No wonder that, once he becomes original, he is accused of "formlessness.*" (Busoni 1911).

Nevertheless, the main formal principles will be, in most cases, identical to those in use in traditional music (Manoury 2017). That is:

- Tension/resolution
- Repetition and reprise
- Variations and modulations
- Introduction/transition/conclusion
- Proportions and symmetry

The notion of structure is more ambiguous. As mentioned previously, the term *structure* is often used instead of *form* to designate the arrangement of sections and patterns of a piece. We would like, however, to differentiate form and structure in our work and to do so, to give structure a more precise definition. This distinction will later give us the conceptual apparatus to approach compositional strategies that bridge matter and form.

Tenney, for instance, considers the *structure* as one of the two essential components of the musical form, along with the *shape*:

> FORM. In the most general sense: *shape* (contour, the variation of some attribute of a thing in space or time), and *structure* (the disposition of parts, relations of part to part, and of part to whole). (Tenney 2015)

To go deeper into that question, it may be useful to step outside the strict framework of music, and to consider the structure as defined by the linguists Ferdinand de Saussure (Saussure 2016) and Louis Hjelmslev, and of course by the structuralists, Lévi-Strauss in particular: a formal ensemble of relations of opposition or equivalences between elements. Hjelmslev gives a somewhat more concise definition: "*an autonomous entity of internal dependencies*". (Hjelmslev 1970, my translation).

In regard to music, we consider the structure from a poietic point of view, as the set of relations between elements that allow the emergence of forms. Thus, on an *esthesic* level, that is from the point of view of the "receiver" (by referring again to the tripartition of Molino and Nattiez), the structure is, contrary to the form, not directly perceived. Its outcomes, however, such as the phenomenon of expectation, or the formal coherence, are. Possible compositional strategies of sound organization could be to consider "*operational structures*", as defined by Piaget (Piaget 2007), that is, to consider that what matters first are not the elements or the form, taken as separate concepts, but the relations between those, and the associated compositional processes. Chowning, for instance, declares about his piece *Stria* (1977): "[...] *there were rules for determining the details of the structure, from the microsound level up to the level of a phrase*" (Interview with Chowning, in Roads 1985). According to the aforementioned structuralist definition of structure, *Stria* is the product of a rigorous structuralist approach to composition (a thorough analysis of *Stria* is given in section 1.3.4). Likewise, regarding Tenney's model, these ensembles of relations between elements at a lower level determine the emergence of the form at the next higher level (figure 1.1).

Lévi-Strauss states that "*The content draws its reality from its structure and what we call form is the structural disposition of local structures*." (Lévi-Strauss 1997). The structure is what actualizes matter as form.

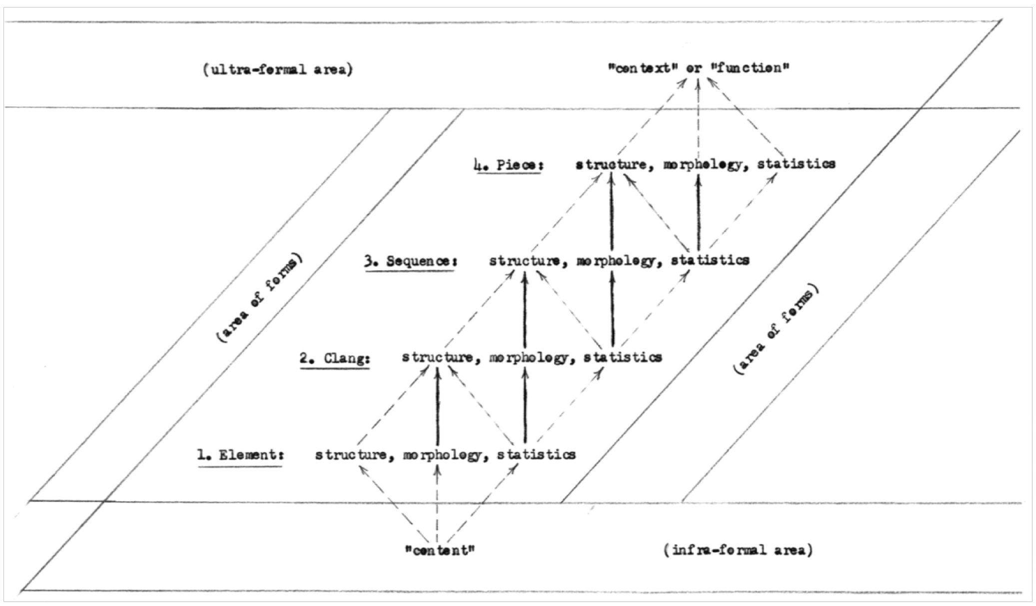

Figure 1.1 - Schematic diagram of relations between the three aspects of form at four hierarchical levels (Tenney 2015)

1.2. Empiricism, experiments, and formalism(s)

> Form is the result of a process. Each of my works discovers its own form. (Varèse, quoted in Knyt 2017).

1.2.1. Signs vs. concepts

Now that we have specified the natures of form, structure, and matter, we can address the question of the compositional strategies to organize the sound material in musical form.

Another dualistic paradigm becomes apparent when considering compositional aesthetics: whether the composer favors an empirical approach, based on the intrinsic qualities of the sound material, or adopts a purely rational and conceptual stance, focusing above all on the musical architecture and on the rules to determine it. Following the Western's thinking inclination for dialectics, these two general tendencies are often articulated in the form of variations around a binary opposition. For instance, Roads summarizes this dualism as the opposition *intuitionism vs. formalism* (Roads 2001). Di Scipio proposes a similar kind of opposition: *materism vs. formalism* (Di Scipio 1994a), and Leigh Landy, the opposition *spectralist vs. formalist*. According to Landy, this is, in fact, an opposition between two prevalent methods of composition: *bottom-up* for the spectralists, consisting first in gathering the sound material, and then organizing it, in a later phase; *top-down* for the formalists, consisting first in planning a form and then subordinating the sound material to it (Landy 2007).

Okkels and Conrad suggest to employ the opposition introduced by Lévi-Strauss in *La Pensée Sauvage*, that of the *bricoleur vs. engineer* (Okkels and Conrad 2000): the bricoleur is the wild, working with "*whatever is at hand*" (Lévi-Strauss 1966), the engineer the scientist, working with his mind to create new tools. "*The engineer works by means of concepts*" says Lévi-Strauss, "*the bricoleur by means of signs.*" To a certain extent, this echoes the provocative statement of Schoenberg at the Breslau conference in 1928: "*One makes music with concepts*" (Schoenberg 1984, my translation). Xenakis, as well, stressed the need for a "*new sort of musician*", at the crossroads between the arts and sciences, and proposed the term "*artist-conceptor*" (Xenakis 1985).

A concrete example of this opposition manifested, both on an aesthetic and technological level, during the 50's and 60's in France in the form of tensions and rivalries between, on the one side, the pioneers of Musique Concrète, Schaeffer and GRM (Groupe de Recherches Musicales), and on the other side, Boulez and IRCAM (Institut de Recherche et Coordination Acoustique/Musique). An antagonism that the anthropologist Georgina Born defines in her ethnological study of IRCAM as *experimental empiricism vs. post-serialist determinism* (Born 1995). Born opposes the predetermined, abstract, and highly scientific methods carried out at IRCAM to the experimental and empirical approaches of the Musique Concrète pioneers - Boulez said that Musique Concrète amounted to "bricolage", leading back to the opposition as formulated by Lévi-Strauss-, approaches free from any symbolic representation and formalism. Indeed, a music based on concrete sounds, that is, on sounds that cannot easily be represented symbolically, does not lend itself to abstraction, to parametric, quantitative thinking, or combinatorial processing, and consequently, resists any attempt at the formalization of structuring procedures.

It would, however, be inaccurate to think that Musique Concrète and acousmatic composers -we consider here mostly those from the British school of acousmatic music, as well as those from France, Canada, and Belgium- do not attach importance to the organization of the sound material and the notion of form. Indeed, Schaeffer, strongly influenced by Merleau-Ponty and Husserl, questions already in 1948-1949 the distinction between matter and form, a distinction intrinsically related, according to him, to temporal scales:

> Matter and form are made of the same elements […] but these elements have the contradictory qualities of being permanent and of varying. Insofar as they are permanent, in a short space of time they constitute a matter: insofar as they evolve, in a space of time only ten times longer they give rise to forms. (Schaeffer 2012).

In his paper *Spectro-morphology and Structuring Processes*, Smalley shows several structural functions, that can be applied at every hierarchical levels, from the morphological design of the sound object to the higher-level structures (figure 1.2, Smalley 2003), and that are very reminiscent of the fundamental formal processes of Wallace Berry (Berry 1986): introduction, expository process, transition, developmental process and resolution.

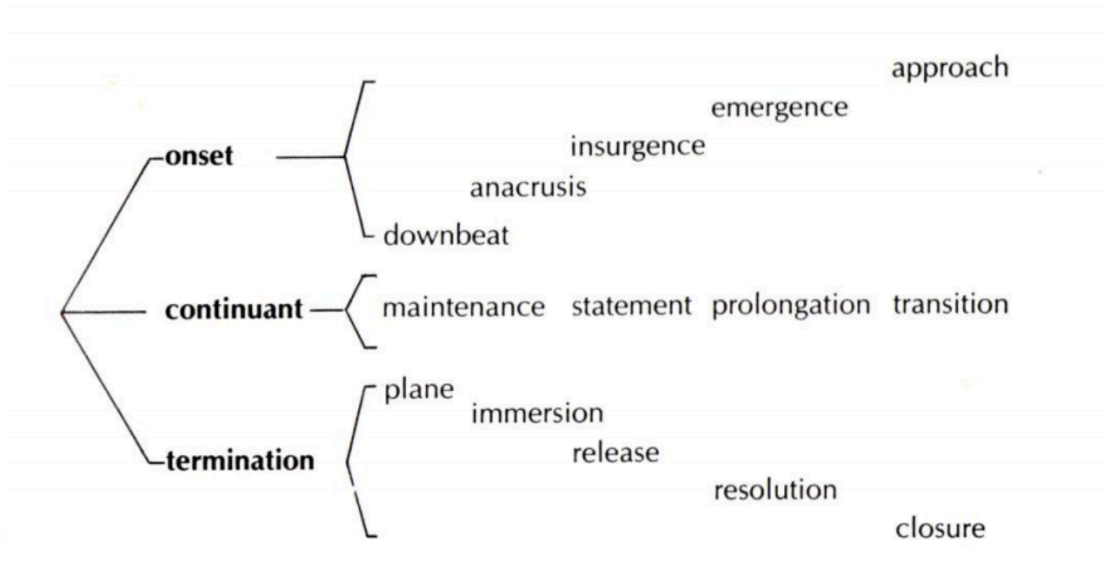

Figure 1.2 - Structural Functions (Smalley 1986)

That being said, Schaeffer considers the sound object and its manipulations at the lower hierarchical levels primarily, but barely address -at least in his writings- the question of larger forms, at higher hierarchical levels. The same applies to Denis Smalley, whose spectromorphology is mostly concerned with the intrinsic characteristics of sound events and with their morphological changes, and accords only a relatively limited place to the higher forms as such, the macro-levels of the musical work. Moreover, in the pair matter/form in Schaeffer, the form corresponds to the *shape* as defined by Tenney: the variation in time of one or several attributes of the sound object. To add to the confusion, to designate the form as we previously defined, Schaeffer and Smalley prefer to use the term *structure*.

To summarize, in a deliberate simplification, for Schaeffer and Smalley, the preliminary step consists in determining and gathering the sound material. Only after, in a later phase, structuring procedures are undertaken. For the formalists, such as Boulez, the production of the sound material is subordinated to its structural organization (Decroupet 2003).

While it is pertinent to highlight the prevalence of these conceptual pairs, sign/concept, intuition/formalism, bottom-up/top-down, the reality, beyond rivalries and postures, is more nuanced. It would be wrong to establish a clear-cut boundary between the intuitive or empirical methods and the formal structuring procedures. A distinction must be drawn between the formal theories, writings and essays, and the actual compositional strategies of the composer, "in practice". Derrida objects to Lévi-Strauss: "*the engineer is a myth*", in other words, an ideal of absolute truth, an illusion, produced by the bricoleur himself. He further adds: "*the engineer and the scientist are also species of bricoleurs*"(Derrida 1978). Within the conflict between formalism and empiricism, between the bricoleur and the engineer, there is a continuous spectrum of possible approaches and methods, with different shades of formalism, experimentations, or empiricism.

Boulez observes, about *Répons*: "*As a matter of fact, the composer establishes some plans, then he addresses the material, and all his work supposes a series of back and forth*"[1] (Boulez, Lyotard 1986, my translation). Xenakis, who used rules, for instance stochastic, to generate material, would afterward make intuitive choices and direct manipulations to organize it according to his taste (Solomos, Soulez, Vaggione 2003). He admits, for instance, having made intuitive

[1] Quote translated from French: "En fait, le compositeur établit des plans puis il aborde le matériau, et tout son travail suppose une série d'allers et retours." (Boulez, Lyotard 1986)

adjustments on the algorithmic results on *Nomos Alpha* (1965), maybe his most formalized work, each time he considered those not sufficiently interesting (Vriend 1981). The same applies for *Atrees* (1962), "*the piece most freely adapted by the composer from the original data,* [which] *challenges most dramatically the need to respect the output of the program*" (Harley 2004).

Roads questions the notion of the purity of an absolute formalism: an algorithm that generates an entire composition is the product of the decisions, preferences, and aesthetic choices of the composer. If she is not satisfied with the output of the algorithm, she will often proceed to adjustments, aesthetically motivated, and will then ask the algorithm to generate a new score. The fact that these decisions can be expressed in the form of a coded algorithm does not make them more valid than if they were expressed in the form of intuitive, direct, manipulations (the "bricolage"): they are human decisions in both cases (Roads 2015). Thus, a purely formal approach could be considered as a composition method relying on automated (coded) procedures, with discretized and offline possibilities of interventions and adjustments (what Roads calls a "*batch mode of composition*"). In other words, the degree of formalism is a matter of constraints - that is, determining an ensemble of rules to generate a score-. Moreover, according to Di Scipio, the level of formalism in computer music is related to the level, both in terms of planning and in terms of interactions/modifications, at which algorithms and computational procedures are primarily employed: for instance, for bottom-up compositions, computation, and processing happen primarily at the level of timbre-composition, at the lower time scales (audio and control rate); for purely top-down compositions, computation happens primarily at higher levels (at "*note time* and *event-time level"*) (Di Scipio 1994a). Thus, in the extreme case of a purely formal work, computation happens at a high level, and modifications are possible only offline in a sequential manner.

To a certain extent, formalism shares similarities with sonification. This is particularly clear in Xenakis's works, for instance in *Mycenae-Alpha* (1978), or in his works influenced by physics and natural sciences, such as in *Pithoprakta* based on the mechanics of gases. While formalism aims to be perceived as formalism (that is: can we hear it, the formalism? Can we assume, just from listening, an underlying deeper, formal structure?), and sonification aims to reveal a process sonically (a natural phenomenon, or a data set for instance), to show a hidden beauty, pattern, or strangeness that only sound can uncover, both are facing the same fundamental issue of the link (or possibly absence thereof) between the conceptual and the sensible: how does it translate sonically? Is it meaningful?

At the other end of the spectrum, Michel Chion, a disciple of Pierre Schaeffer, is a composer who attached particular importance to the form and to its articulation, both in his writings and in his compositions. While he is arguing against the idea of an absence of divide between material and organization -as proclaimed by some formalists-, and clearly rejects its two immediate corollaries, the material determining the form -an option he calls "*naturalist*" -, and the form submitting the material unconditionally, he nonetheless considers that material and organization have a moving common boundary and that the material can, and must, be remodeled during the process of composition (Chion 2017).

Moreover, he also challenges the traditional status of the sound material as commonly apprehended by the Musique Concrete composers: for Chion, the material is not a starting point, but a point of arrival (Chion 2002), in that the sound material, always malleable, is the culmination of the composition process. Furthermore, Chion wants the form of his works to be clear and legible, by using what he calls "*form markers*" (Chion 2018), and by explicitly adopting formal principles such as repetition, in *L'Isle sonante* (1998) or in his *Requiem* (1978) for instance, wait and expectation (*Troisième symphonie, l'audio-divisuelle* 2016), symmetry (in *Requiem*, or in *La Messe de Terre*, 2014, figure 1.3), and by using forms drawn from the classical repertoire, such as the rondo, in *La Tentation de Saint Antoine* and in the *Gloria* of *La Messe de Terre*. Chion's approach is thus a constant back and forth between a bottom-up strategy and a top-down strategy, due to the fact that Chion often determines a form to "*assert the work as a global project*" (Chion 2019, my translation).

FIGURE 1 Forme de *La messe de terre* (1996) de Michel Chion, d'après le tableau manuscrit de l'auteur figurant dans le documentaire *La messe de terre illustrée* de Jérôme Bloch.

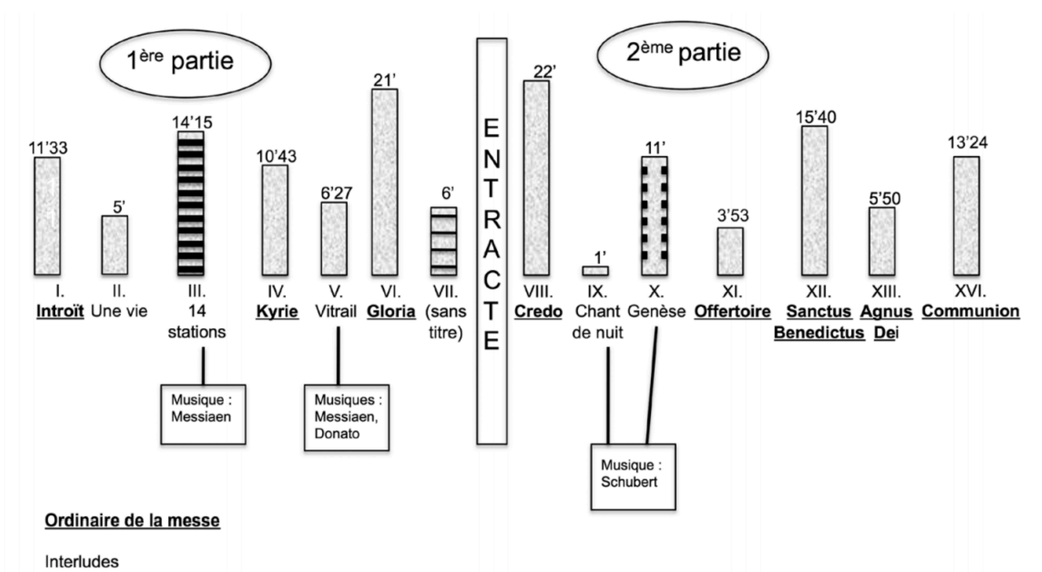

Figure 1.3 - Form of the Messe de terre *from Michel Chion*

1.2.2. Approaches, methods, strategies

> Musical form, considered as the result of a process, suggests an analogy with the phenomenon of crystallization [...] The internal structure is based on a crystal unit, the smallest grouping of the atoms having the order and composition of the substance. The extension of the unit into space, forms the whole crystal. In spite of the relatively limited variety of the internal structures, the external forms of crystals are almost limitless. (Varèse, quoted in Mellers 2010)

It would be an endless task to review all the possible compositional strategies to organize the sound material in a musical form. After all, the proliferation of forms in the field of computer and electronic music is the direct result of the proliferation of materials, and methods, techniques, and processes to organize it. We will focus on the compositional approaches that relate more closely to our own strategies. These are therefore subjective choices, and by no means an exhaustive list.

