Algorithm and Decision in Musical Composition

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Attached CD-ROM Contents

So as to permit full inspection of algorithmic programming by the reader, a CD-ROM containing the files that correspond to algorithm illustrations throughout the text is attached to the back cover of this document.

The file named GATO WORKSPACE is a *workspace* file, which can be opened after installing the OpenMusic application (currently at version 6.10) freely available from the IRCAM website:

http://forumnet.ircam.fr/shop/en/forumnet/43-openmusic.html

The Esquisse library must be enabled for certain patches to run properly. This is configured in OpenMusic preferences and should be done at startup.

The files are named and numbered as the figures that contain algorithms the reader wants to inspect further.

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Author's Declaration

I, Gonçalo Alves Gato Lopes, the author, do hereby grant powers of discretion to the Librarian of the Guildhall School of Music & Drama to allow the thesis to be copied in whole or in part without further reference to the author. *[Note: This permission covers only single copies made for study purposes, subject to normal conditions of acknowledgement.]*

Parts Published or Submitted for Publication

1. The vectorial harmony technique, first used on this research to compose the piece *Shapes*, was the subject of a publication written during this doctorate (Gato 2013).
2. Material relating to the piece *The Life is Ours* was submitted and accepted for publication as a chapter in the upcoming *The OM Composer's Book 3* published by IRCAM/Centre Pompidou (Gato in press).

Abstract

Algorithm and Decision in Musical Composition

Gonçalo Alves Gato Lopes

Through a series of creative projects this doctorate set out to research how computer-assisted composition (CAC) of music affects decision-making in my compositional practice. By reporting on the creative research journey, this doctorate is a contribution towards a better understanding of the implications of CAC by offering new insights into the composing process. It is also a contribution to the composition discipline as new techniques were devised, together with new applications of existing techniques.

Using OpenMusic as the sole programming environment, the manual/machine interface was explored through different balances between manual and algorithmic composition and through aesthetic reflection guiding the composing process. This helped clarify the purpose, adequacy and nature of each method as decisions were constantly being taken towards completing the artistic projects.

The most suitable use of algorithms was as an environment for developing, testing, refining and assessing compositional techniques and the music materials they generate: a kind of musical laboratory. As far as a technique can be described by a set of rules, algorithms can help formulate and refine it. Also capable of incorporating indeterminism, they can act as powerful devices in discovering unforeseen musical implications and results.

Algorithms alone were found to be insufficient to simulate human creative thought because aspects such as (but not limited to) imagination, judgement and personal bias could only, and hypothetically, be properly simulated by the most sophisticated forms of artificial intelligence. Furthermore, important aspects of composition such as instrumentation, articulation and orchestration were not subjected to algorithmic treatment because, not being sufficiently integrated in OpenMusic currently, they would involve a great deal of knowledge to be specified and adapted to computer language.[1] These shortcomings of algorithms, therefore,

[1] The most developed current algorithmic software for orchestration is *Orchids* (Esling et al. 2014), developed at IRCAM during the same period as this research. "It provides a set of algorithms and

implied varying degrees of manual interventions to be carried out on raw materials coming out of their evaluations. A combination of manual and algorithmic composition was frequently employed so as to properly handle musical aspects such as cadence, discourse, monotony, mechanicalness, surprise, and layering, among others. The following commentary illustrates this varying dialogue between automation and intervention, placing it in the wider context of other explorations at automating aspects of musical composition.

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features to reconstruct any time-evolving target sound with a combination of acoustic instruments, given a set of psychoacoustic criteria". It, thus, serves the specific purpose of orchestrating a *target sound* that is fed into it.

I Introduction

I.1 Research Question

The principal research question is:

How does computer-assisted composition of music affect decision-making in my compositional practice?

Subsidiary questions arise and are addressed by this research:

- Why use algorithmic tools to compose music?
- In what ways can I implement algorithmic results into scores?
- How do aesthetic concerns guide algorithm design?
- Do aesthetic concerns dictate whether automated algorithms are used or not?
- What kinds of compositional procedures are most adequately handled by computer algorithms?
- What are the fundamental differences between manual and machine composition?
- What aspects of human thought and creativity can't machines simulate?

I.2 Algorithms and Computer-Assisted Composition

Three important definitions are of utmost relevance to this doctorate:

> **Algorithm** – "a process or set of rules to be followed in calculations or other problem-solving operations, especially by a computer" (Oxford University Press 2013a).
> **Automation** – "the use or introduction of automatic equipment in a manufacturing or other process or facility" (*Ibid.*).
> **Automatism** – "[Art] the avoidance of conscious intention in producing works of art, especially by using mechanical techniques or subconscious associations" (*Ibid.*).

An algorithm can be automated, but it doesn't necessarily have to be. It can be carried out manually (like an algebraic operation such as division). Hence, it follows that algorithms as defined above are familiar to all composers, and they have been used for a long time. As David Cope writes:

> Most composers employ algorithms when composing. That is, most composers apply rules, steps, or sets of instructions when composing music, especially when composing music in a particular style (Cope 2000, p.2).

I would perhaps replace the expression "in a particular style" with 'using well-defined techniques'. Algorithms in composition can, therefore, be considered to be any *systematic*[2] compositional procedure. Consequently, manual composition can, at least conceptually, encompass algorithmic composition. Nevertheless, the term algorithm is usually reserved for computerized processes.

The term automatism, by definition, already implies a certain aesthetic attitude. Ligeti, in his influential article on Boulez's *Structure Ia*, employs the term to denote procedures where:

> Elements and operations . . . are, as it were, fed into a machine, to be woven into structures automatically (Ligeti 1960, p.36).

This 'unconscious' method of composing is, thus, not exclusive of automated composition nor does it always have to be associated with it.

Roads (1996a) gives us a good historical account of important developments related to algorithmic composition. In Figure I.2-1 a timeline is shown, listing the most relevant for this research.

What we could consider to be the first instances of algorithmic thinking in music date back to Aeolian harps: defined arrangements of tubes (the mechanical device) that are blown by the wind to produce melodies and harmonies. One of the first instances of real algorithmic composing though, is, curiously, the *Musikalisches Würfelspiel*, attributed to Mozart. It was a "dice game for assembling minuets out of a set of prewritten measures of music. The sequence of measures was determined by a set of dice throws" (Roads 1996a, p.823).

[2] "Done or acting according to a fixed plan or system; methodical." (Oxford University Press 2013a)