Chance, stochastic processes and fractals - The form as a result of a process

We introduce in this section a few methods and examples of the uses of chance, indeterminacy, stochastic processes and fractal algorithms for structuring procedures or for controlling some aspects of the overall form of the composition.

Chance and Indeterminacy

Stockhausen's *Klavierstück XI*, the graphic scores of Morton Feldman, such as *Intersections*, *Projections*, John Cage's *Music of Changes* for piano and *Imaginary Landscape No. 4* for 12 radio receivers: all these works involve the chance factor as a central element, either at a performative level or at a compositional level.

In the case of *Music of Changes* and *Imaginary Landscape No. 4*, the use of random or chance processes happens during the course of the composition: both works effectively involve elements of chance by using the *I Ching*, the ancient Chinese book of divination, to define for instance tempi, durations, sounds. The score itself is fully determinate, only the process of composition involves indeterminate elements. Moreover, as pointed out by Alvin Lucier and to go back to what we previously said in the section (1.2.1) about choice and direct manipulation, chance procedures as used by Cage don't necessarily imply the absence of intuitive and personal adjustments:

> It really isn't random at all in a certain sense. So much is chosen and controlled by the composer. So much is personal. No other music sounds like this; it sounds like Cage. (Lucier 2012).

In the case of Stockhausen's *Klavierstück XI*, chance is involved during the performance of the piece. In *Klavierstück XI*, the characteristics of the material and the way the piece is divided into segments are determinate. However, the sequence of these segments is indeterminate: their arrangement is determined spontaneously by the performer during the actual performance. Thus, a new form emerges at each performance (Cage 1961). Similar approaches are found in Earle Brown's "open form" works (*Twenty-Five Pages*, which may be performed in any order), or in Feldman's graphic scores, such *as Intermission 6* (figure 1.4), for one or two pianos, where "*the composition begins with any sound and proceeds to any other*" (Feldman 1953).

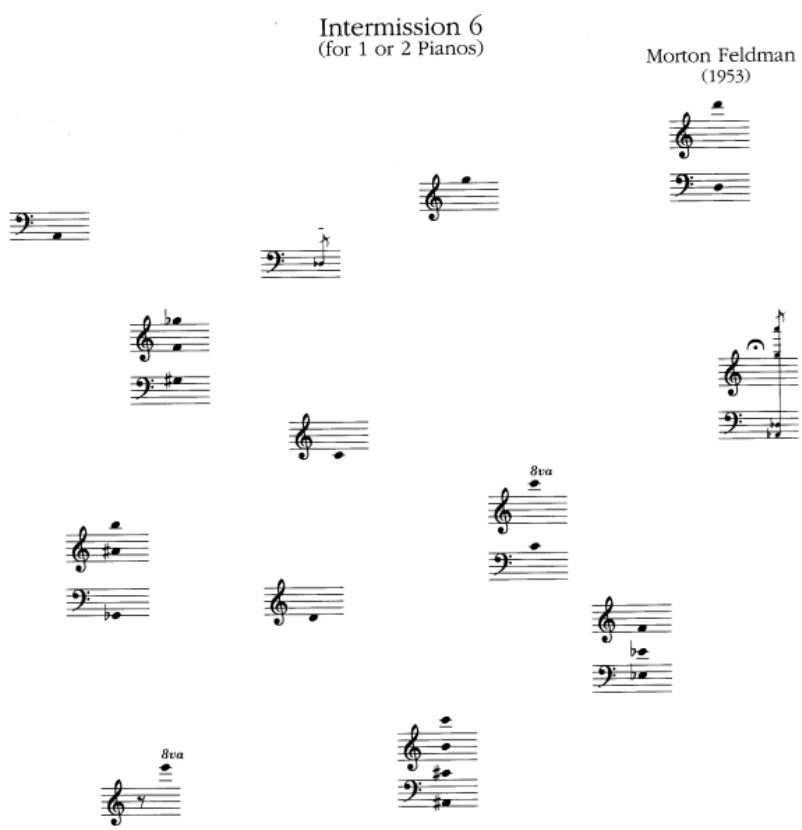

Figure 1.4 - Intermission 6 *(Feldman 1953)*

Stochastic processes

The term *stochastic* was first introduced in music by Iannis Xenakis in the first edition of *Musiques formelles* (Xenakis 1963). Preferred to its more common and less scientific synonym *random*, stochastic simply refers to the use of probability distributions, not only for sound synthesis, but also in the structuring procedures of the piece. Compared to the former examples, which are not based on precise mathematical principles, stochastic compositions make systematic use of algorithms as structuring techniques for musical processes and/or for the overall form of a composition.

Xenakis proposes in “New Proposals in Microsound Structure” (Xenakis 1992) 8 methods based on stochastic variations:

- Method 1: the stochastic variation is any probability function, such as Poisson, exponential, normal, uniform, Cauchy distribution.
- Method 2: combinations of a random variable X with itself, by means of a n-fold convolution of a probability function with itself, or any other linear, polynomial function of the variable X.
- Method 3: the random variable of pressure (amplitude) or time are function of other variables, or even of random variables.
- Method 4: the random variable moves between two reflecting (elastic) barriers.

- Method 5: the parameters of a probability function can be considered as variables of other probability functions (randomization, mixtures)
- Method 6: linear or polynomial combinations of probability functions or composite functions
- Method 7: the probability functions are filed into classes. These classes are then considered as elements of higher order sets.
- Method 8: classes of distributions envisaged in method 7 are applied to the level of macrocomposition

Xenakis raises the question: "*What is the minimum of logical constraints necessary for the construction of a musical process*?" (Xenakis 1992). Indeed, stochastic processes may be seen as an efficient way to reduce the amount of data required for the creation of a score (Jones 1981). Large collections of values can be generated and shaped stochastically within ranges defined by the composer, for instance to control the behaviors or transformations of a large set of sounds. Moreover, as proposed in Xenakis' Method 8, the overall form of a piece may be determined by such stochastic processes.

Usual stochastic algorithms for compositional applications include the use of probability distributions (as in Xenakis's *Pithoprakta*, based on Maxwell-Boltzmann distribution), set theory (Chrissochoidis, Houliaras, Mitsakis 2005), Markov processes, and, even if these can be fully deterministic, grammar based approaches (Jones 1981).

A more thorough analysis of compositional applications of stochastic processes of the program GENDY is given in section (1.3.1).

Fractals and self-similarity

Noises, fractals, self-similarity or chaos generators, find use not only in digital sound synthesis, to drive parameters of a sound synthesis method, for instance of granular synthesis (Truax 1988; Di Scipio 1990), or FM synthesis (Truax 1982), but also as ways to structure the piece at the macro-level. For instance, Yadegari proposes a "*system* [that] *uses hierarchy and recursion principles* " to generate self-similar structures, from the sound synthesis level to the macro-level of the composition (Yadegari 1991).

Dodge, in his piece *Profile* (1984), used a 1/f noise algorithm to generate the pitches, timings, and amplitudes of three self-similar musical lines of increasingly smaller time scale (Dodge 1988). According to Dodge, the final form of the piece is analogous to the Koch snowflake (figure 1.5). McNabb is another composer who made use of fractals and self-similarity in his compositions, for instance to generate melodies in *The far and brilliant Night* (1992) and in one movement of his ballet *Invisible Cities* (1985), using the Weierstrass-Mandelbrot function (McNabb 2003).

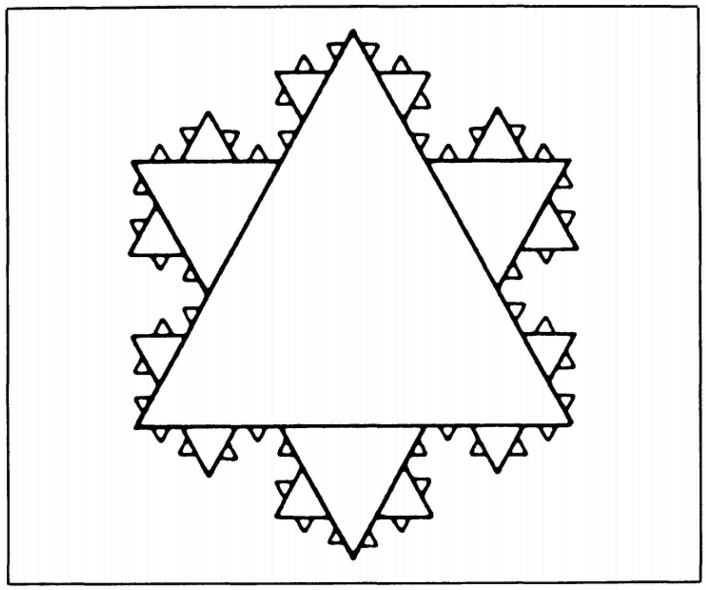

Figure 1.5 - Koch snowflake to four levels (Dodge 1988)

Form-bearing material

Composing means: building an instrument. (Lachenmann 2004)

On a lower level, the material can be considered as a space of potentialities, containing its own possibilities of structuration. As Lachenmann pointed out:

> Composition is by no means a "putting together", but rather a "taking apart" and more: a confrontation with the interconnections and necessities of the musical substance. (Lachenmann, quoted in Assis, 2011)

In that regard, and following the parallels established by Paulo de Assis between Lachenmann's concepts of musical material and structure and Deleuzian philosophy, structures are "*reterritorialization of forces and energy*", that is, re-structuring potentials, and "*building an instrument*", as argued by Lachenmann, is to establish such structures. This is reminiscent of our initial postulate, derived from Aristotle's concepts of potentiality and actuality: matter is being given a potential, and, through actualization, becomes form. During the conference on musical time in 1978 at IRCAM, Deleuze, sitting next to Boulez, Risset, Berio et Foucault, states:

> What we are witnessing [..] in contemporary music is the birth of a sound material that is no more a simple or undifferentiated matter, but a very elaborated, very complex material; and this material will not be subordinated to a sonic form, as it will not need it: it will itself be asked to render audible forces that, by themselves, are not, and the differences between these forces. The pair *raw material-form* is replaced by a new pairing *elaborated sound material-imperceptible forces*, that the material will make audible and perceptible.
>
> (Deleuze 1978, my translation)[2]

More concretely, as mentioned in section (2.1), morphological changes of the material can be considered as form-bearing. A timbre, for example, can develop

[2] Quote translated from French: "Ce à quoi l'on assiste [...] dans la musique actuelle, c'est à la naissance d'un matériau sonore qui n'est plus du tout une matière simple ou indifférenciée, mais un matériau très élaboré, très complexe; et ce matériau ne sera plus subordonné à une forme sonore, puisqu'il n'en aura pas besoin: il sera chargé, pour son compte, de rendre sonores ou audibles des forces qui, par elles-mêmes, ne le sont pas, et les différences entre ces forces. Au couple matériel brut-formes sonores, se substitue un tout autre couplage matériau sonore élaboré-forces imperceptibles que le matériau va rendre audibles, perceptibles." (Deleuze 1978)

a sense of direction, suggest a movement, and therefore create expectation: it is form-bearing (McAdams and Saariaho 1985). Thus, sound transformations and morphological variations become structuring processes, and form can be experienced through the exploration of a multi-dimensional timbral space.

Wishart has, for instance, elaborated a theory of structuring based on continuous sound transformations (Wishart 1994). He proposes not to do any separation between structure and expression, "*an arbitrary divide created by the limitation of notation*", thus emphasizing that the form emerges from the morphological manipulations of the material.

Similarly, Di Scipio considers that the possibilities of computer music challenge the dualism formalism vs. materism. He proposes to blur the divide between models of synthesis and models of form design, and therefore, to make the form emerge through a "*process of timbre formation*" (Di Scipio 1994b). According to Roads, granular synthesis is an ideal link between microstructure and macrostructure: granular models of sound "*can lead to higher-level musical structures*" (Roads, in Solomos 2012). As emphasized by Vaggione, these granular models are rich in musical applications, as one is able to pass from the signal level -the sound synthesis level- to the symbolic/operative level (Vaggione 2010).

Indeed, the more abstract methods of sound synthesis[3] (granular synthesis in the case of Roads and Di Scipio, or FM synthesis in Chowning, as exemplified

[3] We refer here to the taxonomy of digital synthesis techniques from Julius O. Smith (Smith 1991). According to Smith, sound synthesis methods can be divided into four categories: processed recording, spectral model, physical model, and abstract

in his piece *Stria* for instance), lend themselves to such compositional approaches (Meneghini 2003), that is, compositional approaches that can operate at several hierarchical levels, from low-level sound synthesis parameters to piece organization. In those cases, the sound synthesis operates both as means to generate sound material and for structuring.

Space as a structuring element

> If, having fixed the original form in our mind's eye, we ask ourselves how that form comes alive and fills with life, we discover a new dynamic and vital category, a new property of the universe: reverberation (retentir). (Minkowski 1994).

Space, and its associated methods of composition are intrinsic elements of computer and electronic music and can be considered as an essential structuring element of a piece. Sound spatialization facilitates segregation between sounds and perception of sound relationships. Moreover, spatial movements, interrelations between sounds and space and between sounds themselves, and perception of proximity or distance play an essential role in establishing formal coherence and hierarchical relations, in clarifying the sense and direction of sounds, and thus, in

---

algorithm. A sound synthesis method may belong to several of these four categories simultaneously. Abstract methods use mathematical expressions to create sounds that have no connection to a physical or natural phenomena.

the phenomenon of expectation, and in the emergence of a narrative, all these being crucial factors for the apprehension of musical structures.

Several composers proposed spatial composition and listening strategies, such as Wishart, with the concept of *Landscape* (Wishart 1996), Smalley with the concept of *Space-form*, "*an approach to musical form, and its analysis, which privileges space as the primary articulator*" (Smalley 2007) and, of course, Natasha Barrett, (Barrett 2002), to whom space in a central element of her compositions, as exemplified by her piece *The Utility of Space* (2000), an "*exploration of spatial musical structure*" realized in ambisonics. In the field of popular electronic music, Alessandro Cortini deploys long reverberations, merging with, and extending the evolving sound morphologies and textures of his Buchla synthesizer, as a means to maintain coherence and create anticipation, for instance in *Gloria* (2013) or *Scappa* (2015).

Boulez's *Répons* (1981-1984) is an emblematic example of the compositional use of space, and that on two levels. First, through a unique spatial disposition of the musicians in the auditorium: a chamber ensemble of 24 musicians is sitting at the center, surrounded by the audience, itself surrounded by six soloists and six speakers. Second, by means of a wide variety of spatial manipulations applied to the musical events: rotations through a set of speakers, panning back and forth between speakers, sound events randomly assigned to speakers, simulation of distance (by adjusting the dry/wet ratio and settings of the reverberation and early reflections), infinite reverberation etc.: a real showcase of what IRCAM technologies in the 80's (namely, the 4X computer from Di Giugno) made possible. As pointed out in the *Répons* technical manual: "*Out of the ten sections with electronics in* Répons*, nine use spatialization as a way of moving a sound source in the performance space*" (Gerzo). By means of this spatial disposition of the instruments and of the spatialization, Boulez establishes a dialog between the electronics and the instruments, while maintaining a formal coherence.

Figure 1.6 - Répons - *Reed Family Concert - Steven Schick, conductor. Mandeville Auditorium, UC San Diego, 2017. (Photo: Tina Tallon)*

1.3. Case Studies

1.3.1. Stochastic processes in Xenakis's *GENDY3*

GENDY3 (1991) by Xenakis is a work entirely made using the program GENDY, which we detail below. The entire composition is conceived by means of stochastic variations, from the synthesis method to the macrolevel of the composition, that is the form of the piece itself.

<u>GENDY</u>

GENDY (GENeration DYnamic) is a program written in 1991 by Xenakis with the assistance of Marie-Hélène Serra, and implementing an extended version of his dynamic stochastic synthesis technique (Xenakis 1977): a polygonal waveform is made up of a succession of linear segments. The first breakpoint of a waveform n+1 (one period later) is equal to the last breakpoint of the waveform n, which ensures continuity.

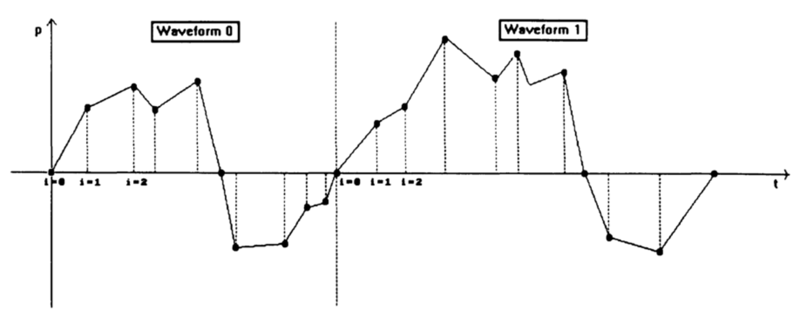

Figure 1.7 - Two successive polygonized waveforms with ten segments (Serra 1993)

The duration of the waveform (i.e. its period) is the sum of all the segment durations. The coordinates (x=amplitude, y=time) of each breakpoint of waveform n+1 are calculated by stochastic variations of the breakpoint of the same rank of waveform n:

$$x_{i,n+1} = x_{i,n} + fx(z)$$

$$y_{i,n+1} = y_{i,n} + fy(z)$$

where i is the rank of the breakpoint, n the waveform number and fx and fy the stochastic functions applied on the random number z. The pair of values (x,y) of each breakpoint is constrained within specific ranges using *mirrors* that reflect the input value if it exceeds the specified range (figure 1.8).

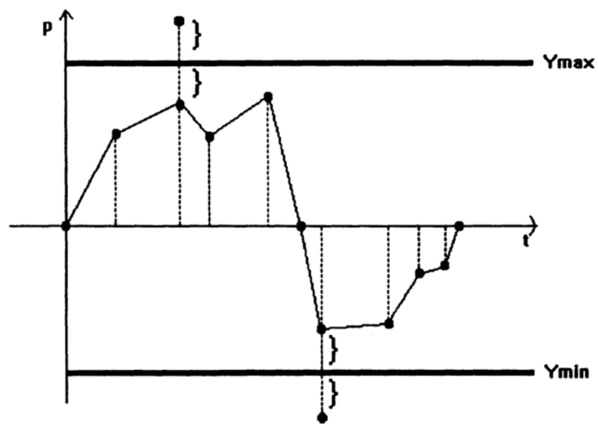

Figure 1.8 - Amplitude barriers (Serra 1993)

Examples of stochastic functions fx and fy used in GENDY are uniform, Cauchy and exponential distributions. The input parameters of the synthesis method are the number of segments in the waveform, the stochastic distributions fx and fy and the mirror boundaries.

Structuring

The structure of *GENDY3* consists of a succession of eleven sections, each section being defined by: a number of voices, the arrangement of these voices, and the allocation of synthesis parameters to each voice (Serra 1993). The entire piece can be represented as a matrix (voices, time fields) (Di Scipio 1998), where each time field is defined by two parameters: its duration and its status, active (sounding) or passive (silent).

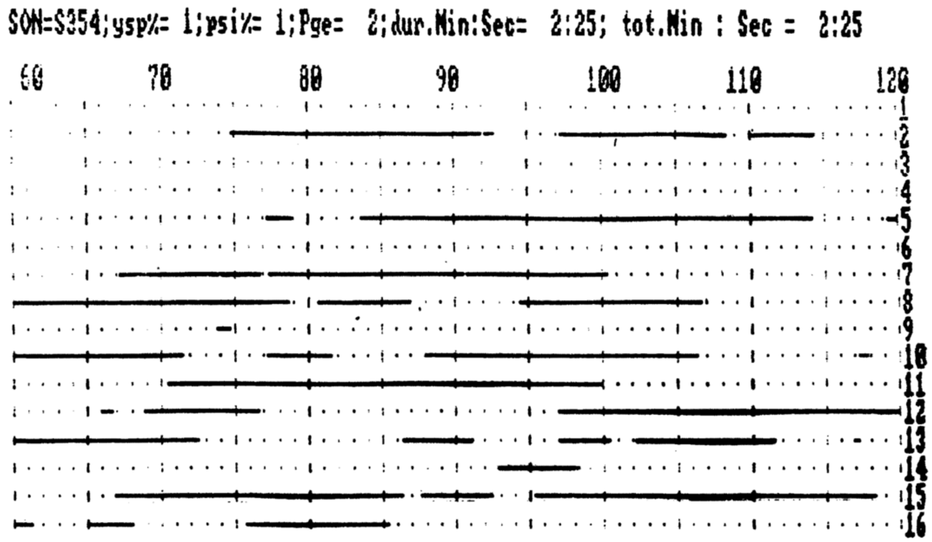

Figure 1.9 - First two minutes of the first section of GENDY3. 16 voices. Time in seconds (Serra 1993)

Status decision

The active/passive decision is made according to a random Bernoulli trial, which has only two outcomes, success or failure (that is, a software generated "flipping a coin" procedure). In GENDY, if we consider p the probability of success, and z a random number of the interval [0,1] with uniform distribution, the outcome is “success” if $z \leq p$. In that case, the time field is active. Otherwise, it stays silent. The parameter p is determined for each voice in each section.

<u>Determination of durations</u>

The duration of each time field is calculated according to the exponential law:

$$d = \left(-\frac{1}{D}\right) \log\left(1 - z\right)$$

where D is the mean duration and z a random number of the interval [0,1] with uniform distribution.

Thus, the work is composed according to stochastic laws, and generated entirely from the same program, GENDY, from the microlevel of sound generation, to the macrolevel of the architecture of the piece, the human compositional intervention (besides of course programing GENDY!) consisting in defining the number of voices in each section, the allocation of synthesis parameters to each voice of the section, and the choice of input parameters (Serra 1993).

1.3.2 Chance and indeterminacy in Robin Rimbaud's radio pieces

The British electronic music composer and artist Robin Rimbaud, who used to work under the name *Scanner*, is probably best known for his works featuring found sounds such as intercepted mobile phone and radio communications using a radio scanner, mostly composed and performed during the nineties. If these pieces are at the confluence of many music genres, electronica/IDM and ambient above all, but also techno, industrial music, or even John Oswald's *Plunderphonics*, Rimbaud himself cites John Cage and David Tudor as key influences, due to the use of chance and indeterminate composition techniques in his own works (Rimbaud, personal communication, November 2017). However, even if Rimbaud effectively uses chance and indeterminacy techniques at a compositional or performative level, there are significant differences with, for example, Cage's notions of indeterminacy (Carter 2014).

The sound material in *Scanner* (1992) and *Scanner 2* (1993), the early works of Rimbaud, relies for the most part on found sounds, in the sense that they are "*intercepted cellular phone conversations of unsuspecting talkers* [..]*, edited into minimalist musical settings as if they were instruments*" (Rimbaud, interview by Jose Miguel G. Cortes 2001). Similarly, Rimbaud's performances during the nineties, mostly improvised, consist in live scanning and real time processing of radio and telephone communications. In that regard, each of these performances is unique, and at least partly indeterminate, due to the random sound elements introduced by the radio scanner. It seems however that the intrinsic characteristics of the radio communication sounds (noises and buzzes), and the narrative emerging from the intercepted bits of conversations are the dominant traits in Rimbaud's works aesthetics, more so than the notion of indeterminacy.

In *Surface Noise* (1998), Rimbaud superimposes a transparent score of *London Bridge is Falling Down* ("My Fair Lady") over a London map, each note suggesting a geographical location at which Rimbaud would record urban environmental sounds and make pictures. Even if Rimbaud defines this approach as "*Cagean*" (Rimbaud 2001), or if Carter considers it maybe "“*akin to Cage's use of chance operations*" (Carter 2014), it seems to us that no actual notions of chance and indeterminacy are really at play in that specific work: the process of composition consists in relying on a determinate score (the *London Bridge is Falling Down* melody) to determine locations at which to collect sound material.

Rimbaud returned to the concepts of indeterminacy and randomness in his recent works with the modular synthesizer, relying on chance, random voltages and improvisation (Rimbaud, personal communication, November 2017). In that regard, this can be considered as similar to Subotnick's method on *Silver Apples of the Moon*, described in section (1.3.3).

However, chance and random techniques in Rimbaud's works don't seem to play a central role in his compositional aesthetics and are not inspired by any formalism: the adoption of such procedures is here motivated by more pragmatic considerations. The use of a radio scanner, the *Surface Noise* composition process and the use of random voltages in his modular synthesizer-based works are primarily methods to gather raw sound material, which will be subsequently processed and ordered.

Rimbaud adopts a bottom-up composition process based on found sounds, creating soundscapes and playing explicitly with the phenomenon of sound-source recognition, symbols and emergent narrative. In our opinion, more than following in the footsteps of Cage or Tudor, Rimbaud follows closely the tradition of acousmatic composers such as Luc Ferrari.

1.3.3. Morphological changes and voltage control: control tracks and ghost scores in Morton Subotnick's works

The American composer Morton Subotnick is best known through his works involving the use of electronics, and in particular of the voltage-controlled Buchla synthesizer. His works demonstrate a unique use of electronic tools, relying on a set of expressive and intuitive interaction techniques. The *ghost scores* of Subotnick are often considered the culmination of these techniques, allowing real-time performance of electronic music with live instruments (Whipple 1983).

Two aspects are intimately tied in Subotnick's body of work: gestures ("*I thought of everything as gestures*", (Subotnick 2010) and sculpting of sound morphologies, or in other words, considering electronic music as sound sculpture ("*I always thought of my work with electronic sounds and tape recorders as* “sculpting*” with sound in time and space*" (Subotnick 1976)). Subotnick was primarily interested in translating physical gestures into musical gestures, and through his collaboration with Don Buchla in the early sixties, played a key role in the genesis of the first Buchla synthesizer, the Buchla 100 Series voltage-controlled synthesizer (Bernstein 2008): his ambition was indeed to design an expressive and *gestural* electronic instrument allowing real-time sculpting of sounds.

In *Silver Apples of the Moon* (1967), one of his early electronic works, Subotnick relies on random processes, creating random loops with the Buchla sequencer and random voltage sources, manually perfecting them, recording several takes on tape, and eventually keeping only what he wanted (Gluck 2012).

Subsequent works such as *Touch* (1969), *Sidewinder* (1971) or *Until Spring* (1975) innovate with the introduction of "control" tracks, allowing greater accuracy, therefore more expressivity, and offering the possibility to modify or rearrange the composition. In those pieces, Subotnick would record on a tape a sine wave controlled for instance by his voice using an envelope follower, or by his finger pressure on the Buchla touch-plates (Gluck 2013). The recorded control tracks would then be patched to the Buchla synthesizer modules (envelope followers, for audio signal to control signal conversion, voltage controlled amplifiers, voltage controlled oscillators, ring modulators), to control pitches, timbres, position of sounds in space, duration etc.

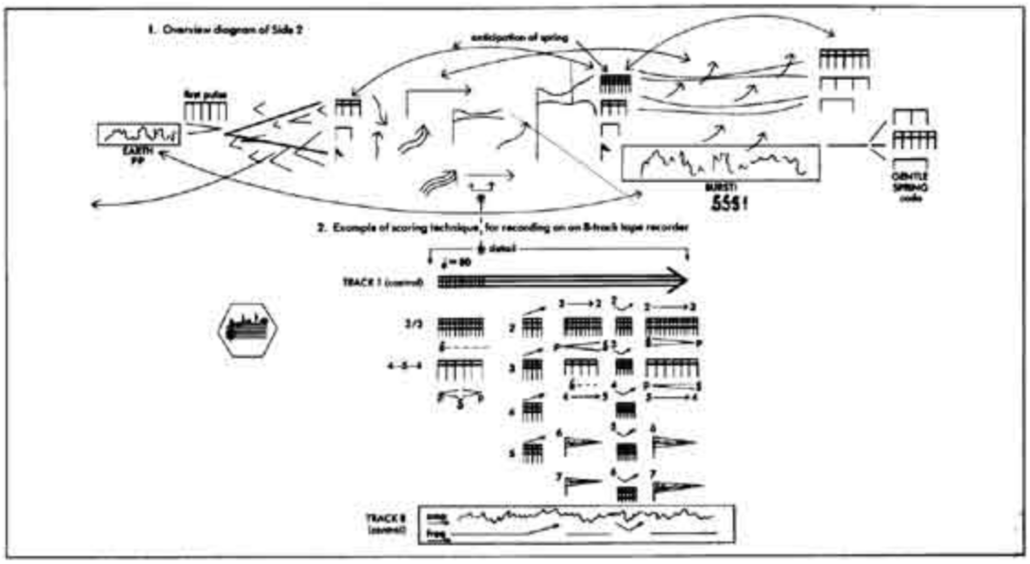

Figure 1.10 - Until Spring *liner notes (Subotnick 1976). Control track at the bottom.*

Ghost scores apply the techniques of control tracks to acoustic instruments: instead of controlling a synthesizer, they are used to modify in real-time the sound of live instruments picked up by microphones. The principle is similar: control tracks are recorded on a tape. The tape is patched to signal processing modules, typically envelope and frequency followers (to convert the audio signal of the tape into proper CV control signals), and then to audio processing modules called *ghost boxes*, such as ring modulators, frequency shifters, voltage controlled amplifier (VCAs) (figure 1.11). Because the signals on tape are never heard, Subotnick simply named the tape-recorded control tracks *ghost score* (Whipple 1983).

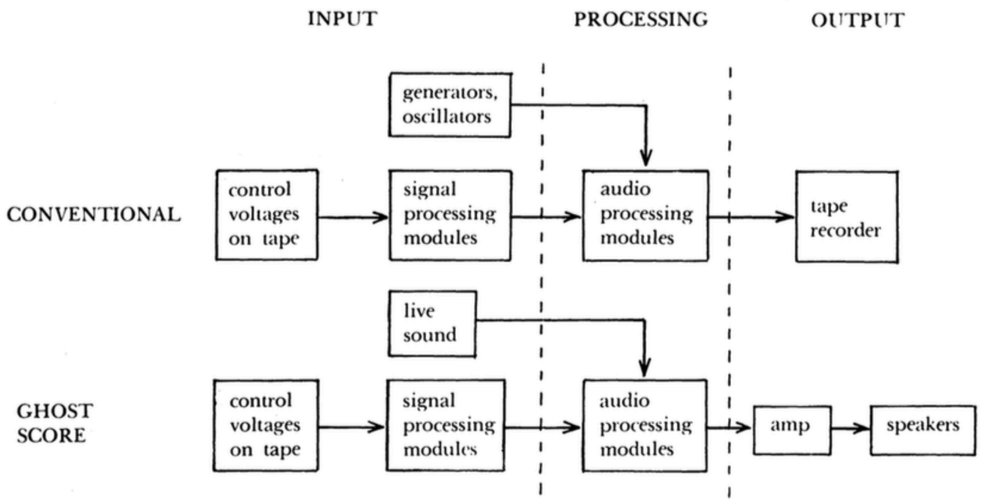

Figure 1.11 - Ghost score diagram (Whipple 1983)

1.3.4. Microstructure and macrostructure composition in Chowning's *Stria*

Stria from Chowning, composed in 1977 at CCRMA (Stanford University's Center for Computer Research in Music and Acoustics), is a classic example of a piece where procedures that determine the microstructure, at the level of sound synthesis, are applied as well to the macrostructure, that is the form of the piece: "Stria *evolved from a microstructural notion. The piece as a whole reflects the shape of the event in its smallest unit.*" (Chowning in Roads 1985).

In *Stria,* the golden ratio Φ ($= \frac{1+\sqrt{5}}{2} \cong 1.618$) is used to determine the inharmonic partials of the sounds, to divide the pitch space and to determine the durations of sounds and events, that is, the formal structure of the piece (Zattra 2016).

<u>FM synthesis</u>

Stria is the third piece of Chowning making use of Frequency Modulation (FM) synthesis (Chowning 1973), after *Sabelithe* (1971) and *Turenas* (1972). Chowning "*stumbled upon*" Frequency Modulation synthesis in the middle of the 60's (Chowning 2007), while experimenting with vibrato at extreme speed and depth. He discovered that when the vibrato rate was in the audio range, with a high depth of modulation, a wide range of harmonic and inharmonic spectra could be generated.

We present here a brief description of the synthesis technique.

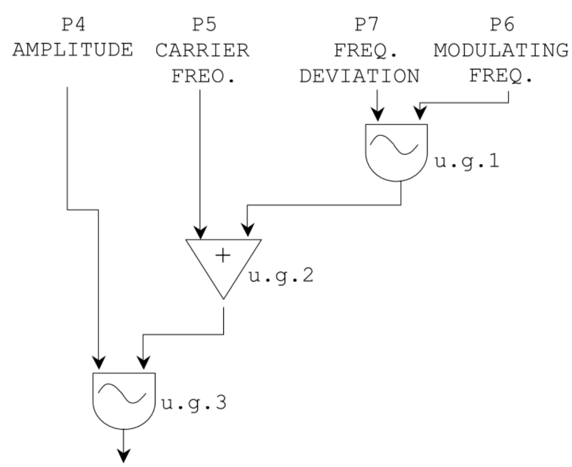

Figure 1.12 - Simple FM circuit - One carrier, one modulator. (Chowning 1973)

FM synthesis consists in modulating at audio-rate the frequency of a carrier oscillator using another oscillator, the modulator. If we consider two sinusoidal oscillators, a carrier and a modulator, specified respectively by (A_c, f_c, ϕ_c) and (I_m, f_m, ϕ_m), the general FM formula is given by:

$$FM(t)= A_c \cos[2\pi f_c t + \phi_c + I_m \cos(2\pi f_m t + \phi_m)]$$

The amplitude of the modulator I_m is the modulation index. Knowing that

$$f(t) = \frac{d\emptyset(t)}{dt}$$

we obtain the instantaneous frequency of the carrier:

$$f_i(t)= f_c - I_m(t) f_m \sin(2\pi f_m t + \emptyset_m)$$

$d = I_m(t) f_m$ is the amount of frequency deviation from f_c. When $I_m > 0$, sidebands appear at $f_c \pm k f_m$, with k an integer.

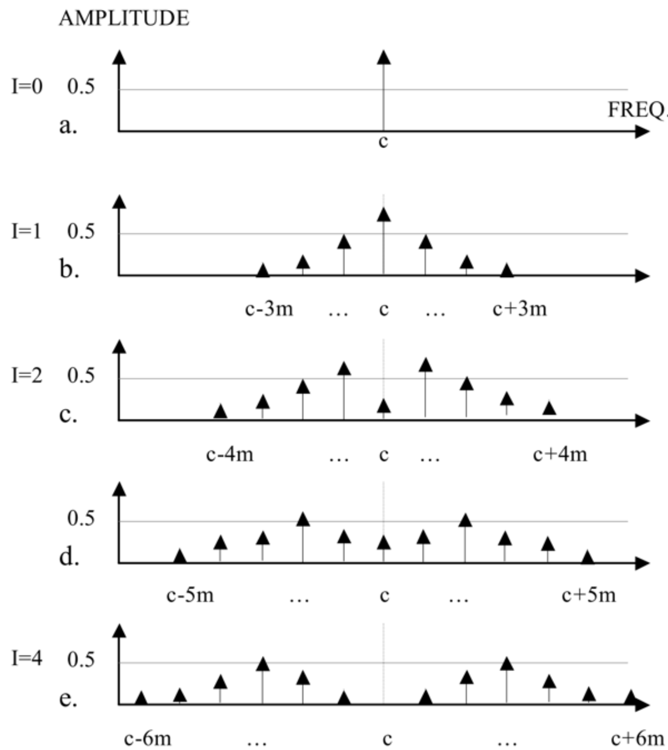

Figure 1.13 - Increasing bandwidth of FM spectrum with increasing index of modulation (Chowning 1973)

The amplitude of the carrier and the sidebands are given by Bessel functions of the first kind and k^{th} order: $J_k(I)$. As the index of modulation increases, the spectrum becomes brighter, and its bandwidth increases.

The spectrum of the resulting sound is given by (ignoring the phases for simplicity):

$$y(t) = \sum_{k=-\infty}^{+\infty} J_{|k|}(I) \sin(2\pi(f_c + kf_m)t)$$

The resulting spectrum is harmonic if the ratio f_m/f_c is a rational number N_1/N_2, N_1 and N_2 both integers. In that case, and if all common factors between them have been eliminated, the fundamental frequency of the resulting sound is $f_0 = f_c / N_1 = f_m / N_2$.

The stability of the spectrum through the pitch space when keeping the ratio constant, and the direct relation between the modulation index, which can be time varying, and the bandwidth of the generated spectrum, offer perceptually relevant synthesis parameters and allow the creation of pertinent and expressive musical sounds.

In *Stria,* the carrier and modulator frequencies are both powers of Φ: $\frac{c}{m} = \frac{\Phi^n}{\Phi^m}$, with n and m integers. Consequently, the resulting sidebands are all the linear combinations $\Phi^n \pm \Phi^m$, that is, sums or differences of powers of Φ (Meneghini 2007).

Inharmonic spectra and pitch space in *Stria*

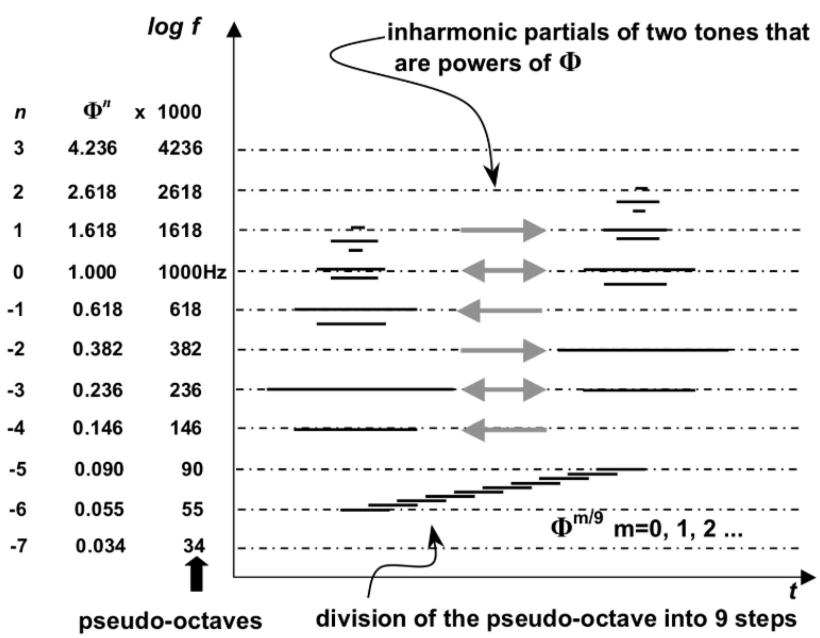

Figure 1.14- The pitch space in Stria *(Chowning 2007)*

The pitch space is based on compressed octaves (pseudo-octaves), that are powers of the golden ratio, around the reference frequency 1000 Hz. Each pseudo-octave is further divided into 9 equal steps.

Knowing that powers of Φ can also be expressed as linear combinations of Φ and Fibonacci numbers: $\Phi^k = F_k\Phi + F_{k-1}$, with k integer and F_k the k^{th} Fibonacci number (1 ,2 ,3 ,5 ,8 ,13 etc.), several sidebands of the generated inharmonic spectrum are powers of Φ, and therefore correspond exactly to the pseudo-octave division of the pitch space. Following the same logic, two sounds one pseudo-octave apart will share several sideband frequencies. Thus, similar to the relationship between the harmonic series with the traditional tempered scale, the inharmonic spectra are structured in a complimentary way to the division of the pitch space, providing perceptual coherence.