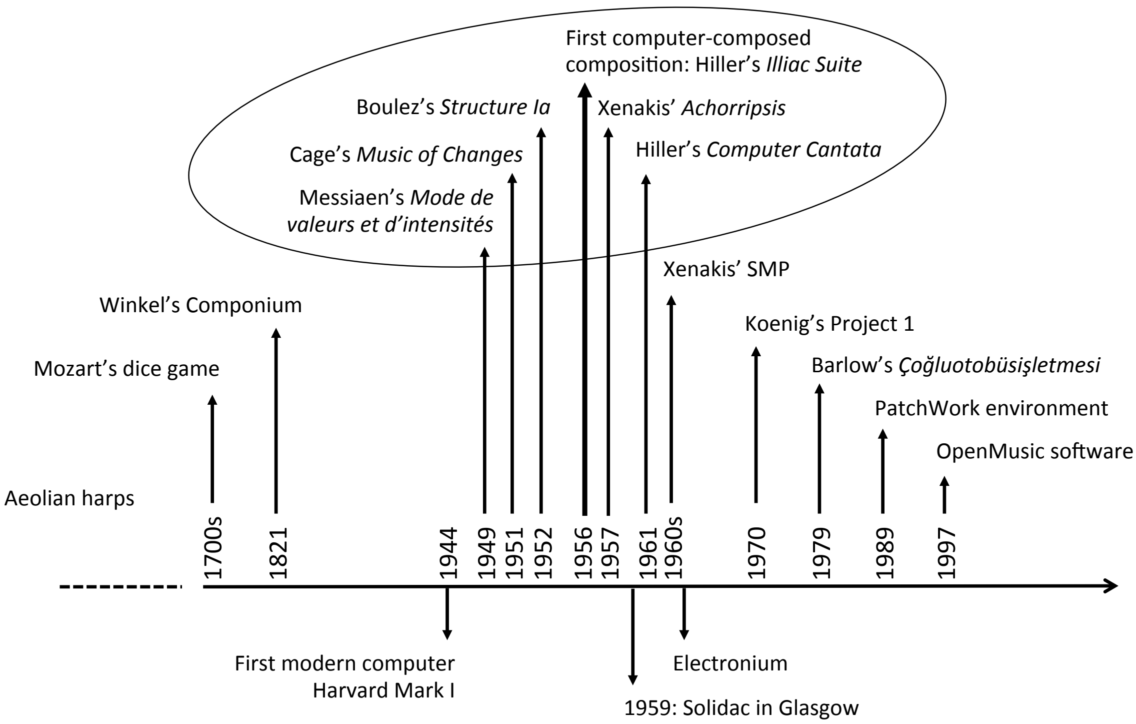

Figure I.2-1 – Timeline showing important historical events of algorithmic composition.

Winkel's Componium, from the nineteenth century, is the first known purpose-built composing machine. It is currently maintained at the Musical Instruments Museum in Brussels, which, on its website, makes reference to a "unique aleatory mechanism, which enables it to produce a stream of endlessly diverse music. […] To achieve this, Winkel used two cylinders which take it in turns to play two measures of music. An ingenious system . . . determines quite unpredictably whether or not the cylinders move, the traditional way to change tune. This creates a sort of musical collage which is almost never repeated" (Musical Instruments Museum of Brussels 2014).

After the invention of the modern computer in the 40s, scientists soon began exploring its potential for the automation of musical composition. The *Illiac Suite* (1956) for string quartet, composed by LeJaren Hiller, was the first computer-assisted composition. Hiller (originally a trained chemist) and his collaborator Isaacson programmed it jointly by using binary machine language, a remarkable achievement. He would later assist John Cage in writing *HPSCHD* (1967-69), a piece which, importantly, uses material from Mozart's dice game, an homage Cage wanted to pay. "It gradually evolved into a large intermedia environment held in the Assembly Hall at Urbana; an enormous theater-piece with fifty-two channel tape-orchestra, seven performing harpsichordists, and equally impressive visual resources and unique audience circumstances" (Husarik 1983, p.1).

The circle in Figure I.2-1 groups the aesthetic trends surrounding the *Illiac Suite*; namely highly formalized, automatic music composition. Accordingly, Hiller's total-serialization method used during the composition of the *Computer Cantata* (1961) "was taken almost in *toto* from György Ligeti's account of the compositional procedures which Pierre Boulez used for his *Structure Ia*" (Hiller and Baker 1964, p.78). If in *Structure Ia* (1952) automatism corresponded to very prescriptive serial procedures controlling pitch, duration, dynamics and articulation (Ligeti 1960), in Cage's *Music of Changes* (1951) it corresponded to (also very prescriptive) chance procedures controlling "sonority, duration and dynamics" (Pritchett 1996, p.79). Importantly, instead of defining individual pitches, durations and dynamics, Cage's charts cells define "sonorities of various complexity", rhythmic cells juxtaposing "several different simple durations", and constant or evolving dynamics.

The idea of algorithm can be closely linked to the idea of *compositional technique*. Xenakis' development of 'Stochastic Music' (his own term) provides a good example of a group of compositional techniques created out of aesthetic reflection, later to be automated in his Stochastic Music Program (SMP, developed in the 1960s). In the important article *The Crisis of Serial Music*, from 1956, he laid out the fundamental reasoning behind the development of these techniques:

> Linear polyphony destroys itself by its very complexity; what one hears is in reality nothing but a mass of notes in various registers.
> […]
> There is consequently a contradiction between the polyphonic linear system and the heard result, which is surface or mass.
> […]
> [This] macroscopic effect can then be controlled by the mean of the movements of elements which we select. The result is the introduction of the notion of probability (Xenakis 1992, p.8).

The adjective 'stochastic' relates to the use of probability theory (statistics) to deal with mass phenomena that can't be predicted precisely (indeterminism). According to Gibson (2011, p.66), *Pithoprakta* (1955-56) was the first piece Xenakis used in his writings as an example of the application of probability theory, therein used to calculate *glissandi* speeds. In *Achorripsis* (1956-57), he extended the application to all parameters: "besides speeds, densities, intervals of durations and pitch, the whole structure of the work is based on laws of probability" (Gibson 2011, p.71).

If a given technique can be strictly described and formalized in terms of the process it involves, then it can be regarded as an algorithm. In 1967, Koenig was claiming that:

> Every rule of composition that can be formulated can also be programmed and carried out by a computer (Koenig 1967).

One should note that, although the use of a formalized technique implies a *set of rules* to be obeyed, that does not imply that *musical results* be always the same (determinism). It depends on the starting musical material and on the degree of flexibility and control (adjustment) the technique admits. A deterministic algorithm[3] can be desired when composers have a precise idea of what they want. This can provide the composer with the musical results to be incorporated directly into the score or with a starting material to be fed into yet some other process, whether manual or automated. Koenig goes on to write about the relevance of computers for composition theory research:

> Naturally, one does not programme known rules of composition but also tries to find out whether events not yet expressed in the form of rules are feasible. The computer thus has a stimulating effect on research in composition theory (Koenig 1967, p.3).

Later in 1970, he created the Project 1 program, which "composes by applying seven selection principles to a database of five musical event parameters: instrument, rhythm, harmony, register, and dynamics" (Roads 1996a, p.839).

Composer-programmers kept playing a key role in the development of algorithmic composition throughout the later quarter of the twentieth century. Clarence Barlow's *Çoğluotobüsişletmesi* (1979), composed using extremely automatic procedures, preceded the creation of his program Autobusk (Barlow 2000) written from 1986 to 2000. He said:

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[3] An algorithm in which every step is uniquely determined (Basu 2013, p.133). A non-deterministic algorithm, by contrast, depends on alternatives at one or more of its steps.

> I remember in the 70s I would definitely have been very strict, but I would have changed the rules if I didn't like the result and gone back to the beginning. *Çogluotobüsisletmesi* is like that, exactly worked out in all its details (Barlow 2009).

The PatchWork environment (Laurson and Duthen 1989) came in the late 80s and is of particular importance since it laid ground for the software OpenMusic (Assayag et al. 1999), the main tool used to carry out the research contained in this doctorate. Composers such as Tristan Murail and Mikhail Malt, among others, developed and shared user libraries for use inside PatchWork, a practice that has continued with OpenMusic.

Within the realm of algorithmic composition, so-called Computer-Aided Composition (CAC) constitutes the main interest of the present research. Anders and Miranda, in their recent article (2009), wrote:

> When doing computer-aided composition, composers apply or even develop certain technical means, but these technical means are not the actual purpose; the main result of their work is the artistic output. Composers decide which compositional parts or aspects of the music the computer generates, and which parts are composed manually (p.134).

The authors discuss some strategies of interfacing 'manual' and 'machine' composition particularly through the use of constraint programming. What composers decide, and how, constitutes a nuclear subject of this doctorate.

Important reflections surround the purpose of automation tools in composition. Some of them have been mentioned above. To sum up, I'll list the ones I find most relevant to my practice. I would consider using algorithms in musical composition mainly because they:

1. speed up formalized processes, can be readily tested, customized and refined on a computer.
2. can be very helpful to achieve precise calculations and prevent errors in application of some compositional procedures.
3. can model and crystalize a given compositional technique. Testing helps understand what a technique can lack in order to be musically useful. The technique can then be reformulated and tested again. This is a way of making progress in composition as a discipline.

4. can be a physical necessity if the composer is basing his material on a large amount of data, or if he/she wants to use sound analysis and processing techniques.
5. can be in some degree non-deterministic, and thus a source of unforeseen musical material that can reveal great potential.
6. can come from other disciplines — such as biological algorithms for growth, for instance — and reveal new creative compositional possibilities. However, this was not researched in the present doctorate.

I.3 Decision in Composition

While composing, composers have to take many decisions so as to direct the progress of a work towards a desired goal. Being able to take appropriate decisions is, thus, an important part of a composer's thought, although this varies from individual to individual. Unlike science, art does not search for general truths, so given decisions taken by a particular artist can be inappropriate for another artist. These choices define an *aesthetic* — "a set of principles underlying and guiding the work of a particular artist or artistic movement" (Oxford University Press 2013a) — and, being crystalized in a work, constitute authorship:

> In aesthetics, art forgeries are banished to the basement because the relationships reproduced were not created — not chosen — by the forger (Meyer 1998, p.17).

With all relevance to this research, in an interview given to Rozalie Hirs in 2007, Tristan Murail said:

> I'm interested in the experience of the listener. [...] I've become increasingly interested in what we could call syntax, in general, and how harmonies, sound objects, or timbres interfere with or contribute to the syntax of a piece. I think that's why creating musical structures merely through algorithms doesn't work for me, because I need objects that have a meaning: expectation, closure, opening, or whatever (Murail 2009, p.11).

For Murail, algorithm-generated materials must be subjected to further compositional procedures imposed by various aesthetic concerns of the composer;

algorithms alone are not musically satisfying because he is mostly interested in ‘the experience of the listener’. That is the reason he *decides* not to create musical structures solely on the basis of algorithms. These kinds of considerations are inherent to computer-assisted composition.

More general considerations about decision-making in composition abound in the literature. In 1994, Birtwistle said:

> [Y]ou can’t control everything, every possible parameter — it’s been tried and we know what the results sound like... (Birtwistle 1994, p.334)

What this interesting (and still very relevant) statement reveals is a concern with the 'negative' effects that can arise from using too much control in composing; not leaving enough space for spontaneity, intuition and other things that can’t quite be systematized. In all probability, Birtwistle was referring to the most serialized forms of music, where every aspect is controlled by some mechanism. Nevertheless, the first pieces of minimalist music were also strongly process-based. On that account, Steve Reich and John Adams also give evidence of this shift from process to intuition. According to Schwarz (1990), by 1974, Reich was emphasizing intuition rather than process:

> In fact, although there is always a system working itself out in my music, there would be no interest in the music if it were merely systematic (p.246).

In this light, composing is taken to be an active process, taken over a time span, and not just a mere realization of an intended program. Ligeti clearly articulates this important tension by saying:

> In my music the musical instinct plays an important role. Nevertheless, this instinct must never be over evaluated, so that this alone guides the compositional result… During the composing, the instinctive and the constructive are complementary modes (Ligeti et al. 1983, pp.33–34).

Aesthetic decisions direct the artistic production of the composer. Therefore, matters such as personal taste/bias, background traditions and use of intuition are major factors defining a composer’s output. This constitutes a second part of the decision-making research: why and how to balance manual composition with algorithmic composition. What can be the role of spontaneity and intuition in computer-assisted composition?

All these reflections and associated issues were to remain constantly on my mind throughout the research. As new artistic situations arose, I'd reflect about the musical goals and composition strategy. This implied aesthetic decisions to be taken regarding the *modus operandi* I'd choose to follow. Then an experimentation period followed where I would assess preliminary results and possibly reformulate the strategy. As I progressed, more and more decisions would accumulate and start to shape the artistic work more and more definitely. I would then try and assess the impact of those decisions in order to either make more changes to the composing process, or take conclusions about what was it that did not go well. Frequently, the next artistic project would in some way address the shortcomings of the previous one.

I.4 OpenMusic Software and Literature

All automated compositional algorithms discussed in this doctorate were programmed using IRCAM's software for computer-assisted composition OpenMusic (Assayag et al. 1999).

This application was built for musicians and provides an object-oriented visual programming environment[4] in which music materials — from very elementary to more complex ones — can be represented and manipulated. It contains a set of predefined objects called *classes* such as NOTE, CHORD and CHORD-SEQ - used for directly inputting musically notated materials and/or to represent them - but also more abstract ones like INTEGER and FLOAT that are used for inputting numbers. Besides these, one can choose from another set of objects called *functions*. These perform operations on the *classes*. By visually connecting classes and functions, the user can define a particular algorithm that will look similar to a flowchart. By evaluating the process, information flows from top to bottom, entering patches, feeding the functions or classes that are daisy-chained to one another but that can also bifurcate.

[4] The term object-oriented means "using a methodology which enables a system to be modelled as a set of objects which can be controlled and manipulated in a modular manner." (Oxford University Press 2013a)

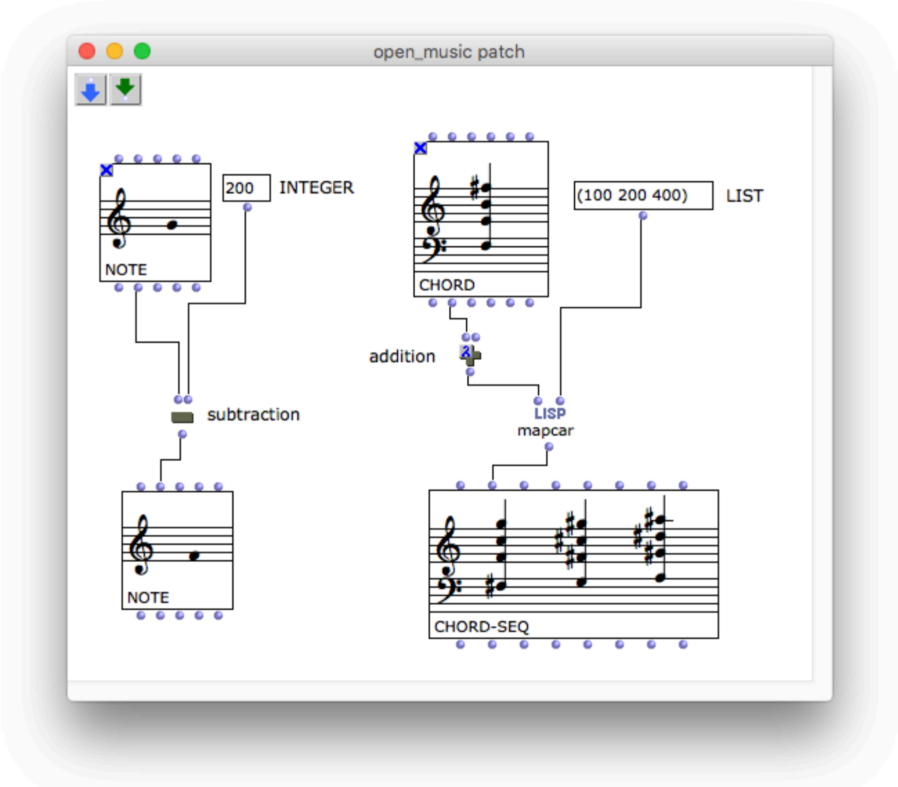

Figure I.4-1 – The OpenMusic patch window. Classes are named as uppercase and functions as lowercase.