Structure, sections, spatialization

The structure of *Stria* consists of 6 sections, each section composed of events, each event composed of several elements (FM sounds) with superimposed "*child sounds*", using recursive procedures to include structures "*in miniature form*" within themselves, similar to a fractal (Chowning 2007). The temporal structure and the arrangement of sections is ordered according to the Fibonacci series, with the climax of the piece happening right at the golden section (around 9', out of a total duration of 15'46" for the CCRMA version. There is another longer version, with a duration of 16'57", edited by Wergo en 1988).

Stria is intended to be played on a quadraphonic system. The spatialization consists essentially in reverberation and distance simulation (by adjustment of the ratio direct sound/reverberated sound) and, with regard to spatial trajectories, slow rotations (Baudouin 2009). Contrary to *Turenas*, Chowning didn't implement a Doppler simulation in *Stria*, due to the central importance of pitches: the resulting change of frequencies would make the complex and subtle structure elaborated by Chowning collapse.

2. The absent body and the dislocation of liveness

Introduction

In the first chapter, we focused on the poietics, that is, the procedures of production of sound material and sonic structures. This led us to raise a series of dialectical oppositions, to -partially- address the question of formalism and to investigate some strategies for material organization and form articulation in computer music.

Yet, the advent of digital technologies, and especially the computer, has not only raised compositional issues and prospects, but has also opened a whole new range of possible relationships between an action, a gesture, and a musical event, that is, new possibilities of interaction. Often, the sound material will be articulated in a deeply interactive way, even in the most formalized works.

Thus, the same way electronic and computer music has changed the way we listen, by putting the emphasis on the meaning of sound itself (Demers 2010), it has also, not only redefined but expanded the ontological statuses of both performance and liveness. Moreover, the digital technologies and the computer have, in some cases, magnified the possible interactions with the sound material, and enhanced, augmented, our perception of a performance (Sanden 2012a). Central to these questions is, of course, the issue of human agency, or to go a bit further, the way an agency -real or virtual- is perceived or inferred.

This will lead us, in the coming chapter, to question the notions of performance, liveness, authenticity, and embodiment, notions that are as significant aesthetically in computer music as those we investigated in chapter 1, the form, structure, and material. We will show first that liveness, far from having been eradicated by the intrusion of digital technologies in the music field, has instead been dislocated and fragmented.

2.1 Performance in electronic music and the notion of liveness

2.1.1 Live performance and liveness

Philip Auslander argues that the very notion of a *live performance* is a modern concept, intrinsically "*bound up with the history of modern media*" (Auslander 2008). Obviously, before the advent of recording techniques, music could only be experienced live. A distinction, crucial today, between what is *live* and what could be *not live* would not have made any sense: a performance was always live.

As Auslander points out, the term *live* first appeared as a reaction to its opposite concept: the recording. Moreover, the need to distinguish between *live* and *recording* became a necessity, in the early 30's, not so much due to the recording technologies, but rather due to the advent of communication technologies, namely, the radio: "*Unlike the gramophone, radio does not allow you to see the sources of the sounds you're hearing; therefore, you can never be sure if they're live or recorded*" (Auslander 2002). Recording techniques -that is, the possibility to experience music at another time, another place- and the uncertainty regarding the nature of the music being heard, live or recorded, due to the absence of the visual link between the sound and its source: these are the two reasons that gave the notions of *live* and *liveness* such a pivotal importance in musical aesthetics.

To begin with, a debate has emerged between the notions of a supposedly *original* work and its reproduction – a studio recording, for instance - with its inevitable corollary, the question of authenticity. In that regard, the notion of liveness shares many similarities, at least on a cultural and aesthetic level, with Walter Benjamin's concept of *Aura* (Benjamin 1991). In the context of live electronics or a computer music performance, how can we know if the performer is doing something? Is it *authentically* live? Is *liveness* a quality we can infuse, perceive, and maybe quantify, in the flow of sounds of a music performance?

Moreover, what is a *live performance*: is it a situation, a category? First, the traditional notion of *liveness* emerged from the classic live situation (a band playing in front of an audience, for instance), involving two aspects: temporal simultaneity and co-presence in the same physical space of the performer(s) and the audience. Furthermore, according to Marvin Carlson, a performance can be based on three concepts: the public demonstration of skills, the display of "*recognized and culturally coded pattern of behavior*", or, lastly, the evaluation by an observer/listener of the "*general success of the activity in light of some standards*" (Carlson, 1996). However, these three definitions, as well as the condition of sharing the same spatiotemporality, and the reductive opposition live vs. recording, don't suffice to identify the variety and specificities of live performances in electronic music, and their consequences in terms of the apprehension of liveness.

Live electronic performances are indeed *mediatized* through technology. As said previously, due to the electroacoustic and electronic innovations applied to the field of music, the sound may now be cut from any visible production mechanism: the simple causal relationship between a sound and its origins is broken. In the last decades, the rapid development of real-time sound generation techniques in computer music further increased this divide: hereafter, the computer musician often operates only on a laptop, perceived as an impenetrable black box by the audience.

Moreover, criteria such as spontaneity, risk, and acceptance of failure and errors, or indeterminacy (Hagan 2016), which are the typical criteria of liveness in the case of live acoustic music, don't seem as relevant to estimate the degree of liveness of an electronic music performance: for instance, how can the audience estimate a potential risk of failure, when the performer is hidden behind a laptop, making minimal bodily gestures on the keyboard and the touchpad? Furthermore, what does actually mean the notion of risk of failure in the case of a computer music performance?

It seems impossible to categorically answer these questions due to the vast range of works, approaches, and ways to interact and perform in electronic music. However, we can try to identify the reasons which make the notion of liveness so difficult to apprehend in electronic and computer music. We may try to identify its factors and attributes which would help us to define more precisely the nature of liveness, factors and attributes that greatly differ between the situations, and between the authors who have examined this question.

2.1.2 The dislocation of liveness

Our interrogations have their origins in the impossibility or difficulty to identify the origins of the sound due to the introduction of recording and communication techniques, what Pierre Schaeffer designated by the term *acousmatic situation*, a situation which "*emphasizes the perceptual reality of sound, as such, by distinguishing it from its methods of production and transmission*" (Schaeffer 2017).

In fact, this rupture of the causal link between the sound and its origins happens at three levels, which Emmerson calls *acousmatic dislocation*: at time level (with the advent of the recording techniques) and space level (telecommunications and recording), as noted by Auslander, but also at the mechanical level: a rupture with the visible production mechanisms of a sound (due to the advent electronics and digital technologies) (Emmerson 1994). Consequently, this has led to a fragmentation, a "dis-location", of the notion of liveness. Auslander, for instance, distinguishes between six types of liveness (Auslander 2008): the "classic" liveness (ex.: a concert), the live broadcast (ex.: a live event on the radio), the live recording (ex.: CD), the Internet liveness (a "*sense of co-presence*"), the social liveness (a "*sense of connection*"), and the "*Website "goes live"*" (ex.: chatbots). For Sanden, the concept of liveness results from the tensions between the "*values of traditional performance*" and the "*threat of technological encroachment on these values*". He further proposes seven non-exclusive categories of liveness, which, combined, form a "*network of liveness*":

- *Temporal Liveness*: Music is *live* during the time of its initial utterance.
- *Spatial Liveness*: Music is *live* in the physical space of its initial utterance.
- *Liveness of Fidelity*: Music is *live* when it is perceived as faithful to its initial utterance, its unmediated (or less mediated) origins, or an imagined unmediated ideal.
- *Liveness of Spontaneity*: Music is *live* when, in its utterance, it demonstrates the spontaneity and unpredictability of human performance.
- *Corporeal Liveness*: Music is *live* when it demonstrates a perceptible connection to an acoustic sounding body.
- *Interactive Liveness*: Music is *live* when it emerges from various interactions between performing partners and/or between performers and listeners/viewers.
- *Virtual Liveness*: In some cases, music can be *live* in a virtual sense even when the conditions for its liveness (be they corporeal, interactive, etc.) do not *actually* exist. Virtual liveness, then, depends on the perception of a liveness that is largely created *through* mediatization.

(Sanden 2012a)

While the first three categories of Sanden correspond to the commonly accepted definition of liveness, the last four are of particular relevance to live electronic performances. If, for instance, we advance the postulate that the liveness of a music performance relies on the perception of a causal relationship between an action and a musical event (an example of *corporeal liveness*), then the acousmatic dislocation aforementioned not only leads to a wide range of possible answers to it, interaction strategies or approaches to live electronic performances (and, we believe, to fruitful obstacles), but leads also to different ontological conditions of *liveness*.

For Stroppa (Stroppa 1999) and Croft (Croft 2007) for instance, the visible presence of a human performer seems a necessary condition of liveness. In addition, they both emphasize the crucial importance of the instrumental paradigm: not only the performer should be physically there, and visible, but he should be seen playing an instrument. Likewise, Butler stresses the importance of the "*clear display of instruments and performers, especially performers' faces and the parts of their bodies in direct contact with their instruments*" in electronic dance music performances (Butler 2014). For Collins, similarly, the human participant is essential, and his or her actions should be clearly visible, although in a different form, for instance through the projection of the laptop screen, displaying in front of the audience what the *live coder* is typing (Collins 2011).

Croft distinguishes actually between two sorts of liveness: *procedural liveness* (i.e., real-time transformation or generation of sounds, that is, a method) and *aesthetic liveness*, a causal relationship between the actions of the performer and a musical event, this relationship being established by means of procedural liveness. For Croft, the causality, that is, the proportionality between the action of the performer, in gestural and energetic terms (the "*bodily effort*"), and the resulting sound, is a necessary condition of an "*aesthetically pertinent 'liveness'*".

Yet, this proportionality between a cause and its sonic result is never certain in the context of computer music: there is no intrinsic link between the physical effort of the performer and the resulting sound. Keane observed that "*electronic music generation makes possible sonic gestures which are not proportional to the physical bodily force exerted to produce the gesture*" (Keane 1979). Thus, to re-establish a link between bodily gesture and sound production process, a gesture-sound mapping is required. This situation raises several questions: what is then a correct and *aesthetically pertinent* mapping between the physical effort and the resulting sound? If proportionality is a primary goal, would such a mapping become only the supporting structure of a simulacrum of energetic processes, which could be then considered as arbitrary?

Furthermore, today's audiences generally tend to accept laptop performances as bona fide live performances. The condition of the visibility of the performer's actions does not even seem to apply to all of the live situations, for instance in live audio/visual performances (Cooke 2011), or the increasingly popular screenings of silent films with live electronic music. In both cases, the performer is often in the dark, the face dimly lit by the laptop's screen, the audience's attention directed towards the screen, and yet, these events are experienced as live. The nature of a live event does not merely consist of the sounds produced by a performer and the way each listener, individually, reacts to them, looking for spontaneity, risk-taking, or virtuosity. It is instead a "*pattern of relationships*" (Small 1998): between the performer and the listeners of course (the *Interactive Liveness* of Sanden), but also between the listeners and the physical space, between the listeners themselves, between the sounds being played, the social context, etc. In electronic dance music, electronica or IDM, for instance, the context, the physical setting, the social structure and the interrelations between listeners are essential components of the liveness of an event, more so than the visibility of the DJ. Site-specific events, with 'immersive' audio and visuals, which often do not show any performer (for instance, Robert Henke, *Lumière II*, 2015), are also recognized as live, for the same reasons of the intricate interrelationships between space, time, context, performers and listeners.

2.2. Embodiment, human agency, and physicality of sound material

The questions of live performance, liveness and interaction can't be discussed without at the same time addressing the question of the body, with regard to its particular status in electronic and computer music. As we have seen in section (2.1.2), the rupture of the causal link, and its consequences, such as the fragmentation of the notion of liveness, have radically modified the perception of the role of the performer, his body and musical gestures during a performance. They are not anymore, as before, a mere necessity, imposed by the very physicality of the instruments (they had, after all, to be played). Hereafter, bodily gestures and physical presence, due to their optional character, become all the more indicative of compositional choices, and therefore, their role is magnified and emphasized. In this section, we will address first the question of the mind/body problem in music, and the notions of *embodiment* and *sonic images*. We will then introduce the notions of *gestural surrogacy* and *living presence*, both emanating from the British acousmatic school, and we will advance the hypothesis that each sound suggests a musical gesture, and more generally, could suggest a physical motion or phenomenon. Lastly, we will introduce the notions of *musical personae* and *virtual personae*, as well as that of the presence of the tool and the material, that we believe is fundamental in our own musical practice.

2.2.1 Embodiment and sonic images

> Thinking is movement confined to the brain. (Arvid Carlsson, Nobel Prize in Physiology or Medicine, 2000)

Embodiment and intercorporeality

The dialectic of mind and body has a central importance in music. The traditional notion, asserting that the music is a product of the mind, imagined, understood, thought and perceived by the mind (after all, this was the primary perspective in the first chapter of this dissertation), has been dramatically challenged in recent decades, and consequently, the long-established dualism mind/body thoroughly questioned. Suzanne Cusick summarizes the mind/body problem in music in these terms: "*Music, an art which self-evidently does not exist until bodies make it and/or receive it, is thought about as if it were a mind-mind game*" (Cusick 1994).

This recent shift towards the body in the music theory field is a consequence of the embodiment theories of Husserl and Merleau-Ponty, who, through these, proposed an alternative to the mind/body problem. Husserl introduced the concept of the *lived body*, the *leib*, the body experienced from a first-person position, our subjective view over the world:

> In perceptions of *external things* I myself am given to myself within the total perception of an open spatial world, a perception that extends still further into the all-embracing [...]. In this focus on external experience (in the world of space) my subjectivity and

> every other mental subjectivity is a component of this concrete being as person and consequently it is the correlate of a certain external apperception within the all-embracing apperception of the world. (Husserl, 1997)

As Zahavi observed, for Husserl, "*every worldly experience is mediated and made possible by our embodiment*" (Zahavi 1994). Merleau-Ponty drew upon Husserl's concept of "lived body", and pointed out that the body is "*our point of view on the world* [...], *it is our expression in the world, the visible form of our intentions*". (Merleau-Ponty 1964). The embodiment theories of Husserl and Merleau-Ponty suggest that cognition depends primarily upon the body and its interactions with the environment. Moreover, and strongly relevant in our study, Merleau-Ponty introduced the notion of *intercorporeality*, an *intersubjectivity* of embodiment (Merleau-Ponty 1960). By *intercorporeality*, Merleau-Ponty means the connection with others is established through a shared embodiment. That is, we perceive and understand the actions and gestures of others by perceiving, feeling, them in our own body.

Sonic images

Many scholars in the field of performance studies and music theory have applied embodiment and intercorporeality theories to music, live musical performances, and liveness, such as Sanden with the aforementioned notion of *corporeal liveness*. Fisher and Lochhead apply precisely these ideas to the act of listening: "[...] *hearing entails a bodily enactment of musical meaning that links* *listeners, performers, and creators in the same musical enterprise*". Furthermore, in the situation where the performer is not visible, such as listening to a recording, Fisher and Lochhead state that "*performative enactment of musical meaning relies on a prior backdrop of experience that allows listeners to imaginatively engage the physical activities that went into its production*" (Fisher and Lochhead 2002).

Similarly, Arnie Cox proposes a "*mimetic hypothesis*", based on developmental and neuropsychological studies, advancing that we understand sounds through our prior embodied experience in producing sounds ourselves and that this process involves "*tacit imitation, or mimetic participation*" (Cox 2001). Moreover, according to Cox, such imitation can be "*overt*", that is, represented by our motor actions, or "*covert*", when these bodily actions are inhibited. In that case, the covert imitation is motor "*imagery*": the motor actions are imagined, informed by prior experiences of performed actions, which is, of course, noticeably reminiscent of the famous assertion of Carlsson: "*Thinking is movement confined to the brain*". Such motor images are not necessarily strictly those of the sound-producing action itself (playing the instrument, for instance). They can as well be of an analogous sound-producing action or an action related to a different modality (dancing being the most obvious example) (Cox 2011).

Godøy similarly stresses the importance of the *motor-mimetic* element in music perception (Godøy, 2003), and proposes the term *sonic image*, a mental representation of a sound-related action (Godøy 2010). Moreover, by dividing the sound production into two components, action and reaction, he distinguishes the *motor images* (images of "*what we do*") from the *material images* (images of "*the* *effects of what we do*") (Godøy 2001). For Godøy, these sonic images are fundamental in our perception and understanding both of human agency, an essential factor of liveness, and of the sound material itself, its physicality. It is no surprise then, that the theories of embodiment and the concept of sonic images, both stemming from a purely phenomenological perspective, would meet the Schaefferian concept of the sound object, as seen for instance in (Godøy 2006), with the concept of *gestural-sonorous objects*, and in Smalley's notion of surrogacy, which we analyze in the next section.

2.2.2 The present absence

Surrogacy and living presence

The influence of phenomenology is indeed evident in Smalley's writings. In a very similar way to Cox and Godøy (but surprisingly not cited by any of them, probably because of their particular focus on the reception of performances more than on the production processes of music), the composer Denis Smalley, points out that, because of years of unconscious "*culturally-acquired*" knowledge of "*sounding gestures*", we are able detect human activity behind sounds themselves. He introduces the concept of *gestural surrogacy* and defines several orders of it, each of them with a decreasing degree of the perceived relationship between a sound and its causes (Smalley 1997). First-order surrogacy and second-order surrogacy refer, for instance, to sounds with recognizable sources and gestural causes. Third-order surrogacy happens when a gesture is "*inferred or imagined in the music*", analogous to Godøy's concept of sonic image. Lastly, remote surrogacy, a higher degree of remoteness from a cause or gesture, relates to the recognition of some characteristics of gestural trajectories in the sound itself, without direct reference to a supposed human gesture or an imagined source. Both third-order and remote surrogacies are possible through the perceived spectral changes of the sound, its "*energy-motion trajectory*", and the sounds relying on them are an integral part of the vocabulary of electronic and electroacoustic music.

Furthermore, according to Smalley, these energy-motion trajectories of imagined gestures, conveyed by spectral changes, sharpen expectations and introduce a sense of direction and narration. Thus, imagined human gestural activity and stimulation of expectation patterns suggest an intention and a will, and consequently, the presence of an agent, what Emmerson names psychological presence. For Smalley and Emmerson, inferring causes and intentions is a systematic process, suggesting a *living presence* (Emmerson 2007), an indispensable attribute of liveness, even without the physical presence of an actual performer.

Similar processes of attribution of causality, and inference of human agency are, in the visual domain, clearly demonstrated in the experimental studies of Fritz Heider and Mary-Ann Simmel (Heider and Simmel, 1944): by showing simple animations of geometrical shapes, viewers systematically would infer causal interactions, and would attribute motivations, intentions, and emotions to the objects, and even relationships between them.

Timbre and attribution of causality

Following Smalley's notions of higher-order surrogacies, we would then suggest that we are not only looking for human gestures behind sounds themselves but, more generally, we are trying to detect archetypical physical phenomena as the causes of the sound, such as impulse-resonance. Such a process happens by relying on a broad set of prior experiences, and therefore on an intuitive understanding of laws of mechanics (momentum, force, acceleration, for instance). "*Audition*", Jean-Claude Risset states, "*is in search of mechanical causalities*" (Risset 1992, my translation). Timbre, attribution of causality, physical plausibility (which is not the same thing as "realism"), and identity are all intrinsically linked. It becomes apparent that the initial rupture of the causal link inspires the construction of new, supposed or imagined, causes (Emmerson 2007). Trevor Wishart observes: "*Different kinds of intrinsic morphology affect us differently and this is something to do with the assumed physicality of the source (which is not the same thing as source-recognition)*" (Wishart 1986). Interestingly, McAdams and Saariaho reach similar conclusions, but from an opposite perspective, pointing out that the construction of pseudo-causes of sounds might help in creating a perceptual coherence of timbres (McAdams and Saariaho 1985).