Algorithms (or processes) are contained inside windows called *patches* (see Figure I.4-1). These constitute the main working unit of the application and provide *inputs* and *outputs*, so that the user can also interconnect them. When a particular patch is contained inside another, it is called an *internal abstraction*. Abstractions can thus be used to clean up the visual environment because they enclose processes, making them visible only by double-clicking (opening the abstraction in a new window). Also, they can be generalised in order to be usable in the same form inside different patches. In that case they are called *global abstractions*. For further information, the online documentation is available for browsing (see Diatkine 2011).

Three important books have been published so far, devoted exclusively to the use of OpenMusic by composers:

- *The OM Composer's Book 1* (Bresson et al. 2006)
- *The OM Composer's Book 2* (Bresson et al. 2008)
- *Contemporary Compositional Techniques and OpenMusic* (Hirs and Gilmore 2009)

These three books provide a good panoramic view of composers' practice in the field, apart from compiling an invaluable set of compositional techniques and associated aesthetic reflection.

Despite the unquestionable value of each author's contribution to this literature — whether composer or musicologist, describing mainly algorithm's construction principles and musical purposes — relatively small importance is given to describing the alternation between algorithmic and manual composition in producing the finished score, as well as to the score implementations and manual interventions carried out on algorithm-generated materials. Only scarcely can one find instances of this sort of reflection.

In *The OM Composer's Book 1*, the readability of score excerpts is many times, and unfortunately, strongly hindered by insufficient graphic resolution. Score excerpts serve almost always to show that the algorithmic calculations find their way into the final score. But a more complete comparison between the algorithm outputs and their score implementation, together with the aesthetic discussion of the choices involved, is not carried out.

For instance, on page 40, Bloch discusses a score excerpt of an algorithm's implementation, but neither a score of the algorithm output that served as a basis, nor an aesthetic discussion of the choices involved, is provided; only a correspondence between the score excerpt and the 'structure' of the underlying canons. In page 104, Kretz shows a score excerpt featuring many parts, but only the piano part is (not very clearly) corresponded with an algorithm-generated pitch sequence and a rhythmic rationale in the text. We're left with no information regarding the other parts of the score excerpt or how exactly was the piano part derived from the pitch sequence. So I would say that some parts of CAC are not sufficiently addressed and discussed.

In *The OM Composer's Book 2*, Mawhinney, reporting on his use of algorithms, writes that:

> CAC often refined and improved imagined musical ideas, whereas my own sense of taste often led me to re-write by hand the music generated by OpenMusic (p.105).

but he never actually compares an algorithm output with its score implementation. In a subsequent chapter, Cipollone admittedly uses OpenMusic to:

> discover what [he] want[s] to do. [...] When the simulations are effective and credible . . . the computer has fulfilled its maieutical task: strengthened by the acquired experience, I resume composition by hand (p.111).

but this is used just as an introductory text to the algorithmic descriptions, the actual transition from algorithmic to manual methods never being exposed. In yet another chapter, PerMagnus Lindborg writes that:

> the various compositional elements were collected in a *poly* object and transferred to Finale, where minor editing such as chord spelling, as well as substantial and detailed orchestration work were carried out (p.211).

but again, we're left with no actual example and aesthetic discussion of how this happens.

In the previously cited Murail interview featured in the book *Contemporary Compositional Techniques and OpenMusic*, he admits: "creating musical structures merely through algorithms doesn't work for me" (p.11). So I ask: how do algorithmic materials actually end up in the finished work? This is only partly analysed musicologically by Hirs in the chapters *On Tristan Murail's Le Lac* (pp.45-92) and *Frequency-based compositional techniques in the music of Tristan Murail* (pp.93-196). The correspondence between the algorithm outputs and the score implementations is carried out and discussed, but we miss the composer's perspective: his own words describing the various phases of the composing process along with the aesthetic reflection involved.

The present doctorate aims at bridging the various gaps mentioned above by proving detailed discussions referring to all the stages involved in various, and diverse, CAC projects:

1. Algorithm design and aesthetic underpinnings.
2. The algorithm output creation/selection.
3. The steps and choices involved in implementing the output into the score.
4. The coexistence of manual and algorithmic materials in the score.
5. Post-compositional reflection.

In doing this, this doctorate hopes to clarify how, while composing with computers, composers face all the challenges that affect purely manual composition.

I.5 Definitions and Terminology

I.5.1 Terms as Used in this Research

Algorithm – this term, previously defined on page 27, will be reserved for the automation of processes or set of rules. It can be used interchangeably with the term '*automated procedure*'.

Algorithmic tool – the particular mechanical device and software in which algorithms can be programmed and executed.

Compositional technique – any process or set of rules to be followed in order to organize sound, or the elements of sound, so as to create music.

Deterministic algorithm – an algorithm in which every step is uniquely determined (Basu 2013, p.133). This means that the result will be exactly the same each time the same set of initial parameters is fed into the algorithm in question. Algebraic operations — such as sum and multiplication — are good examples.

Non-deterministic (or indeterministic) algorithm – an algorithm in which action corresponding to one or more steps is dependent on a number of alternatives (Basu 2013, p.133). These algorithms frequently — but not necessarily — rely on verification criteria to test the correctness of a given alternative.

Aesthetic decision – a decision taken according to principles underlying artistic creation of a particular composer. These principles involve criteria of judgement that enable the selection or rejection of materials and procedures.

Operational decision – a decision taken purely for technical reasons.

Manual composition – any procedure used to create music without automation. The act of merely notating (and not creating) music by using notation software is not included in this definition.

Manual complementation – manual composition performed so as to coexist with algorithm-generated materials of a different conception, thus completing a given musical texture. It typically creates an additional musical layer with varying degrees of relatedness to the pre-existing algorithmic materials.

Manual elaboration – manual composition performed so as to develop pre-existing algorithm-generated materials. This presupposes a shared conception between the two.

Manual intervention – manual modification/alteration of algorithm-generated materials. This can encompass simple actions such as assigning or changing the instrumentation or dynamics, or more 'destructive' actions such as changing or deleting some of the pitches or durations.

Algorithmic elaboration – an automated procedure designed and performed so as to develop a certain initial material.

Manual implementation – using an algorithm output as reference so that its incorporation in the score is carried out manually. This means that it is up to the composer to write the notes on the score, generally implying manual composition.

Automatic implementation – copying an algorithm output into the score by using automated procedures.

Spontaneity – "performed or occurring as a result of a sudden impulse or inclination and without premeditation or external stimulus" (Oxford University Press 2013a).

I.5.2 Interval Notation

Intervals can be denoted by their amount of semitones. For instance, the major third has 4 semitones, and so it would be notated simply as '4'. Ascending intervals are positive (+), whereas descending ones are negative (-). This numeric notation is particularly useful because it is similar to the way intervals are defined in OpenMusic.[5] Nevertheless, it is not the most informative.[6] For that reason, I also use an abbreviated traditional notation: a major third would be notated as 'M3' (uppercase M), whereas a *minor* third would be notated as 'm3' (lowercase m). The following table gives the complete conversion for one octave.

Table I.5-1 – Interval notation. Top row indicates the number of semitones. Bottom row indicates the qualitative abbreviated notation.

0	1	2	3	4	5	6	7	8	9	10	11	12
U	m2	M2	m3	M3	P4	A4/D5	P5	m6	M6	m7	M7	P8

The prefix 'c' indicates a compound interval and '↑/↓' indicate quarter-tone sharp and flat. Therefore, 'c-M7↑' is a compound major seventh, a quarter-tone sharp. The plural of each interval is notated by appending the letter 's': for example, major ninths would be notated as 'M9s'.

[5] Inside OpenMusic the unit used is the Midicent, which corresponds to the number of semitones multiplied by 100 cents (1 semitone = 100 cents). A minor third is, thus, 3 × 100 = 300 midicents.

[6] Numeric notation treats every interval as a number, whereas an abbreviated traditional notation reveals more information about the sonority: *m* for minor, *P* for perfect, etc.

II Analytical Commentary on Folio Pieces

II.1 Scope, Overview and Methodology

The analytical commentary contained in this chapter reflects the creative, practice-based research carried out during the research period. Although the analyses and discussions deal with nuclear topics — such as aesthetics, compositional techniques, CAC[7] methodologies, algorithm design, pre-composition and personal reflections — complete and exhausting music analyses were not carried out. The research topic and associated questions are indeed what define the scope of the analytical commentary.

The research journey can roughly be depicted as an exploration of different balances between manual and algorithmic composition as shown in Figure II.1-1. This constituted a substantial part of the research methodology.

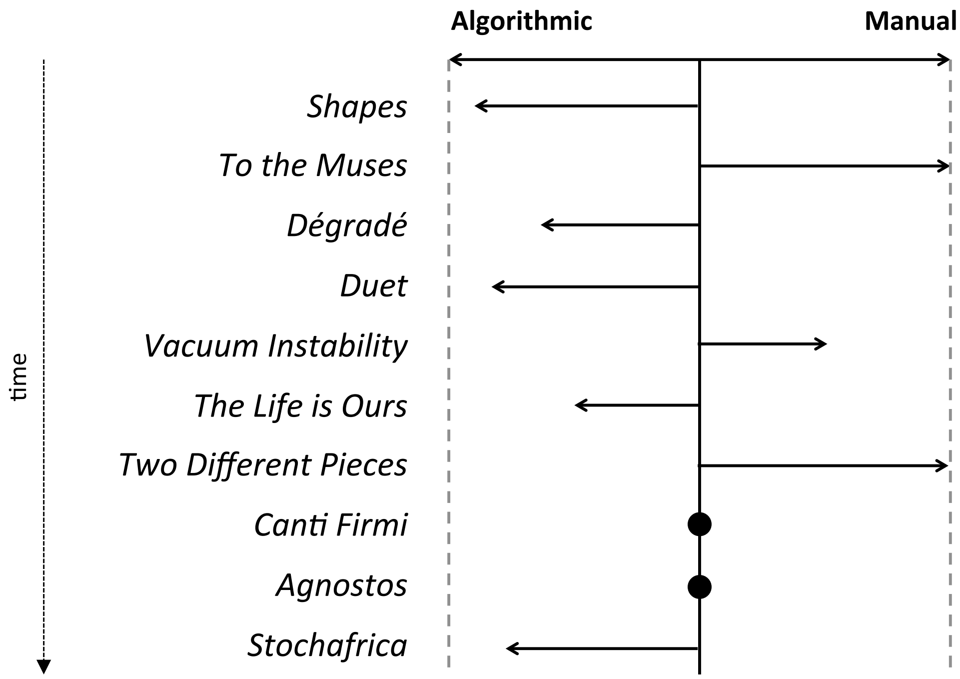

Figure II.1-1 – Timeline of research showing the balance between manual and algorithmic composition.

Composing for different instrumentations was also methodologically relevant as it had an impact on composition strategy. This is summed up in Table II.1-1, along with pieces' durations.

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[7] Computer-assisted composition.

Table II.1-1 – Instrumentation and duration of folio pieces.

Piece	**Instrumentation**	**Duration**
Shapes	String quartet	5’
To the Muses	Soprano and Piano	6’
Dégradé	5-part Ensemble	10’
Duet *	Two Pianos	7’30’’
Vacuum Instability	8-part Ensemble	7’30’’
The Life is Ours	Symphonic Wind Band	8’
Two Different Pieces +	Violin and Piano	7’
Canti Firmi	8-part Ensemble	4’
Agnostos *	Symphony Orchestra	12’
Stochafrica *	Percussion	8’
* not premiered yet; + premiered but not recorded		75 minutes total

The creative research was constantly recorded by means of sketches, analytical notes, analysis drafts, audio notes, research notes, references, computer files of algorithms, preliminary scores and finished scores. These were either exposed or subjected to reflective analysis as I wrote the commentary.

The visual programming of the algorithms is featured in figures throughout the commentaries. So as to prevent enlarging the discussions too much, many algorithm descriptions were placed in Appendix IV.1, page 155. Algorithm outputs were usually placed on separate figures, to enable proper musical notation and readability. Should further inspection be needed, the reader should open the files of the algorithms using the provided CD-ROM (see instructions on page 19).

II.2 Algorithm Design

Algorithms, as stated in the Introduction, can be equated to compositional techniques if one considers only their function: an initial material (either musical or non-musical) is fed into a process, which finally produces musical results. This means that algorithm design always encompasses compositional technique formulation, and in this sense, aesthetic principles. These principles embody *aesthetic decisions*. But automating a compositional technique requires the composer's ability to program a machine so that it performs as intended. This purely technical dimension of algorithm design embodies *operational decisions*.

Completeness of Results

As the following sections will show, many times I did not program the computer to output finished musical results. To get complete and definite music materials — that would simply be copied to the score, needing no further change nor any addition of other materials — was seldom the aim, less and less so as I approached the end of the creative research journey. There were many strong reasons for leaving enough space for manual composition, increasingly so as the purpose, adequacy and nature of each method (algorithmic and manual) became clearer. Thus, the fact that algorithms frequently produced incomplete musical materials (needing further manual procedures) cannot be related to insufficient, incomplete or inadequate programming. At the core of computer-assisted composition (CAC) is the balance between manual and automated methods and, as I explored each of them, I learned to select the aspects I found artistically most useful.

Music Cognition Concerns

An engagement with cognitive principles strongly influenced the compositional decisions taken during the first projects of the portfolio: *Shapes*, *To the Muses*, *Dégradé* and *Duet*. Particularly while composing *Duet*, it strongly influenced algorithm design: I thought that, by keeping in sight the aural and cognitive impacts of the compositional techniques, the results generated would need less subsequent interventions; they would already be interesting sound entities.

Aural and cognitive impacts were aspects I valued very much after critically reflecting about highly formalized music composition: it focused too much on technique formulations but often did not care enough for their aural impact, let alone their musical significance. Arguably, this issue was firstly raised in the late fifties by Ligeti in his article about Boulez's *Structure Ia* (Ligeti 1960). Criticizing Boulez's aesthetic choice of treating musical elements of a different nature in equal fashion — namely pitch-class (a note quality) and note duration (a quantity) — he wrote:

> What is unorganic is this pointless transplantation of a system; note-qualities labelled with numbers, the dematerialised numbers organized into tables, and the tables finally used like a fetish, as a measure for duration-quantities (pp.39-40).

Hence, Ligeti was reacting against certain aspects of automatism where, above all, composers would let a system impose its mechanism, even if that meant sacrificing sound musical judgement. This is further discussed by Jonathan Bernard in his article *Inaudible Structures, Audible Music: Ligeti's Problem, and His Solution*:

> He found problematic 'the organization of all the musical elements' — that is, pitch, duration, timbre, dynamics, mode of attack — 'within a unified plan' because he 'detected within it a discrepancy: quantification applied equally within the various areas produced, from the point of view of our perception and understanding of musical processes, radically different results, so that there was no guarantee that a single basic order would produce analogous structures on the various levels of perception and understanding. [...] Pre-planning had become so important that it was the real compositional act (Bernard 1987, pp.207–8).