This link between timbre and (constructed) pseudo-causality is nicely illustrated by physical modeling synthesis: a physical model contains, by definition, a system of constraints included in the synthesis method itself. These constraints are what makes the creation of a perceptually coherent timbral space relatively easy with physical models and, obviously, more challenging with more abstract methods (Eckel, Iovino, Caussé, 1995). Our perception is trained to identify the behaviors happening under such a system of constraints, and can easily recognize sounds resulting from it. In other words, these constraints help us to establish a link between a sound and a sound production mechanism (Cadoz 1991), and therefore ensure a perceptual coherence of the timbral space generated by a physical model.

Virtual personae, presence of the machine: ambiguity and intimacy of the sound material

By drawing a parallel with the notion of a *personage* in a theater play or a movie, Auslander introduces the concept of *musical persona*: "*What musicians perform first and foremost is not music, but their own identities as musicians, their musical personae*". Levinson proposes a similar concept, but this time an imagined, virtual identity, by connecting agency to the expressiveness perceived in the music: "*I will refer to the individual indefinitely imagined as the subject of the* [emotional] *state being expressed as the* persona *of the music*" (Levinson 2011).

This concept of a *virtual persona* is, in fact, closely linked to the process of constructing imagined causes and of inferring an intention or a will, and thus a presence. The *persona* is then defined not anymore only as the role assumed by the performer during a performance, but also as a virtual identity, a presence emerging during the listening process, for instance the virtual persona of the improvising computer in George Lewis's *Voyager* (1992). Lewis quotes the jazz composer Yusef Lateef:

> The sound of the improvisation seems to tell us what kind of person is improvising. We feel that we can hear character or personality in the way the musician improvises. (Yusef Lateef, quoted in Lewis 2000)

Sanden investigates the idea of a *virtual persona* in his paper "Virtual liveness and sounding cyborgs: John Oswald's 'Vane'" (Sanden 2012b), to illustrate his notion of *virtual liveness*. Sanden argues that, even in the case of a piece fully mediatized through technology, without any presence of a performer (as in John Oswald's *plunderphonics*), we are still in front of a performance, the performance of the machine, that he calls "*sounding cyborg*".

Glitch music, *electronica*, or *dub techno*, in particular, often over-emphasize the presence of the machine and the material, by revealing and magnifying the signs of its own mediatization: artifacts, glitches or noise, for instance in Mika Vainio's pieces, Ryoji Ikeda's work, and more generally, in the whole catalog of Raster-Noton. Clearly audible artifacts of audio editing (cuts, clicks), aliasing, distortion, low bit-depth, or tape hiss: a full range of techniques are deployed to create a form of proximity and intimacy with the sound material. These popular electronic music genres thus adopt an aesthetic stance towards the problem of authenticity mentioned at the very beginning of this chapter, by exposing their own mediatization, and by opposing themselves against "overproduced", and therefore, maybe more sterile forms of pop music. Iyer observes: "*More than a century after the invention of recording technology, we have become accustomed to recorded, disembodied, and electronically generated music. But still, music tends to bear these same traces of embodiment*" (Iyer 2004). He points out that, by taking as an example the extreme micro-editing of recorded breakbeats in Squarepusher's music, popular electronic music frequently relies on a "*playful ambiguity*" between bodily presence and machine presence, thus evoking an ever-changing virtual persona, a man-machine chimera. Such ambiguity is, of course, not the prerogative of popular electronic music only. About the music of Ligeti, Grisey, Murail, or Stockhausen, Jonathan Harvey observes as well: "*they are all playing with the identity given to objects by virtue of their having a timbre, in order to create* ambiguity. *The 'timbral experience' is fundamentally one of shifting identities*" (Harvey 1986). The same could be said, of course, about Harvey's own *Mortuos Plango, Vivos Voco* (1980).

Clearly, the listening process can't be reduced so easily to the sound object only, cut from its origins and meanings: the two other modes of listening, causal ('what is it?', 'how is it produced?') and semantic ('what does that mean?', 'what's the intention?') are often, if not always, at play in electronic music. Several other examples of *liveness infused* works may illustrate the ambiguity, the presence of the material and the interplay between sounds and their inferred causes: the anecdotal music of Luc Ferrari of course (*Presque Rien N °1*, *Le Lever Du Jour De La Mer*, 1967-1970), the machineries and metal objects of Marc Ainger's *Shatter* (1998) or Åke Parmerud's *La vie Mécanique* (2004), the fusion of "natural" and synthetic sounds in Jean-Claude Risset's *Sud* (1984-1985), or the ambiguous and ever-changing sound morphologies of Natasha Barrett's *Volvelle 1* (2015).

2.3. Interactions

> Interaction is more powerful than algorithms. (Wegner 1997, cited in Vaggione 2008).

The notions of attribution of causality and emergence of a living presence or a virtual persona, as presented in the previous section, are intrinsically linked to the time-varying behavior of timbres and the variations of musical processes. They are at the source of our interrogations regarding the cause of the sound, they stimulate expectation, suggest an intention, and build a sense of direction and narration. In this regard, we believe, simple sound processes, varying in rich and intricate ways, will generally be more convincing than the opposite, in the same manner as the simplistic geometrical shapes of Fritz Heider and Mary-Ann Simmel suggest complex behaviors, interactions, and narrations through their animation only. The possibilities of electronic and digital technologies have cut the causal link, but this rupture offered new opportunities of interactions. It is thus nowadays rare that a computer music piece, even deeply formalized, does not interactively articulate the sound material.

GROOVE, a performance system consisting in a computer controlling a voltage-controlled synthesizer, offered new ways of interacting in real-time with the electronics (Mathews and Moore 1970). The MIDI communication protocol, introduced in 1982, allowed easy and convenient, although limited (Moore 1988), communication between MIDI devices, such as synthesizers, keyboards, or computers. Max Mathews' *Radio-Baton*, a performance controller that converts three-dimensional coordinates into MIDI commands (Mathews 1991), and Barry Vercoe's *Synthetic Performer*, accompanying in real-time a live flutist (Vercoe 1984), are other early examples that illustrate novel ways of interacting, made possible by the computer.

Robert Rowe defines an interactive music system as follows: "*Interactive computer music systems are those whose behavior changes in response to musical input. Such responsiveness allows these systems to participate in live performances, of both notated and improvised music*." (Rowe 1993). He proposes a classification system based on three dimensions: first, *score-* or *performance-driven* systems, which differ by the use of stored representations of music events or fragments in the first case, and more general parameters, generally perceptual, in the second case. Second dimension, the response methods, which can be *transformative* (i.e. applying transformations to the material arriving at the input), *generative* (using a set of rules controlled by messages arriving at the input to generate a complete musical output) or *sequenced* (pre-recorded material fragments are sequenced according to messages received at the input). Lastly, the third dimension distinguishes between the *instrument* paradigm (the construction of an "*extended instrument*") and the *player* paradigm (the construction of an "*artificial player*"). Rowe is careful to specify that each dimension is not composed of distinct categories, but is instead a continuum of possibilities.

According to the third dimension aforementioned, an interactive music system such as described by Rowe can play a leading role in the relationship human-computer, and not simply be under strict control of the performer, or can even exists without the presence of a human performer: the artificial player is "*a musical presence with a personality and behavior of its own*" (Rowe 1993). At the condition it is recognized as such by the audience, it becomes a *living presence* (Hagan 2016), a virtual persona.

Garnett defines interaction with the computer in a very similar way: "*Interaction has two aspects: either the performer's actions affect the computer's output, or the computer's actions affect the performer's output*", and he stresses then: "*Note that in both of the above categories of interaction -electronics affected by the performer or performer affected by the electronics- can be mixed, and the boundaries can become blurred.*" (Garnett 2001). On the contrary, Croft, ignoring the *player* paradigm, considers interaction mostly as part of the *instrumental* paradigm: "*By 'interaction' here I refer to any causal connection between a performing body* […] *and a sound-producing system whose observable physical characteristics do not determine the characteristics of the sound produced – for instance, a computer*".

In Risset's *Echappées* (2004), for Celtic harp and real-time digital processing, the sound of the harp is processed using Max MSP (Puckette 1991). Echoes, harmonizing, and feedbacks settings are triggered during the performance, either by the performer using a MIDI pedal or by a computer operator hitting the space bar (Risset 2006). Two other earlier works of Risset, *Duet for One Pianist* (1989) and *Etudes* (1991), demonstrate a different form of interaction: in this series of sketches, the computer responds to what the pianist plays on a computer-controlled acoustic piano, a Yamaha Disklavier. Using Max, Risset programmed different "*interactive relations*". The computer becomes a partner, playing on the same piano, and consequently, a "*reactive presence*" emerges (Risset and Van Duyne 1996), a factor of liveness analogous to Emmerson's living presence, or Sanden's virtual persona. A similar reactive presence materializes in George Lewis's *Voyager* (1992), which emphasizes improvisatory aspects: both the performer and the computer improvise, reacting and responding to each other.

3. Time Unfolded

Introduction

In the two previous chapters of this work, we addressed what we consider the two pivotal points and challenges in our strategies of composition. First: the question of form and material and the structuring processes. Indeed, while it is often easy to create sound material, sound morphologies, or sequences, musical phrases, or segments, it is just as easy to make the whole scaffolding collapse during the development of a higher form. Second, the questions of liveness and performance: from the point of view of their technical counterpart, the interactions, determined during the composition process, and actualized during the performance; and from the point of view of the presence of the material and the machine, and the emergence of a reactive presence, a virtual persona, a chimera made of the performer and her tools.

We propose, encapsulated in a performance for dancer, video, and live electronics, our answers to these questions, in the form of several electronic music studies. These are individual answers to general questions. If it is now common to liken artistic creation to scientific research (and very uncommon to see the opposite allegation, as pointed out by Henke), there are still fundamental differences between them (Hellawel 2014, Croft 2015, Henke 2016), and thus it seems difficult to hope to offer generalizable solutions and definitive answers. While of course there are elements of research instilled in our music, they don't depict what the composition process really is (for instance, how to answer the simple question: "Why did I choose this option instead of that one, just as equally valid?"), and thus, the intrinsic quality of the music is difficult to quantify or evaluate through the lens of research and pure rationalization. Listening, however, allows that. This also gives rise to the question of how to structure this chapter: the research as such consists essentially in the creation of the tools -the instruments- required for the creation of the performance. Some tools or methods were used on several pieces, sometimes with some modifications (then, akin to engineering), while some others were deeply idiosyncratic. It is about a linear description of a composition, based on a network of tools, that is the result of non-linear processes of decisions and aesthetic choices.

This is what we will try to present in this chapter, along with a broader contextualization. Together with the notions discussed in the previous two chapters, we hope, therefore, to provide insights into our research, motivations and explorations, specific to our position as the creator and performer of this work.

3.1 Time Unfolded

Multi-media performance for dancer, 8-channel live electronics, and video.

Figure 3.1 - Time Unfolded

Time Unfolded is an interdisciplinary and immersive multi-media performance, in three movements, combining high-resolution video projection, dance and 8-channel surround live electronics. *Time Unfolded* is an exploration of the movements of a dancer, Verónica Santiago Moniello, filmed in 4.6K (4608 x 2592) at high frame rate (60 fps to 120 fps) and decomposed instant after instant, following and extending the techniques of chronophotography of Eadweard Muybridge and Étienne-Jules Marey. This work was awarded a 3-days residency at the Calit2 (California Institute for Telecommunications and Information Technology) in December 2019, by the Initiative for Digital Exploration of Arts and Sciences (IDEAS).

3.2 Chronophotography and Bachelardian model of time

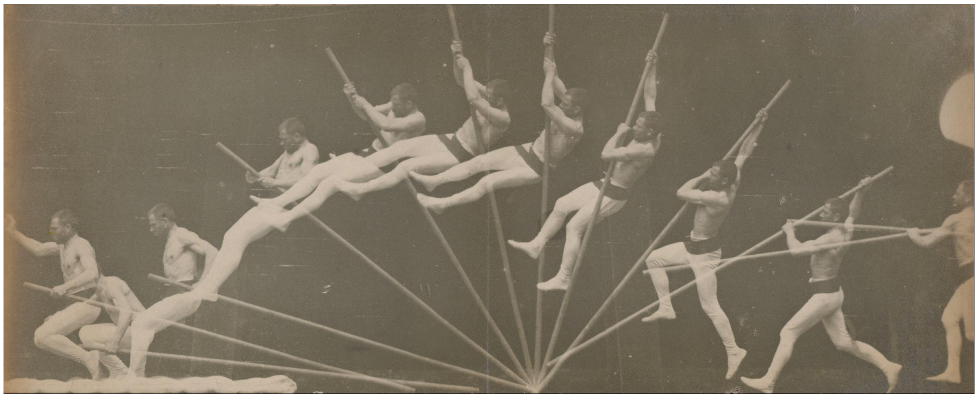

Figure 3.2 - Étienne-Jules Marey - Movements in Pole Vaulting (c. 1890)

This work is in line with a long tradition consisting in seeing time and motion as a succession of moments, events or particles: in other words, a granular view of time, one that is discrete, discontinuous and consists of a succession of moments that are themselves indivisible. These concepts are taken from Greek philosophers, Leucippus, of course, the founder of atomism, but also from Democritus and Epicurus, who saw the universe as a discontinuous space comprised of indivisible atoms. According to Bachelard, in *The Dialectic of Duration*:

> The thread of time has knots all along it. And the easy continuity of trajectories has been totally ruined by microphysics. Reality does not stop flickering around our abstract reference points. Time with its small quanta twinkles and sparks.
>
> (Bachelard, 2000)

Bachelard directly opposes Bergson's conception of duration. According to Bachelard, the moment is the only reality, and any duration of time is an aggregate of moments. Time is inherently discontinuous and it is only "*continuous as possibility*." In contrast to Bergson's notion of pure continuous duration (Bergson 1991), he proposes an illusion of duration, in which continuity is assured through feelings (Regnier 2015). The Bachelardian model of time is situated at the crossroads of the phenomenological approach of experienced time and modern scientific theories. It is indeed an effective model to reveal the missing link between phenomenology, science and art, and thus, is rich in visual and musical applications. So for instance, the chronophotographic works of Étienne-Jules Marey (figure 3.2) or the motion studies of Eadweard Muybridge (figure 3.3), are not only fascinating as scientific studies, but also as aesthetic objects, as evidenced by their influence on Marcel Duchamp (figure 3.4), Francis Bacon and of course the Futurists (figure 3.5), among many others.

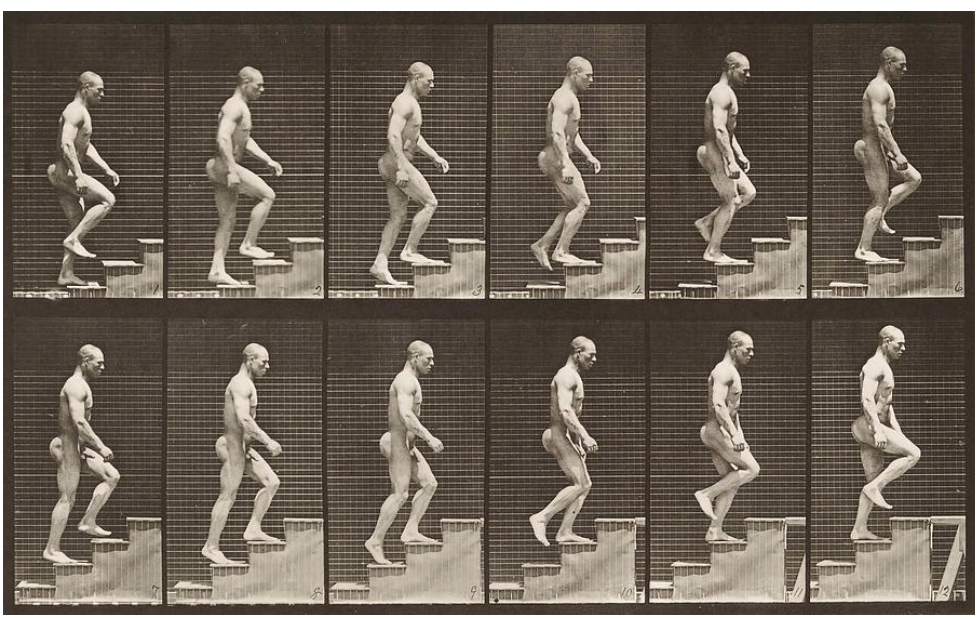

Figure 3.3 - Eadweard Muybridge -Nude Man ascending Stairs (1887)

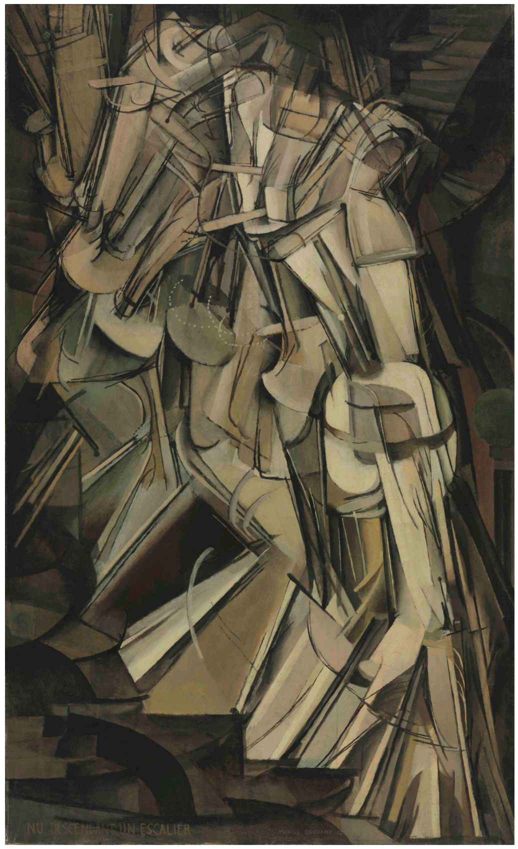

Figure 3.4 - Marcel Duchamp - Nude Descending a Staircase (No. 2) (1912)

Figure 3.5 - Luigi Russolo - Plastic Synthesis of Movements of a Woman (1912)

3.3 Compositions

3.3.1 *Ombak*, for 8-channel electronics

Sound material

Ombak is a short study about timbre morphing and shifting identities. The sound material used in the piece consists of recordings of a soprano, Alexandra Matloka, and of a *Gamelan Batel Ramayana*, used traditionally to accompany the *shadow play* of the *Ramayana* Indian epic poem. The Gamelan Batel instruments consists of four melodic metallophones (2 *kantilan*, 2 *pemade*), always played in pairs, accompanied by a small gong and percussion ensemble. The metallophones in a pair are purposely tuned slightly apart, in order to create beating, called *ombak*, (typically around 3 to 8 Hz). Isolated hits of the *pemade* and *kantilan* pairs were resynthesized by means of modal synthesis.