In Ligeti's words:

> In working out a notional compositional structure the decisive factor is the extent to which it can make its effect directly on the sensory level of musical perception (Ligeti et al. 1983, p.131).

Algorithmic composition frequently deals with numerical representation of musical elements and OpenMusic is no exception: numbers represent pitches, intervals, time location, durations and dynamics. That is why Ligeti's arguments are so relevant and why I relied so much on music cognition principles to design algorithms, along with their associated compositional techniques and subsequent manual procedures. This strong reliance gradually faded throughout the research period, giving way to more poetic and imaginative means of musical expression.

II.2.1 Determinism and Control

A deterministic algorithm is desirable when a composer wants to control *every* aspect of the technique he/she is programming and is after a single result, univocally calculated. Once programmed and given the same initial conditions, a deterministic algorithm will *always* output the same result. To obtain different results, the composer would have to change the initial materials and/or parameters.

Apart from the technicalities of programming, I always tried to focus on the musical process at hand, together with its musical implications. This continuous aesthetic judgement is of prime importance because the programming tasks and sense of technical achievement can potentially overshadow what is fundamentally, and in effect, compositional research.

II.2.1.1 Vectorial Harmony

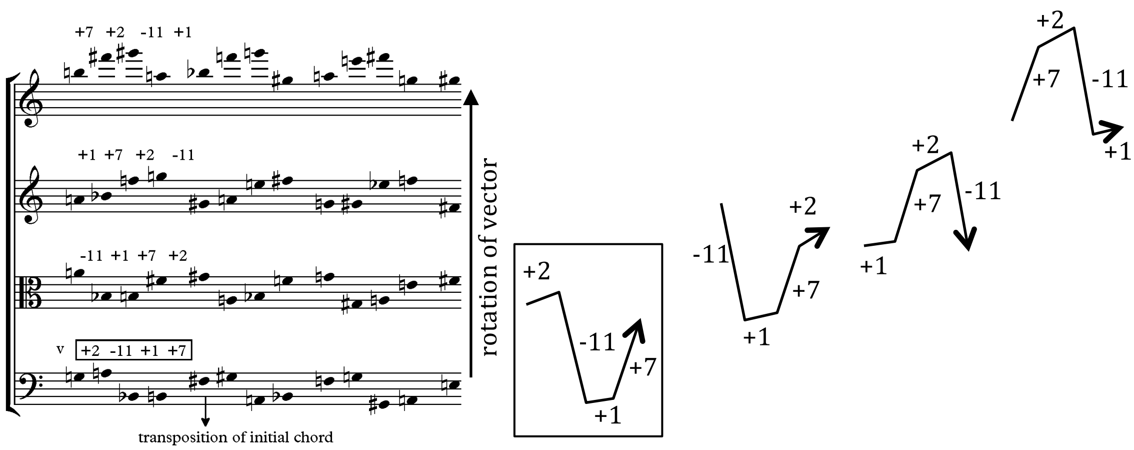

Figure II.2-1 – Rotational vectorial harmony used in the first bars of the piece *Shapes* along with the morphology of the interval vectors.

The automation of vectorial harmony (a personal technique defined in Appendix IV.1, page 155) constitutes a deterministic algorithm and was used in the first piece of the portfolio — *Shapes* — to calculate the progression shown in Figure II.2-1. The interval vector is v = (+2, -11, +1, +7) and it starts with a chord of

M9s (14 semitones). I wanted to get a very pure sound of M9 and this explains why the middle notes are in unison. Instead of one, I used two M9s so as to avoid a purer, but poorer sonority. We apply the vector as many times as we want to the lowest note. After that, we apply the first *rotation* of the vector to the second lowest note; then the second rotation of the vector to the third lowest note, and so forth. What we get is a sequence of four chords that is transposed one semitone down with each reiteration.

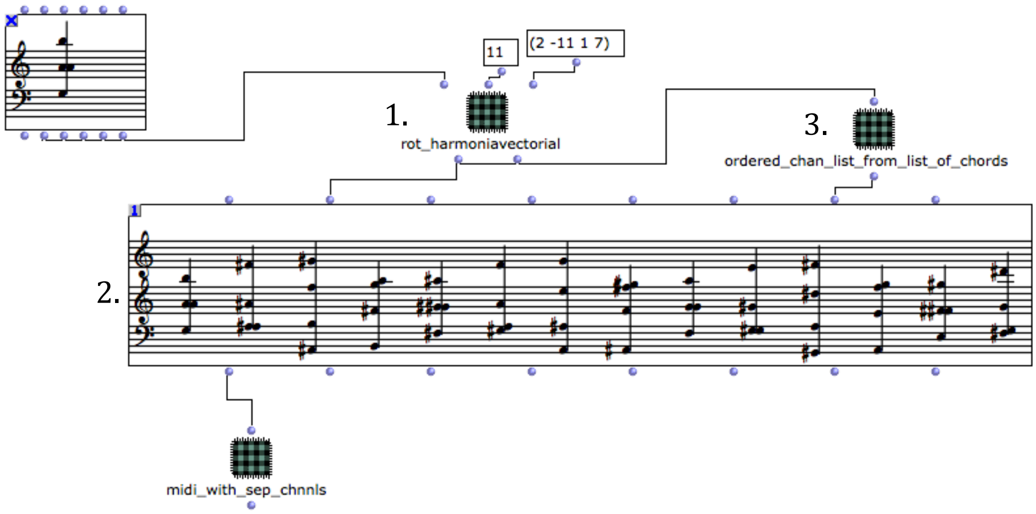

Figure II.2-2 – OpenMusic patch showing the automation of vectorial harmony.

The automation of vectorial harmony inside OpenMusic is shown in Figure II.2-2. The initial chord is fed into an abstraction (labelled 1 on the Figure) configured to produce 11 cycles of application of vector v = (+2, -11, +1, +7). The output is fed into a *CHORD-SEQ* object (labelled 2) configured so that each voice is featured on a different MIDI channel (carried out by the abstraction labelled 3). The bottom abstraction exports a MIDI file, which is then imported into a music notation application.

The intervallic structure for each chord obtained is as follows:

	1st	2nd	3rd	4th		1st	2nd	3rd	4th
in semitones,	14	20	15	2	or	M9	c-m6	c-m3	M2
	0	12	18	13		U	P8	c-D5	m9
	14	1	11	19		M9	m2	m9	c-P5

where the prefix 'c' stands for a compound interval (see Section I.5.2, page 40, for the interval notation used). In terms of the chord progression, this instance of vectorial harmony is internally diversified in terms of intervallic content although, importantly, we can find some prevalence of ninths and seconds. Nevertheless, factors of good consistency are the recurrent strict patterns of voice movement — each voice moves according to a strict intervallic sequence — and the recurring transposed harmonic sequence of four chords. This last factor is very important as it immediately connects this technique with music cognition aspects I value:

1. Auditory memory is stimulated by the fact that the same chordal intervallic structures are reiterated every four chords.
2. Resemblance relations come into play as we compare two transpositions of those intervallic structures (they are similar, but not equal).