Analysis of the *pemade* and *kantilan*

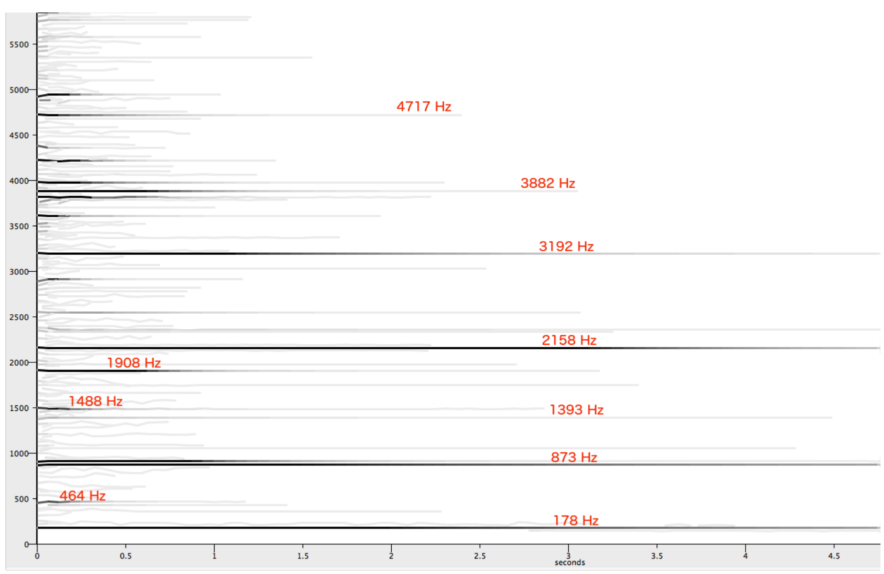

Figure 3.6 - Partials of the higher Pemade

Gamelan metallophones have a rather harsh and bright sound, and a sparse inharmonic spectrum, with a limited number of prominent partials. The beating is what imparts the unique shimmering sound of Gamelan metallophones. The spectra of the 2 pemade and 2 kantilan were analyzed by FFT.

Table 3.1 - Prominent partials of the pemade and kantilan

Low pemade	High pemade	Low Kantilan	High Kantilan
172 Hz	178 Hz	354 Hz	359 Hz
464 Hz	464 Hz	922 Hz	931 Hz
875 Hz	872 Hz	1738 Hz	1786 Hz
1422 Hz	1488 Hz	2883 Hz	2880 Hz
1515 Hz	1908 Hz	3740 Hz	3770 Hz
2215 Hz	2158 Hz		
2400 Hz	2355 Hz		
3304 Hz	3192 Hz		
4086 Hz	3882 Hz		

Table 3.2 - Prominent partials of the pemade and kantilan, as ratio of the fundamental frequency

Low pemade	High pemade	Low Kantilan	High Kantilan
f	f	f	f
2,698f	2,607f	2,605f	2,593f
5,087f	4,899f	4,91f	4,975f
8,267f	8,359f	8,144f	8,022f
8,808f	10,719f	10,565f	10,501f
12,878f	12,124f		
13,953f	13,23f		
19,209f	17,932f		
23,756f	21,809f		

Similar to the relationship between the harmonic series and the traditional tempered scale, the inharmonic spectra of the Gamelan instruments are related to the scale systems used in traditional Indonesian Gamelan music (Sethares 2005), namely the 7-tones per octave *pelog* scale, and the 5-tones per octave *slendro* scale (Kunst 1973).

Resynthesis and morphing

The Gamelan *pemade* and *kantilan* are resynthesized using a bank of 2-pole resonating bandpass filters (figure 3.7). Regarding the filters design, we followed the s- to z-plane transform approach introduced by Zavalishin (Zavalishin 2008), due to its good amplitude and phase responses, excellent time-varying behavior, and computational efficiency. Such filters are thus good candidates for a resonator bank, in particular if time-varying processes such as morphing or frequency modulation are performed.

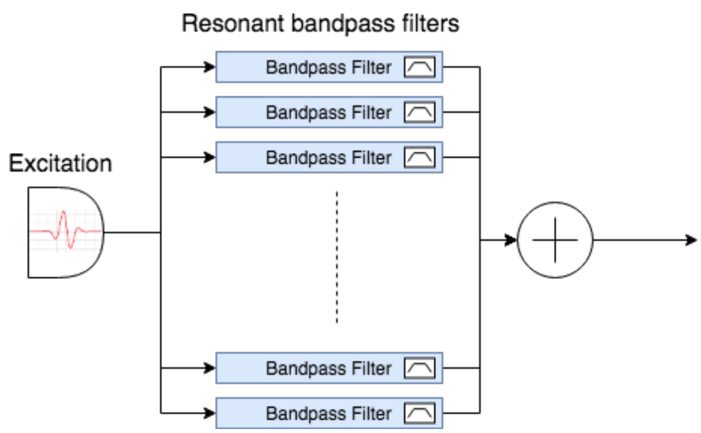

Figure 3.7 - Bank of bandpass resonating filters

The method we followed consisted in expressing a classic 2-pole bandpass state-variable filter (SVF) in the form of a block diagram in the s-plane (figure 3.8), then converting to the z-plane by trapezoidal integration, using a transposed direct form II structure (Smith 2007), which leads to a bilinear transform. Lastly, we avoid introducing any unit delay in the feedback paths by solving the "zero-delay" feedback implicit equations.

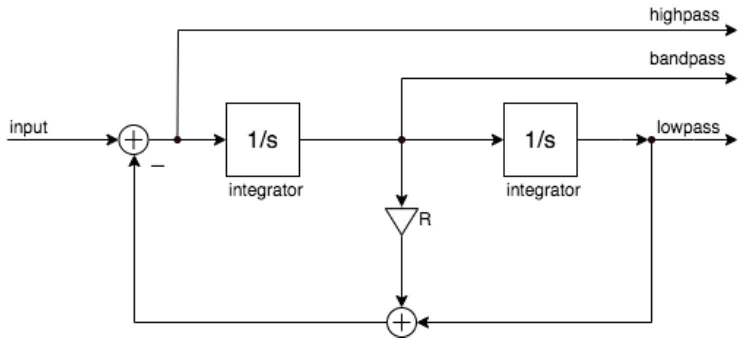

Figure 3.8 - Block diagram of the state variable filter

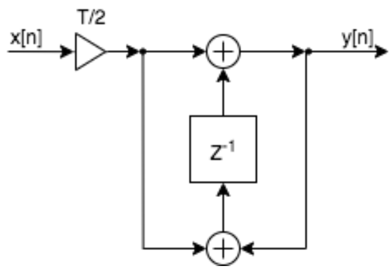

Figure 3.9 - Integrator, transposed direct form II (TDF II)

Replacing the analog integrators by discrete-time TDF II integrators, and solving the zero-delay feedback equations for the bandpass output gives the block diagram in figure 3.10, with $g = \frac{\omega_c}{2.f_s}$ and $d = \frac{1}{1+Rg+g^2}$, f_s sampling frequency, ω_c cutoff frequency, R damping of the filter, s1 and s2 states of the two integrators:

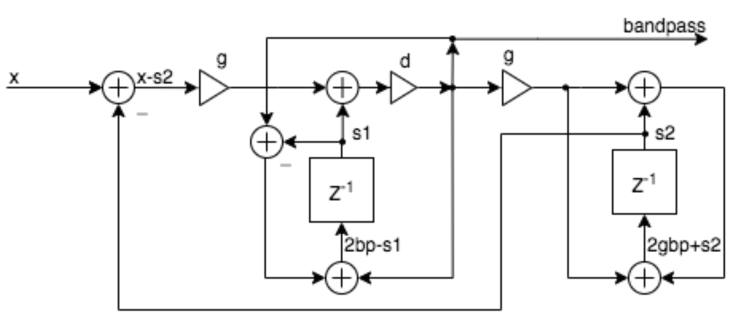

Figure 3.10 - Discrete time SVF filter, with solved delayless feedback loops

The filter bank based on this filter was implemented in Kyma (Scaletti 1987). Each partial of the *pemade* and the *kantilan* is resynthesized using one resonating bandpass filter, and has its own independent decay value (as seen on the FFT analysis, the higher partials don't necessarily have a shorter decay) and own amplitudes. A short burst of white noise with Gaussian amplitude envelope was used to excite the filters. To achieve a more realistic result, the first few milliseconds of the original recordings of the instrument hits was sometimes layered together with the modal resynthesis. Lower and higher instruments of a pair are resynthesized separately, thus enabling control over the beating frequencies, by adjusting their respective tunings.

Once you have control over the partials independently, many operations are possible. The problem is then to determine a few operations that can meaningfully affect the partials globally, within the context of the piece. First, a morphing between different sounds was implemented by means of linear interpolation between the rows of three matrices: one matrix for frequencies (thus, creating glissandi between the partials of the morphed sounds), one for amplitude and one for decay (related to the resonance of the filters). The interpolations are simultaneously controlled over a 2D-plane, enabling morphing between 4 different sounds (one per corner), for instance by means of gestures. Lastly, a few additional operations were added: folding of the partial frequencies using a cosine function, multiphase sinusoidal modulation of the amplitudes of the partials, "tilt" control of the amplitudes (varying progressively from attenuation of the higher partials to attenuation of the lower), modulo operations on amplitudes (odd partials only, 1 out of 3, of 4, etc.) and spatial operations (projecting partials independently in the surround space).

Besides the Kyma implementation, specifically used for *Ombak*, we implemented this filter bank, with 128 bandpass filters, as an external for Pure Data (Puckette 1996), and a simplified 16 bands filter bank on a STM32 ARM Cortex-M7 microcontroller, with touch screen control (figure 3.11).

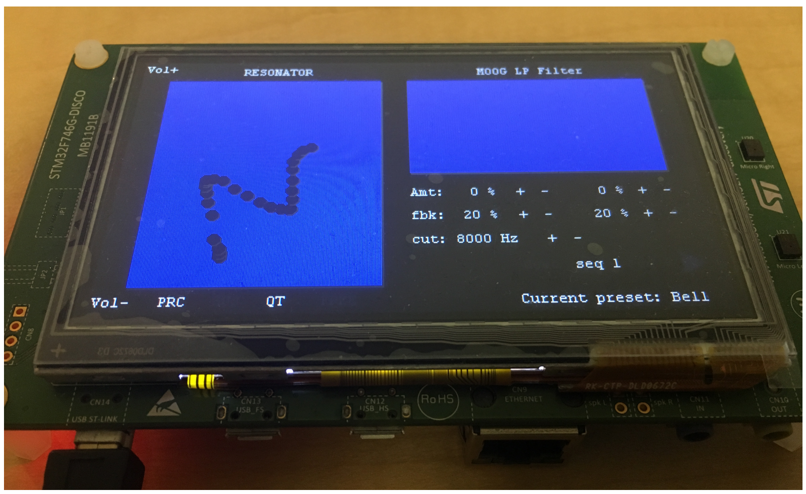

Figure 3.11 - Resonating filter bank on an STM32F7 board

Additionally, morphings, in particular those between the soprano voice and gamelan, are edited using the Kyma TAU (Time Alignment Utility) editor, in order to match the frequency and amplitude envelopes of the voice and the gamelan resynthesized sounds, to slowly morph from the beating of the pemade to the vibrato of the voice, and vice versa.

Structure of the piece

The piece is structured in five parts, each starting with transposed pairs of pemade and kantilan, morphing into the voice. The succession of the parts is shaped like a palindrome, based on an approximation of a 5-notes *slendro* scale (that is, a pentatonic scale).

Figure 3.12 - The five sections of Ombak

3.3.2 *Sieb*, for oud and 4-channel electronics

Sieb is the most formalized piece of all the studies presented here, in regard to electronics. The instrumental part, on the other hand, is entirely improvised. The electronics part is based on the classic Sierpiński Sieve, which is used to generate the microstructure, the sound material, as well as the macrostructure, the whole form of the piece.

The Sierpiński Sieve (or Sierpiński triangle) is a self-similar set, named after the mathematician Wacław Sierpiński, who described it in 1915 (Sierpiński 1975). Constructing the triangle is trivial, by following a finite subdivision rule (one of the many ways to generate it): first, finding the midpoints of the three segments of an initial triangle, second, connecting them to subdivide the structure into smaller triangles. Then repeat the operations in each of the new generated triangles. This algorithm was implemented in Kyma, in Smalltalk (figure 3.13 shows the triangle after n=5 iterations).

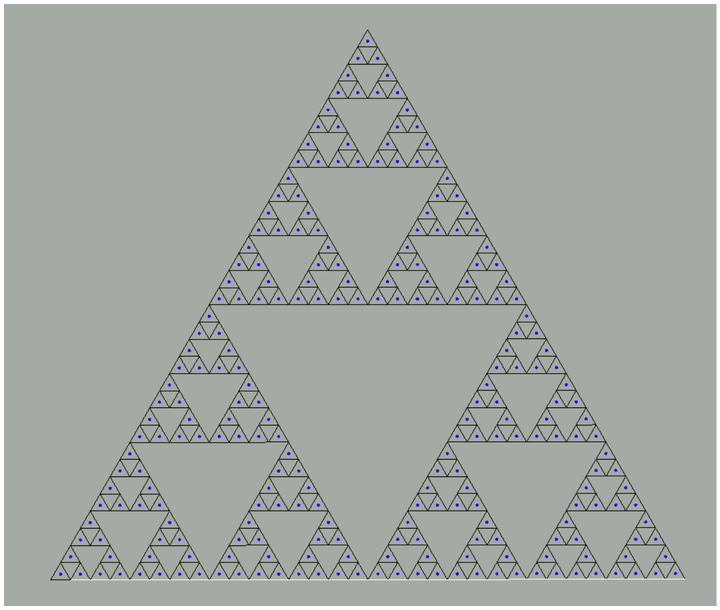

Figure 3.13 - Sierpiński triangle after 5 iterations

The Sierpiński triangle was used in two different ways to generate the electronics part of the piece. First, we calculate the Cartesian coordinates of the barycenter of each triangle (blue dots on figure 3.13), and consider them as a set (time, frequency), with the barycenter of the bottom left triangle having the initial set of values (0, initial frequency). For instance, with 5 iterations, we obtain thus $3^5 = 243$ pairs of (time, frequency) values. Frequency and time scaling values determine the frequency range and duration of the generated sound. Each set is sent to a sine wave oscillator, that will generate the specified frequency at the specified time.

The main structure of *Sieb* is built using 5 iterations, by scanning slowly through the triangle, from left to right, for a total duration of 300 seconds, and with an initial pitch G1. Additional musical elements are generated using rotated and modified (enlarged or flattened) triangles (figure 3.14), and/or with different initial coordinates of the largest triangle, with up to 9 iterations. In addition, the frequency values are constrained: they are folded if they go over or under specified thresholds (similar to GENDY's mirrors). Time values are folded back as well, if they are negative (which can happen when the triangle is rotated). With a large number of iterations, complex evolving spectra can be generated, with formant-like qualities.

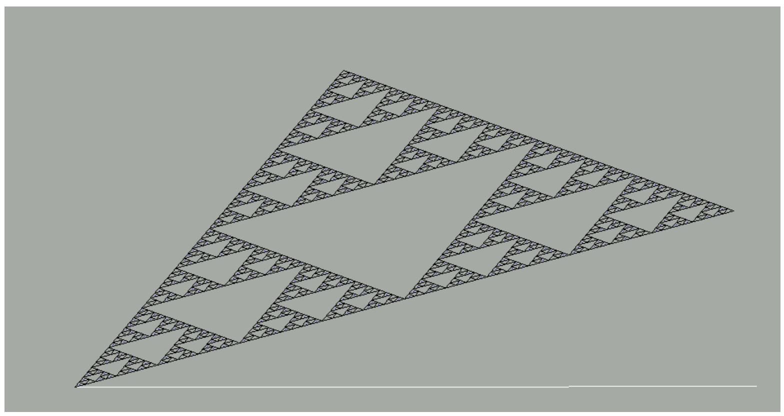

Figure 3.14 - Rotated and flattened triangle, 6 iterations.

Second method based on the Sierpiński triangle: we scan through the triangle and collect in an array a set of frequencies from a specific time (in that case, obviously, the triangle is not rotated). Three frequencies (f_1, f_2, f_3) are randomly chosen from that array, each time the sound is triggered. A resonating filter (similar to the filter described in section 3.3.1) at the frequency f_1 goes through a series of two ring modulators with frequencies f_2 and f_3, to generate bell-like sounds.

The whole electronics was used as basis for improvisation on the oud by Zolfaqar Shaarani. The improvisation was recorded in a single take.

3.3.3 *Tub Grains*, for 8 or 4-channel electronics

Tub Grains is a piece based on improvisation with granular synthesis, and is a concrete example of a live exploration of a multi-dimensional timbral space, and of the notion of *form-bearing material*, presented in section (1.2.2). To describe it is more akin to describe an instrument than a piece per se, an instrument conceived as a simple open system with a pre-determined set of relevant possible interactions. It revolves around the notion that musical ideas emerge from the interactions with the instrument and the sound material.

<u>Preparation and recording of the sound material</u>

2 cooking pots, 1 pan, and a shortwave radio receiver (in a waterproof plastic bag) are immersed in a bathtub, and, while being manipulated, are recorded by means of a hydrophone. Metallic cookware and shortwave radio transmissions provide a wide range of rich spectra, discontinuous sound morphologies, salient sound events, symbols and references. The strong resonances of the bathtub provide a form of sonic coherence, by imparting a specific color to the recordings. 10 samples with approximatively similar durations (around 5 to 7 seconds) are selected out of the recordings.

Techniques and interactions based on the underwater sounds

Granular synthesis was used to resynthesize the 10 selected timbres: it allows to reveal the sonic identities (from shocks between the cooking pots, from snatches of shortwave transmissions), or to dilute, dissolve, them in a global texture, a cloud of grains, depending on the density of granulation (average number of grains at any given point in time), on the duration of each grain, and on the amount of "stochastic" processes at play: random frequency deviations around a specified frequency, random deviations from a specified position in the sample, random spatial positions, and random grain durations. One-dimensional interpolation between the 10 timbres is implemented pre-granulation, by means of equal power crossfades (that is, to smoothly morph from sound 1, to 2, to 3 etc.).

Five instances of that process (interpolation + granulation) are running simultaneously, and are controlled by five fingers, for instance on a tablet: on the X axis, the finger controls the position within the sample, that is, scrubbing across the sample, and on the Y axis, the position of the interpolation between the 10 timbres, thus allowing an intuitive two-dimensional exploration of the entire timbral space of the recorded samples. Additional possible actions are mapped to granulation parameters (three parameters are considered: density, grain duration, and global amount of randomization), and spatialization parameters: rotations in the surround space, and quantity of signal sent to the reverberation.

3.3.4 *Image Temps / Image Mouvement*, for 4-channel electronics

Image Temps / Image Mouvement is piece composed of two parts. Similar to the previous piece, *Tub Grains*, the first part of *Image Temps / Image Mouvement* is emphasizing gestures and improvisation on simple electronic sound generation processes. The control processes are directly inspired from Subotnick's *control tracks* in order to sculpt sound morphologies, by recording and playing back gestures using a bank of "motion recorders".

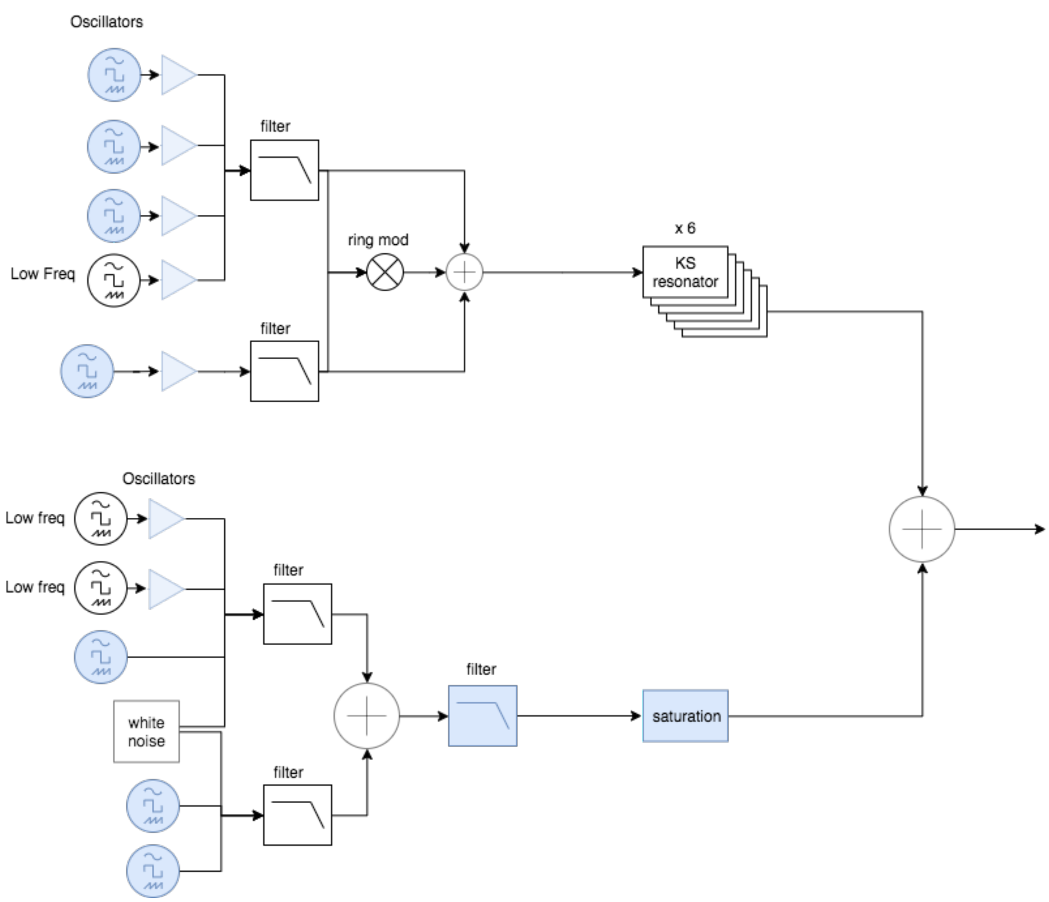

Figure 3.15 - Signal flow of the 1st part. In blue, processes controlled by gestures/gesture recorders.

The patch from figure 3.15 was implemented in Kyma. Gestures are saved in audio buffers. The "KS resonator" is composed of six tuned parallel instances of a Karplus-Strong algorithm. The other sound processes are simple sine, square, saw oscillators, filtering, ring modulation and saturation, similar to the sound processes found in a traditional modular synthesizer.

Throughout the performance, the performer records sequentially or simultaneously a series of gestures, which are played back looped, all of them with different durations. This leads to the creation of a parallel heterarchical structure (Roads 2015), that is, a polyrhythm of continuous sound transformations, that cannot anymore be divided into discrete elements, with constantly shifting relationships between the sound events. The low-frequency oscillators are not used for control, but are mixed together with the audio signals, to slowly introduce variable amounts of asymmetrical saturation (by adding a variable amount of DC offset to the signals, and sending afterwards the sum of all signals to a saturator).

The second part of *Image Temps / Image Mouvement* follows a different direction, and adopts an aesthetic close to *electronica*. The elements of the first part are mixed and time-stretched over five minutes by means of a phase vocoder, while polyrhythms are progressively layered one over another. The phase vocoder aside, the second part of *Image Temps / Image Mouvement* was realized on an ARP 2600 clone and a Serge modular synthesizers.

3.3.5 *Scattered* and *The Aleph*

Scattered and *The Aleph* are two pieces closer to electronic dance music, *electronica* and *glitch music*, and thus, adopt some of their aesthetic canons: a more rigid form, as defined by their particular style, and the presence of a pulse.

Techniques and sound material

Scattered and *The Aleph* were realized on Kyma and on ARP2600 and Serge modular synthesizers. The digital parts make use, in part, of virtual analog techniques, that is computational methods that mimic the sound production principles used in analog synthesizers (such as Moog, Arp etc.) (Välimäki and Huovilainen, 2006).

We decided to model the various filter modes of the Oberheim Xpander synthesizer, and to extend it by implementing other filter modes and morphing possibilities (and not just recreating digitally an analog filter, which would be rather pointless. In that case, why not using the analog filter directly) (Regnier 2019). The Xpander filter is a Curtis CEM3372, a standard 4-pole lowpass filter, made of four first order lowpass filters, and followed by a mixing stage. By linear combination of the outputs of each 1-pole lowpass, different filter responses can be obtained (figures 3.16 and 3.17).

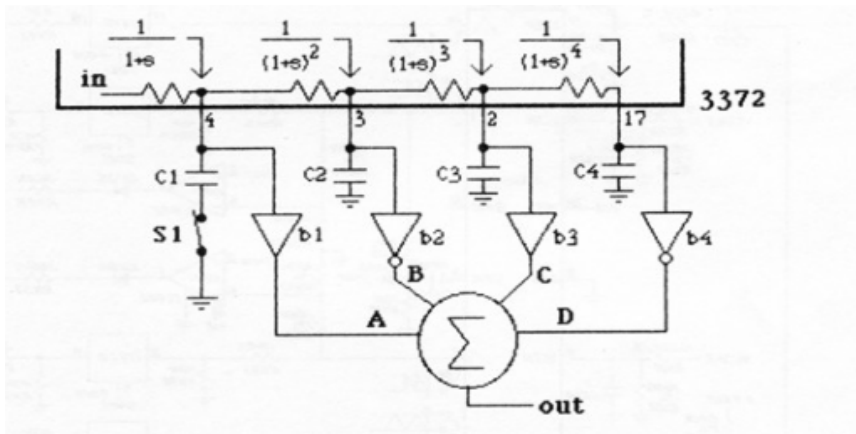

Figure 3.16 - Simplified circuitry of the Oberheim Xpander filter (Oberheim 1984)

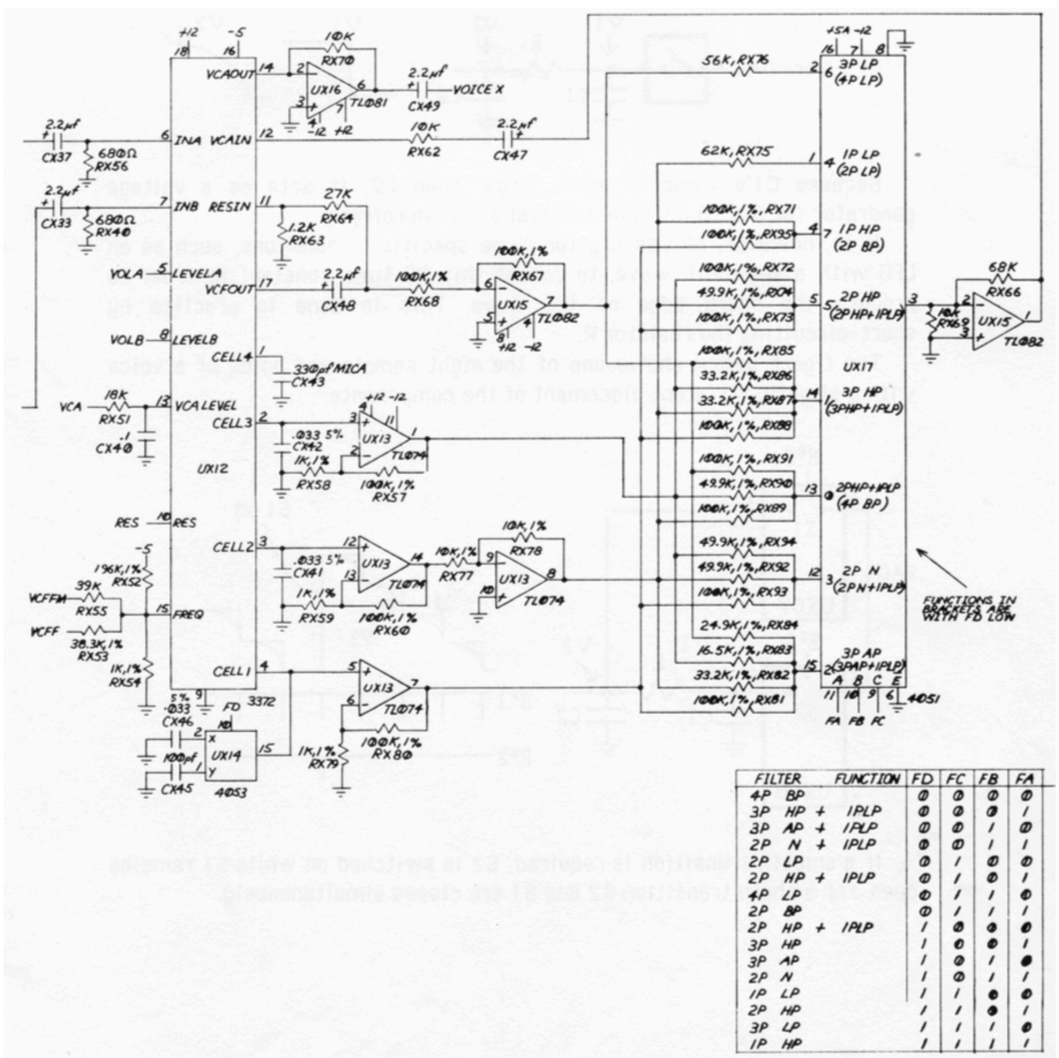

Figure 3.17 - Xpander filter - CEM3372 and resistor array (Oberheim 1984)

First, similarly to the filter in section (3.3.1), we follow an identical method to model a single "zero-delay feedback" 1-pole lowpass, by using trapezoidal integration, and afterwards by solving the zero-delay feedback equation. We consider then a series of one-pole lowpass filters, with a negative feedback loop between the output of the last stage and input of the first (figure 3.18). We avoid adding a unit delay in the feedback path by solving the "delay-less" feedback equation at u, signal at the feedback point, and we generalize for i stages (we only used 4 stages in our implementation, but nothing prevents to chain as many stages as needed):

$u = \frac{x - R\sum_{k=0}^{i-1} G^k S_{i-k}}{1+RG^i}$, with i number of stages,

$G = \frac{g}{1+g}$, given that $g = \frac{\omega_c}{2.f_s}$ (cf. section 3.3.1),

and $S_k = \frac{s_k}{1+g}$, with s_k state of the integrator of index k.

Knowing u and by processing the stages one after the other, we can now compute the output and state of each stage.

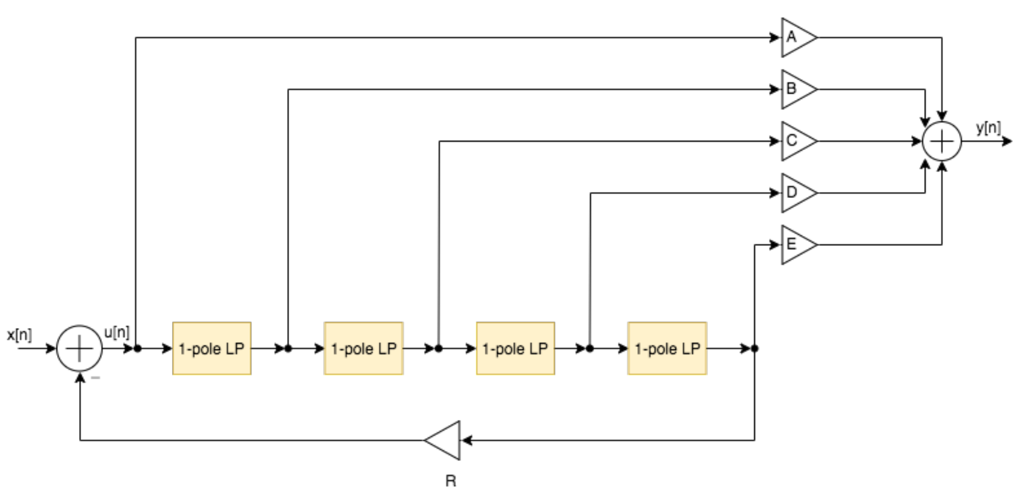

Figure 3.18 - 4-pole structure, with negative feedback and individual stage outputs.

To obtain different filter modes, we need to calculate the gain coefficients A, B, C, D, and E (it is possible, too, to guess some of the output gains by looking at the voltage dividers from the resistor array in figure 3.17). We follow the approach shown in the Oberheim Service Manual (Oberheim 1984, figure 3.16) and in (Zavalishin, 2018). The transfer function of a 1-pole lowpass is given by:

$$H(s) = \frac{1}{1+s}$$

For the stage of index k, if R=0, the transfer function is:

$$H_k(s) = \frac{1}{(1+s)^k}$$

Thus, the transfer function of the whole network, with 4 stages, is given by:

$$H(s) = \frac{A(1+s)^4 + B(1+s)^3 + C(1+s)^2 + D(1+s) + E}{(1+s)^4}$$

Thus, for a given transfer function, we are now able to calculate the gain coefficients A, B, C, D and E.

<u>Examples</u>: for the 4 possible lowpass filters (1-pole, 2-pole, 3-pole, 4-pole), this is trivial, we just tap at the output of any given stage. For instance, C=1 and A=B=D=E=0 give the transfer function of a 2-pole lowpass. For a n-pole highpass (HP) filter, the transfer function is given by:

$$H(s) = \frac{s^n}{(1+s)^n}$$

Which gives (A, B, C, D, E) = (1, -1, 0, 0, 0) for a 1-pole HP, (1, -2, 1, 0, 0) for a 2-pole HP, (1, -3, 3, 1, 0) for a 3-pole HP, and so on (another way to see it is to consider the rows of the Pascal's triangle, with negative sign for the even-numbered column positions). 18 filter modes and their corresponding gain coefficients are shown in the following table.

Table 3.3 - Gain coefficients for 18 modes of an extended digital model of the Xpander filter

Type	A	B	C	D	E
1-pole LP	0	1	0	0	0
2-pole LP	0	0	1	0	0
3-pole LP	0	0	0	1	0
4-pole LP	0	0	0	0	1
1-pole HP	1	-1	0	0	0
2-pole HP	1	-2	1	0	0
3-pole HP	1	-3	3	-1	0
4-pole HP	1	-4	6	-4	1
2-pole BP	0	1	0	-1	0
4-pole BP	0	0	4	-8	4
2-pole LP + Notch	0	0	1	-2	2
2-pole BP + Notch	0	1	-3	4	-2
2-pole HP +Notch	1	-4	7	-6	2
2-pole HP + 1-pole LP	0	1	-2	1	0
1-pole HP + 2-pole LP	0	0	1	-1	0
Notch 1	1	-4	6	-4	0
Notch 2	1	-4	8	-8	4
3-pole Allpass	1	-3	6	-4	1

Two-dimensional morphing is done by linear interpolation between the rows of an 18 x 5 matrix, containing the coefficients for the 18 filter modes, and thus allowing to morph between four different filter characteristics at a time, by means of a gesture for instance. This filter was used on a significant part of the sound material of these two pieces, either as part of purely computer-generated sound, or as additional processing of the modular synthesizers.

Most of the other sound processes in both pieces were designed to magnify the mediatization of the sound material: saturation, reduction of bit depth and sample rate, noise, feedbacks and glitches.

Structuring processes

As mentioned at the beginning of this section, the form in popular electronic music is often rigid and heavily codified, because of its historically more utilitarian nature[4]: rigorous pulse, even subdivisions, strong emphasis on repetitions and tension/resolution. We don't consider this aesthetic codification necessarily negative or positive: it is simply a framework or a canvas that may offer freedom in other areas.

Both *Scattered* and *The Aleph* consist in a single pattern. Variations and structuring are done through a combination of algorithmic processes and live interactions: modulations, simple stochastic processes (randomization of pitches, of events triggering, of spatial positions), and dub mixing techniques (live manipulation on the mixing desk, mute, sends, echoes, reverberation, feedback loops etc.).

[4] *Electronica* and *glitch music* are generally not considered as music made to be danced to. They are however historically firmly related to the techno music scene, in terms of audience, modes of diffusion (festivals, clubs, media) and modes of production.

3.4 Spatialization

We deliberately describe the spatialization of the six pieces together in the same section. Despite their stylistic differences, their instantiation in the same physical space, and reliance on the same spatial algorithms, ensure, we hope, a formal coherence of the whole performance.

Scattered and *The Aleph* are stereo pieces, and the others are spatialized over 4 or 8 channels. The performance is stage centered: the attention of the audience is directed towards the screen and the dancer, and hence it is asymmetrical. Similarly, we keep a rather frontal sound spatialization: the majority of the sound events are being projected from the front. The surround elements are mostly related to "envelopment" and proximity/distance effects, mostly by means of reverberations (or absence thereof), and clouds of sound particles (in *Sieb* in particular). Only *Tub Grains* displays discrete sounds sources moving around the audience (rotations). This is an aesthetic choice, more than a technical imperative[5]: first, we wanted to keep the spatialization simple and centered, to keep the attention of the audience directed towards the dancer and the visuals. Second, we consider that immersion is above all related to the feelings of proximity, distance and envelopment, and can be easily broken, in a stage-centered situation, when sound events appear behind the audience, or move around the audience.

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[5] Even if technical imperatives of course exist: in particular, the issue of sweet post and audience positioning, and the perception of distance, difficult to simulate because of the superimposition of a virtual acoustic space over a physical space, the listening space (itself reverberant).

Sound sources positioning and moving sound sources

Sound source positioning is based on 2-dimensional Vector Based Amplitude Panning (VBAP, Pulkki 1997), an extension of equal-power panning (using sine and cosine functions) for more than two loudspeakers. Positioning and sound trajectories are edited using our own object-based spatial scene editor (figure 3.19), originally designed for Wave Field Synthesis (Regnier and Mauer 2014, Regnier 2015), or are just programmed algorithmically (for instance the rotations in *Tub Grains*, done with a simple ramp -phasor- with variable speed).

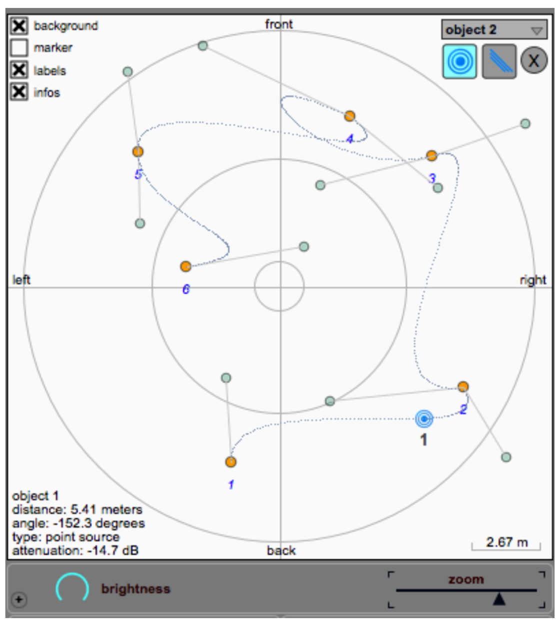

Figure 3.19 - Spatial scene editor - Examples of Bézier splines trajectories (Regnier, 2015)

Reverberations

We designed 2 surround reverberation algorithms for these pieces. The first one is based on an 8-delay Feedback Delay Network (FDN), with 8 uncorrelated outputs (Stautner and Puckette, 1982), with extensions inspired by Tom Erbe's Erbe

Verb (Erbe 2015), namely a lowpass filter before each delay line, added diffusion (a series of 4 allpass filters at the input stage, with short prime delay values and variable gains, and 2 allpass filters, before the delay line 1 and delay line 2), added modulation (independent multiphase sine modulation of all the delay lines and of the 2 allpass filters before the delay lines 1 and 2) (figure 3.20). 8 delay lines with added diffusion and modulation are, in the context of our work, a good compromise between complexity and sound quality. Thanks to the power-preserving operations (lowpass filters aside), infinite reverberations are possible. We used the FDN reverb on most of the pieces, from the simulation of classic "neutral" surround spaces to more uncommon spaces (infinite reverb, heavy modulations etc.).