Resemblance relations such as similarity, contrast and elaboration are important factors of linguistic discourse coherence, which seem to have a direct relation with music. In his book *Music, Language and the Brain* (2008), Patel asks:

> If there are general cognitive processes underlying the perception of coherence in linguistic discourse, might these same processes apply to the perception of coherence in music? (p.337)

This question is very important for me.[8]

II.2.1.2 Melodic Colouring: Testing and Assessing a Compositional Technique

I have always admired the way Messiaen colours melodies, whether they are from birdsong, plainsong, or of his own composition. Melodic colouring is a widely known and discussed technique constituting one of the main foundations of French modern music. Bartók was probably one of the first 'outsiders' to take this influence from Debussy[9] but, certainly, Stravinsky took it too. The way Messiaen approaches this technique, it seems to me, is frequently more dynamic. The timbres change as the melody progresses:

[8] As a composer, I invest in the research of the music-language analogy because it seems to be linked with music cognition — the way we listen and understand music. It helps create and differentiate different kinds of *musical discourse*. For instance, creating a musical passage by using contrasting materials or by using similar materials creates very different senses of musical flow, and this can be related to linguistic concepts.

[9] See article on Bartók in *Grove Music Online* (Gillies 2013).

> When I reproduce a birdsong, every note is provided with a chord, not a classified chord but a complex of sounds which is designed to give the note its timbre (cited in Anderson 2000, p.11).[10]

I wanted to automate the colouring of melodies according to a given harmonic progression (or timbre evolution). A melody and a chord progression of the same size would be input, plus a function (drawn on a graph) controlling the positions that the melody's pitches would take inside each chord (anything between the lowest and highest pitches).

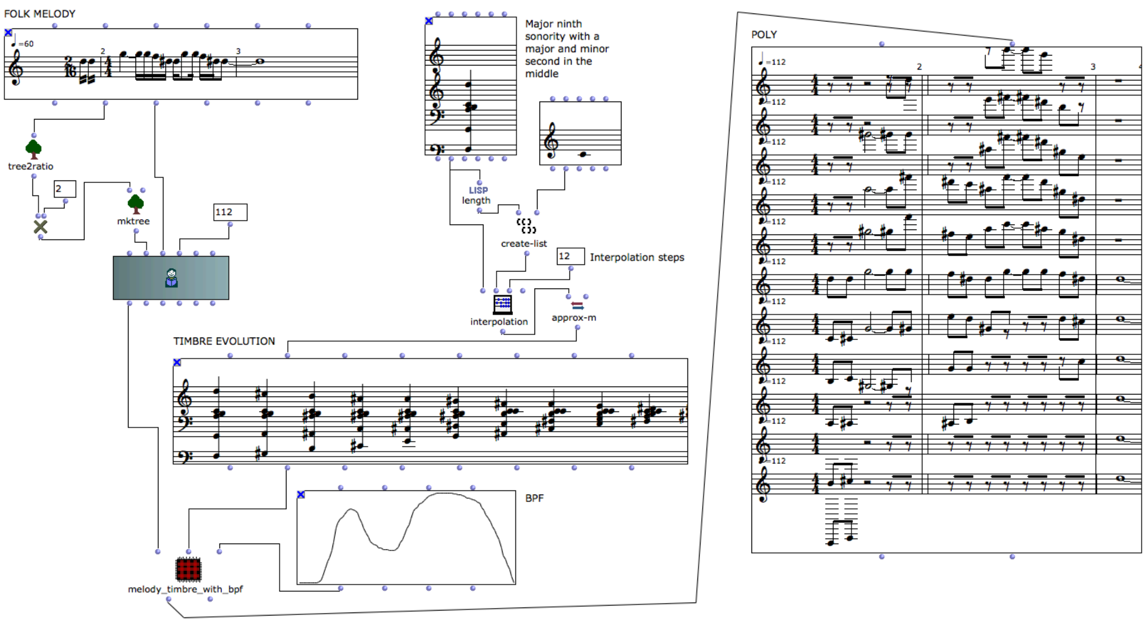

Figure II.2-3 – Algorithm for melodic colouring. The timbre evolution is shown here as an interpolation[11] of a chord to a unison in 12 steps.

Importantly, this algorithm enabled me to test and aurally assess the technique with various melodies, timbral evolutions, and registral evolutions, something that would be very time-consuming to carry out manually, either on a piano, or by writing down each instance on notation software and playing it back.

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[10] A particularly good and simple example is the slow first movement of *Éclairs sur l'Au-Delà*: *Apparition du Christe glorieux* (1988-91). As the pace is slow, one can 'taste' each chord as either timbre or harmony. The fast and staggering third movement *L'oiseau-lyre et la Ville-fiancée* shows, on the other hand, the same technique at work in a more virtuosic manner: in this case I believe we tend to hear mostly the shifting timbre of the melodies.

[11] A numeric process that goes from one number to another through a series of intermediate steps.

In Appendix IV.4.8 (p.172), a description of the algorithm shown in Figure II.2-3 can be found. The output, used to build the music that leads to the main climax of the piece *The Life is Ours* just before rehearsal letter J, is shown in Figure II.2-4. As we can see, sometimes the added pitches are higher than the melody's pitches, sometimes lower. This was controlled by a contour that could be drawn on a graph (*BPF*).

Figure II.2-4 – Melodic colouring used in the main climax of *The Life is Ours* (bars 128-131).

II.2.1.3 Gradual Processes

Algorithmic tools are very suitable to work with gradual processes because they enable the user to quickly change how gradual (slow or fast) those processes are without having to rewrite a whole passage by hand. Importantly, they also allow aural assessment through playback.

Pulse Unfocusing

While composing the piece *Shapes*, I programmed an algorithm to create a gradual shift from a homorhythmic texture of pulses to a polyrhythmic texture of pulses, or the inverse process: I call it *pulse unfocusing*, or *focusing*, respectively. It constitutes a morphological treatment of musical rhythm as it involves a shape, as depicted in Figure II.2-5.[12]

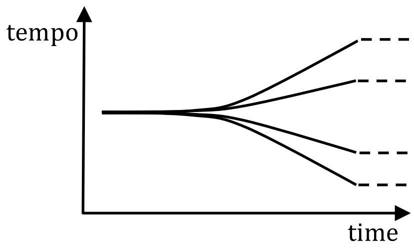

Figure II.2-5 – Pulse unfocusing.

The generation of rhythm is strictly deterministic. The shift from the initial pulse for any given instrument was controlled by means of an interpolation[13] between two values for the time interval between note onsets.[14] An exponential function was used, its curvature visualised and adjusted in order to achieve a satisfying effect of pulse unfocusing on a four-part texture. This was an important trial and error process tied directly to hearing by using the playback functionality of the software. It's an example of how the automation of a compositional technique can help improve its musical result by fine-tuning it.

In terms of pitch, a random generator was used. This was an aesthetic decision related to perception: I wanted the aural experience to be tied to the rhythmic process, not being disturbed by a defined pitch process. If pitch is random, then that means that the listener cannot make sense out of its temporal evolution. Random generators involve chance, which will be thoroughly discussed in Section II.2.2.

An excerpt from the main OpenMusic patch used to create the musical process can be found in Appendix IV.4.1, p.159. The algorithm output is shown in Figure II.2-6. Regarding the rhythm, we can see that only tuplets of 5 or 6 (of

[12] Pulse unfocusing can be viewed as a metamorphosis between two types of polyrhythmic texture (see Appendix IV.6 – Polyrhythmic Textures, p.178): Pulsating Unipulsional Unimetric → Pulsating Polypulsional Polymetric. On the starting and ending textures, and on each voice, the meter equals the pulse (as in a 1/4 or 1/8 time signature), i.e. it is trivial.

[13] See footnote 11, p.50.

[14] A note onset is the time at which a note starts.

crotchet size) exist. This was controlled by configuring the quantization[15] of rhythm so that it didn't use the full spectrum of tuplets (septuplets and so forth). Otherwise, the musical end result would be harder to perform.[16] Therefore, this aesthetic decision meant that the presiding criterion was to arrive at the simplest notation that could express a particular musical idea without compromising it.