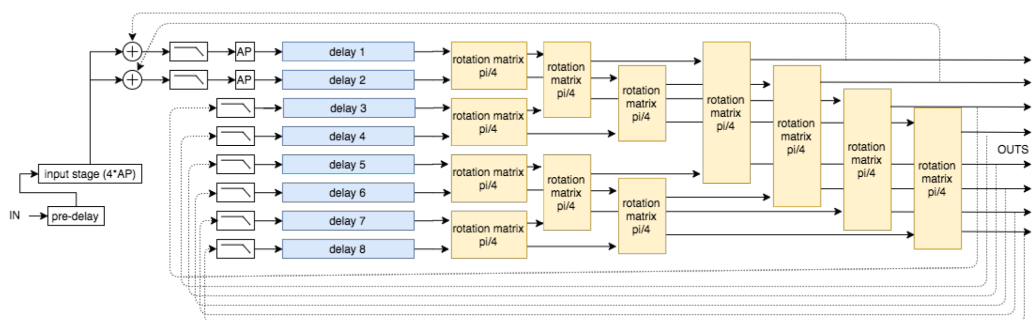

Figure 3.20 - 8-delay FDN Reverberation

The second reverberation used in our pieces is an extension of the Eventide Black Hole, maybe Eventide's most loved reverberation algorithm. It is a rather extreme reverberation, with strong chorusing effect, based exclusively on series of modulated allpass filters. We analyzed the original algorithm on an Eventide DSP7000 effect processor, using their own visual editor *VSig* (Version 2.0; Eventide, 2015). Only the structure and delay times are visible in the editor, the other parameters are kept hidden and could be approximated by listening and comparing. The structure of the algorithm is simple: the signal at the input is summed to mono, it passes through a chain of 16 allpass filters (AP), then is split to two parallel chains of 8 allpass filters (figure 3.21). The output is stereo. Each allpass has its own independent sine modulation, with smoothed randomization of the modulation frequency.

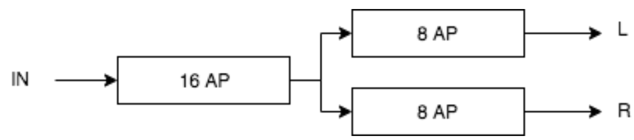

Figure 3.21 - Structure of the Eventide Black Hole

Table 3.4 - Delay values in each chain of allpass filters (in ms)

Input chain	30	30.1	30.3	30.6	31	31.5	32.1	32.8	33.6	34.5	35.5	36.6	37.8	39.1	40.5	42
Chain L	45.3	49	53.1	57.6	62.5	67.8	73.6	79.7	-	-	-	-	-	-	-	-
Chain R	43.6	47.1	51	55.3	60	65.1	70.7	76.6	-	-	-	-	-	-	-	-

Plotting the delay values of all the allpass filters together reveal that they are aligned along a parabola segment (figure 3.22). By fitting the data of table 4 to a quadratic curve using MATLAB, we obtain a reasonable approximation, for i integer, index of the allpass filter in the chain (starting at 0):

$$Delay_{BlackHole}(i) = 0.05i^2 + 0.05i + 30 \text{ , with i integer } \{0,1,2...,31\}$$

After the initial 16-allpass input stage, the delay values are split in the L and R parallel chains: the values of the polynomial are used alternatively, with the odd indexes for the chain L {17, 19,..., 31}, and even indexes for the chain R {16, 18,..., 30}.

In order to design a multichannel reverberation, we extended the algorithm by adding more parallel allpass chains. Starting from the same quadratic polynomial, we use smaller steps to compute additional allpass delay values (0.5 for instance, instead of 1, to obtain a total of 4 8-allpass parallel chains, for a quadraphonic reverb). Other extensions are the possibility to twist the curve by modifying the coefficients of the polynomial (mostly to flatten, expand, or reverse the range of delay values, and thus generate metallic-sounding reverberations, or reverse reverberation effects), and cross-feedbacks for longer and infinite reverberation with high-pass and low-pass filtering in the feedback paths. This reverberation was used in most of the pieces as an effect, to generate unrealistic shimmering spaces, heavily modulated, and/or as an integral part of the sound textures.

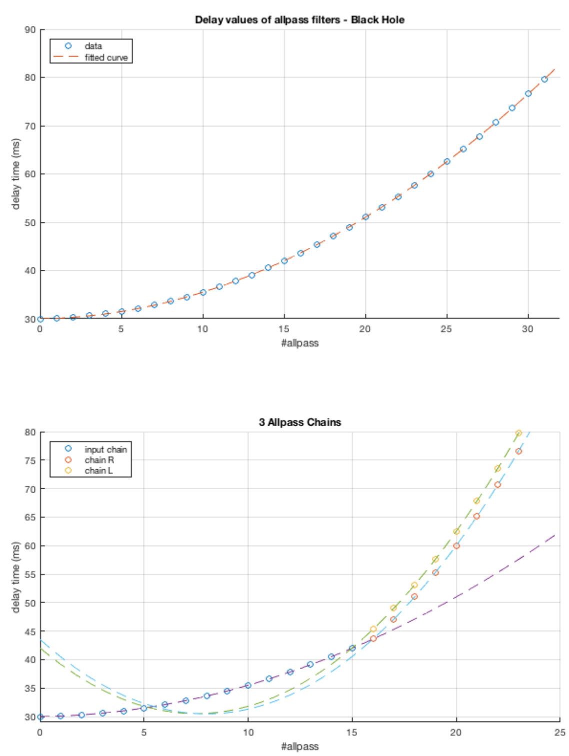

Figure 3.22 - Delay values of the allpass chains and corresponding fitted curves

3.4 Visuals

The visuals are following the chronophotography techniques from Eadweard Muybridge and Étienne-Jules Marey, who both developed tools and techniques to capture motions in several frames on photographic plates: by stopping and decomposing the movement, the invisible became visible. Norman McLaren, in his short dance film *Pas de deux* (1968), adopted such techniques, using high contrast and black background, to create this chronophotographic effect. It is the visual equivalent of an echo or of a feedback, and the techniques are essentially the same: the layering of several copies shifted in time.

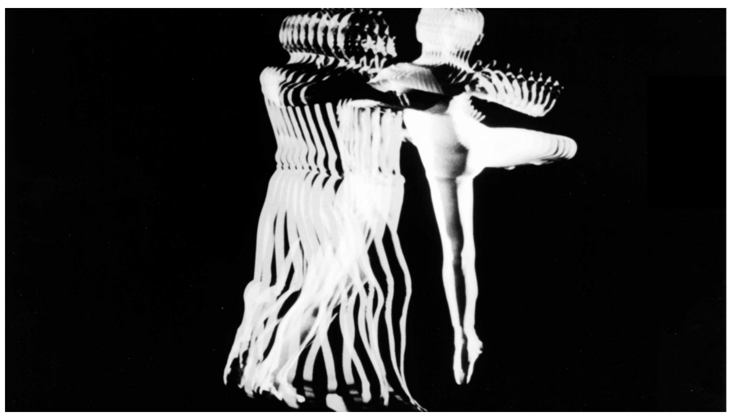

Figure 3.23 - Norman McLaren - Pas de deux (1968)

The techniques we used are simple variations around digital compositing (figures 3.24, 3.25). It allows on the one hand to decompose and reveal the movement, the primary motive of the works of Muybridge and Marey, and on the other hand, to multiply the bodies, to hide and reveal the dancer again and again, to have her dance with herself, and thus, to raise expectation and allow for the emergence of a narrative. The possibilities of digital compositing techniques are numerous, but the technical imperatives, because of the layering of several identical images (from 6 to 32 in our work), are nevertheless similar to those faced by the pioneers Marey et Muybridge. Proper key lighting during the filming, fine adjustments of luminosity, contrast, blend modes and masks during the post-production, are essential to avoid overexposing and burning any bright static element.

Figure 3.24 - Time Unfolded

Figure 3.25 - Time Unfolded

Conclusion

The work undertaken in this dissertation is a study of our approaches on composition and performance of electronic music. We discussed a series of questions and notions, and delineated some conceptual tools and metaphors that we believe are central in our musical thought: in the first chapter, the dualism form/matter, and the questions of structures and organization of the sound material; in the second chapter, the notions of embodiment, attribution of causality, human agency and virtual presence. Lastly, in the third chapter, we presented concrete applications of the concepts we previously addressed, in the form of six studies, within a performance for dancer, video, and live electronics.

Recapitulation

To lay the foundations of the subsequent sections and chapters, the first part of chapter 1 was centered around the dialectic of matter and form, from the perspective of philosophy and aesthetic philosophy, and afterward within the musical discourse. We drew from the Aristotelian theory of substance two fundamental characteristics of the conceptual pair matter/form: first, that matter is relative to an end and a function, and thus, that a form could be considered as the matter of a subsequent form; second, that matter is being given a potential, and, becomes form through actualization. These two characteristics inform deeply Western aesthetic philosophy and art. Similarly, they are the essentials foundations of most of the theories and strategies around form and material organization in Western computer music. We took as example the theory of form from James Tenney. We proposed afterward to distinguish between form and structure, by drawing parallels to the definitions of structure in linguistics and structuralism: we defined form as the organization in time of the sound events, and as the result of a procedure of composition, and structure as an ensemble of relations between the elements of the composition, and thus, potentially, a network of compositional procedures.

The second part of chapter 1 addressed another dualism, intrinsically related to the dialectic form/matter, specifically in regard to the production processes in computer music. We summarized this dualism as the binary opposition signs vs. concepts, a prevalent opposition in computer music aesthetics, and took as an example the tensions and antagonisms between the GRM and IRCAM during the 50's and 60's in France. While acknowledging the pertinence of this opposition, both from the perspective of the aesthetics and the composition methods, we showed that, in practice, the situation is more nuanced, and most computer music pieces exist somewhere on an axis drawn between pure empiricism and pure formalism. The following section discussed three major compositional strategies to organize the sound material in a musical form. We considered first stochastic, chance procedures and fractals for structuring the form, by taking as examples the music of Cage, Xenakis, Dodge and Yadegari, among others. The second approach we discussed consists in considering sound transformations and morphological variations of the sound material as structuring processes. In such cases, the material is a field of potentialities, and the form can be experienced through the exploration of a multi-dimensional timbral space. Lastly, space itself can be considered as a structuring element of a piece, by establishing formal coherence, hierarchical relations between elements, expectation, surprise, and thus, by facilitating the emergence of a narrative.

Following this, we analyzed the works of fours composers: Iannis Xenakis Robin Rimbaud, Morton Subotnick and John Chowning, whose approaches, although disparate, are influential in our own work.

The following chapter was centered around the notions of performance, bodily presence and human agency in computer music. The first part addressed specifically the questions of live performance and liveness. Live electronic performances are indeed mediatized through technology. Due to the electronic and digital innovations applied to the field of music, the causal relationship between a sound and its origin is broken. We examined then the consequences of this assessment, and the nature, factors and criteria of liveness in the context of a computer music performance. We showed that the notion of liveness has actually been dislocated and fragmented.

The second part of chapter 2 focused on the body and human agency, with regard to their statuses in computer music performances. We discussed first the question of the mind/body problem in music, and introduced the notions of embodiment, sonic images, and surrogacy. By referring primarily to the writings of Cox, Godøy and Smalley, we showed that, when the performer or his or her actions are not visible, we understand the sound through a mental representation of a sound-related action, informed by prior experiences of performed actions. Furthermore, these imagined sound-related actions are not necessarily bodily gestures, but can be archetypical physical phenomena.

This led us to establish a network of relationships between timbre, attribution of causality, inference of intention, and emergence of a virtual presence, named virtual persona by Sanden, or living presence by Emmerson. These relationships are at the source of fruitful and creative ambiguities in computer music, allowing to play with the shifting identities of the sound material (as in Jonathan Harvey's music), with an ever-changing man-machine persona (as in Squarepusher's music), or to magnify the presence of the machine (in some popular electronic music genres, and in glitch music in particular). The last part of chapter 2 examined the question of interactions, by referring to the writings of Rowe and Garnett, the works of Mathews, and three pieces of Risset.

We advanced in chapter 3 our answers to the questions and concepts addressed in the previous two chapters, in the form of six electronic music studies within a performance for dance, video and live electronics. The first piece, *Ombak*, revolves around the idea of shifting identities, and is based on morphing procedures between voice and gamelan, resynthesized by means of modal synthesis. The piece structure is palindromic, and is based on a *slendro* scale, the traditional Indonesian pentatonic scale. *Sieb* is a piece with a strongly formalized electronic part, based on the Sierpiński Sieve fractal, that served as a basis for an improvisation on the oud. The entire electronics is generated by the Sierpiński Sieve, from the microstructure, the sound material, to the macrostructure, the whole form of the piece. *Tub Grains* and *Image Temps / Image Mouvement* are two short studies emphasizing gestures and improvisation on simple electronic sound generation processes: morphing/interpolation and granular synthesis controlled on a 2D surface in *Tub Grains*, oscillators, resonators and saturations controlled by gesture recorders in *Image Temps / Image Mouvement*. *Scattered* and *The Aleph* are two pieces closer to electronic dance music and electronica aesthetics, and were realized on modular synthesizers, and by means of virtual analog techniques, in particular an extended model of the Oberheim Xpander filter, with morphing capabilities. Both pieces are structured through a combination of algorithmic processes and live interactions.

Lastly, we detailed the spatialization of the six pieces. We opted mostly for a frontal sound projection, with surround and immersive elements related primarily to envelopment and proximity/distance effects. Two reverberation algorithms were designed, one based on an 8-delay feedback delay network with added diffusion and modulation, the other one is an extended surround version of the Eventide Black Hole, an unrealistic, highly modulated, space reverberator. These two reverberations create a cohesive virtual space for the whole performance, and thus, facilitate formal coherence.

Future work

There is a reason for employing the expression "conceptual tools" throughout this dissertation. The description of the pieces in the third chapter consisted mostly in describing instruments and techniques. Very little actually was said about the actual music: it can't, we believe, be described only that way. It is the result of a thought process, that is described and discussed in the first two chapters: we believe these two chapters have actually more to do with our music as such, than the third chapter.

To consider concepts as tools is to reconcile the bricoleur and the engineer. It means using concepts as signs, by which conceiving a work of art becomes possible. This questions of course the nature of the creative process, and on which foundations we base and build our music. These concepts and metaphors have an obvious value and use in our musical practice, and we consider them as necessary and powerful tools, in the same way as the techniques and instruments presented in the third chapter. To formulate these principles was a necessary step in our own musical practice, especially coming from a sound engineering background (the epitome of the bricoleur). The "myth" of the engineer, as claimed by Derrida in *Writing and Difference*, is, we like to think, the compelling force to create.

Regarding the pieces, individually:

-*Ombak*: the goal was to play with the concepts of shifting identities, based on morphing techniques. It is a work of course strongly inspired from Jonathan Harvey's *Mortuos Plango, Vivos Voco*. The piece can be considered as a study, in the purest sense of the word, and was only partially successful. The choice of Gamelan metallophones as a basis for resynthesis and morphing has proved to be very delicate: the extremely sparse partials of the metallophones gave only little latitude to experiment. Most of the morphing processes, and their musical significance, were thus anchored to the most salient aspect of the instrument identities, namely their beating. The morphing, more than a simple shift of partials, was perceived as a transformation from the beating of the Gamelan to the vibrato of the soprano, and the other way around. This transformation became the central compositional element of the piece. Despite these critical considerations, this was one of the favorite pieces of the dancer, hence our choice to keep it for the end part of the performance, and to dedicate a choreography to it, without the additional projection of a video.

-*Sieb*: *Sieb* was an attempt at a very formalized approach to computer music composition. However, several, if not most, aspects that we consider successful in the piece are based on a series of methods that are not formalized: intuitive manipulations and adjustments, choices and selection of sound material fitting our idea of the piece, mixing and processing techniques deployed (reverberation, granulation in some parts of the piece). Although seductive by its rationalism and its unifying aspect, a pure algorithmic approach, such as the one we followed to build the macrostructure of *Sieb*, was satisfying from the moment that improvisational elements (the oud) entered, counterbalancing the rigidity and predictability of the form. The underlying fractal structure is still perceptible (the algorithm used for the macrostructure is rather simple, and easy to perceive), and a sense of dialog emerges between the oud and the autonomously evolving electronics, rendering the piece subtle and expressive.

- *Tub Grains* is, surprisingly, the piece we consider one of the most successful, in terms of outcome, from all the studies we presented. This was also the piece realized in the shortest amount of time (only a couple of days, in comparison with *Ombak*, composed over a couple of months). The combination of simple techniques (interpolation and granular synthesis) and gestures, the very little editing done (the piece is based on a few takes of recorded improvisations), the careful selection of sound material, facilitated an immediate expressiveness and the emergence of a sonic narrative, in particular when associated with the video used for the performance. On the other hand, the piece raised of course far fewer questions and challenges than *Ombak* or *Sieb*, and, consequently, will have probably a more limited influence on our future musical work. In that regard, and as expected, the least successful works will be the strongest driving factors of our musical explorations in the future.

- *Image Temps / Image Mouvement*, *Scattered*, and *The Aleph* belong more to the genres of electronica and popular electronic music. They are primarily based on live manipulations and simple sound synthesis principles (mostly subtractive synthesis), but integrate as well algorithmic processes, which allowed to pragmatically delegate the control of some musical processes to a few systems of constraints and/or randomization. *Scattered*, in particular, achieved our initial goal of suggesting mechanical causes behind purely synthetic sounds, and of creating a virtual persona, sometimes machine, sometimes human, through a careful design of spectral changes. This, as well as the interrelationships between timbre, attribution of causality, and identity give us the conceptual apparatus that will remain a central source of inspiration for future works, whether written, or musical.

A lot can be learned from the performance itself. First, it was created in a very fragmented and sequential way. The music was composed over several months, with an already precise idea of the direction we wanted to take, the concept and aesthetics of the performance. The second step of the work was to define the choreographies, together with the dancer Verónica Santiago Moniello, during a couple of days in Berlin in September 2019. We afterwards filmed a series of choreographies, one per music piece. The video editing was done in November 2019 in San Diego. The final decisions regarding the performance were taken together with the dancer early December in San Diego: in particular, we decided the final order of the pieces, and agreed on a few changes on choreographies, to not simply replicate what would happen on the video, and to adopt instead a form of counterpoint. We both considered it necessary, in order to build an intricate narrative. The core concept stood the same all along, aiming with the dancer for the same aesthetics, which allowed to keep a formal coherence despite the very fragmented work process and short collaboration time (we worked, all in all, 7 days together. Most of the collaboration happened via email, file exchanges and online discussions).

Moreover, we share, with Veronica Santiago Moniello, and with dancers more generally, a very similar vocabulary, and, most importantly, a complementary appreciation of the inter-relations between movements, gestures, sounds, and narration. This has proved fruitful of course for this collaboration, but has also proved very useful to delineate several concepts presented in the second chapter of this work, and to solidify a conceptual apparatus centered on bodily gestures and timbral changes. Concepts such as intercorporeality, morphing, and machine presence vs. bodily presence have crystallized in a spontaneous way during the work on that performance.

A few remarks form the audience seem to confirm that these notions were also perceived during the performance. In particular, someone in the audience pointed out that "humanity" was emanating from the performance, and from the videos in particular, despite the extremely visible and audible technological means employed. Magnifying human presence by means of electronic processes was pivotal in our work, and from that point of view, we both consider the performance a success, and will certainly pursue that collaboration in the future.

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