Figure II.2-6 – Raw algorithm output of pulse unfocusing, implemented in bars 37-46.

The Harmony/Melody Interface

The idea of blurring the boundaries between musical elements is very dear to so-called 'spectral' composers like Grisey and Murail (Anderson 2000). One boundary that was much explored was that between harmony and timbre, two perceptual attributes of sound (see Levitin 1999 for the definition). Early examples of this kind of musical thought can be found, for instance, in the very well known works for solo instruments by J. S. Bach, where a monophonic instrument creates a sense of harmonic progression by using only melody. The process I wanted to create was of a very different nature since it involved a metamorphosis. The

[15] A means of translating and approximating numeric sequences (durations) to note values.

[16] A compromise always exists between the theoretical musical idea and its notation and performance. It is up to the composer to balance the two.

listener would be led through all the intermediate steps much in the same way as happens during a minimalistic phasing process.[17]

The algorithm started with a 'block' chord — all pitches starting at the same time — and gradually shifted the start time of notes with each reiteration. The process can be depicted as follows:

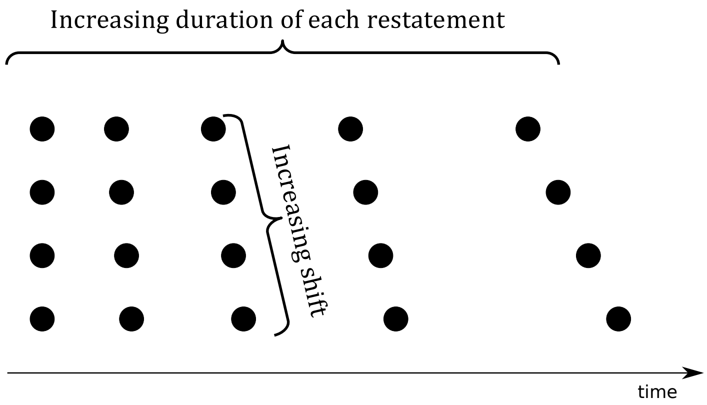

Figure II.2-7 – Depiction of the onsets processing by the algorithm. Durations processing is not depicted.

Simultaneity and overlap would decrease, and sequentiality would increase. After several preliminary designs, I decided to make the algorithm flexible enough to allow customization. That made it tunable and suitable for musical variation. I rendered its output polyphonic so as to allow it to be used on a group of monophonic instruments in the future.

Some experimentation with frequency modulation (FM) functions available in OpenMusic was carried out, after which the underlying harmony was created by using the pitch D4 as the carrier and E3 as the modulator.[18] By fine-tuning the curves of the pitch onsets shifts, I arrived at the musical result shown in Figure II.2-8.[19] After doubling the durations for clarity, the algorithm output was implemented at the beginning of the piece *Duet*.

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[17] Steve Reich's *Piano Phase* (1967) provides a very good example.

[18] The technique of frequency modulation synthesis will be further introduced and developed in Section 1–Consonance and FM Synthesis, p.59.

[19] The algorithm can be found in the attached CD-ROM only: files 'fm chord' and 'harmony to melody'.

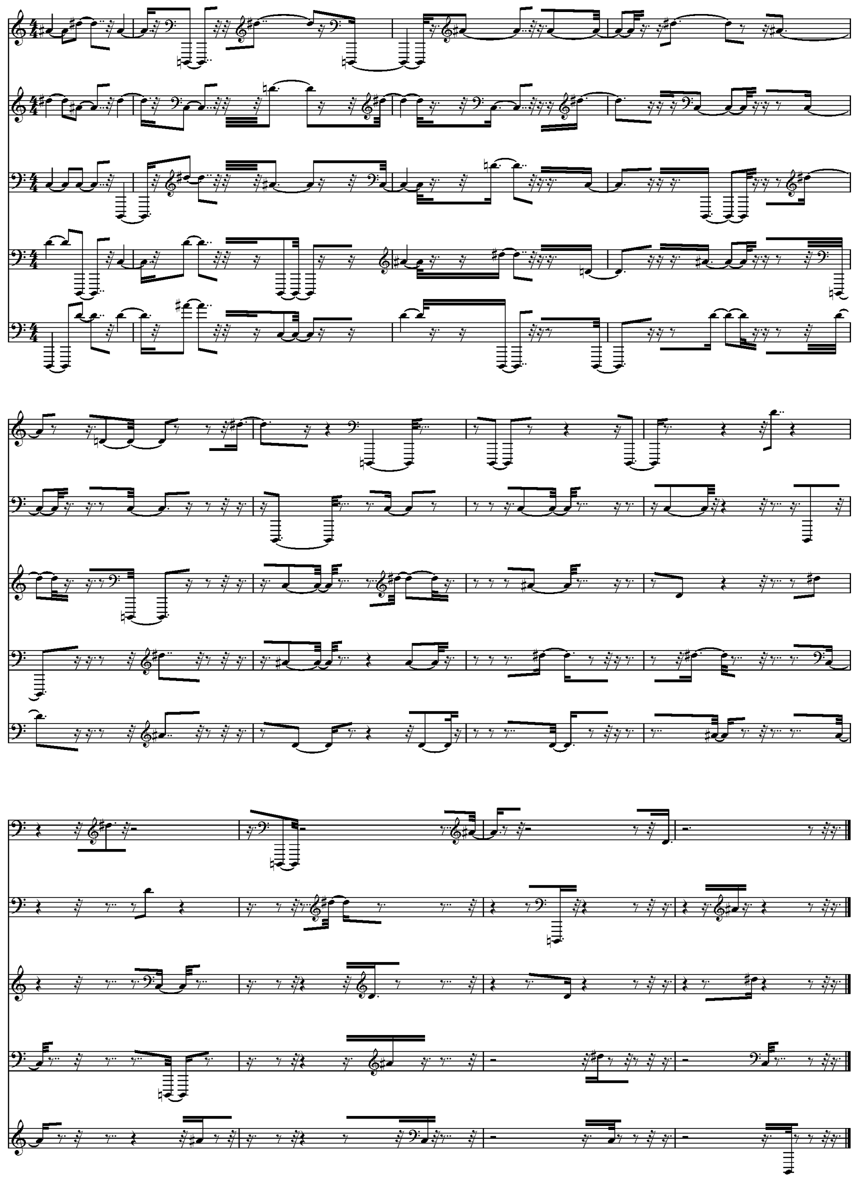

Figure II.2-8 – Raw algorithm output implemented in the first bars of *Duet*.

Rhythm-focusing Heterophony

While composing the piece *The Life is Ours* I selected folk melodies I would use as starting materials. Based on a single melody, I had an idea for a texture that would gradually bring into sync various voices by rhythmic diminution. The voices would start ‘unfocused’ by virtue of the different magnitudes of augmentation. They would then gradually diminish their durations until all voices became synchronized, creating a homorhythmic texture. The process is depicted in Figure II.2-9.

The description of the algorithm can be found in Appendix IV.4.7 (p.170). Algorithm design was directed by a musical goal and its specification: what rules to apply. While programming, I continuously tested the musical results by using the playback feature so that I could modify the visual code and/or the initial parameters to achieve a better sense of *gradual coming into sync/focus*. This shows again how algorithms can be used to fine-tune a compositional technique.

Once I was satisfied with the result, I exported it as a MusicXML file and imported it into notation software (Figure II.2-10). I then selected the part of the sequence that began when all voices were present (not shown), and ended with all voices playing the exact same melody at the same time (the complete sync point).

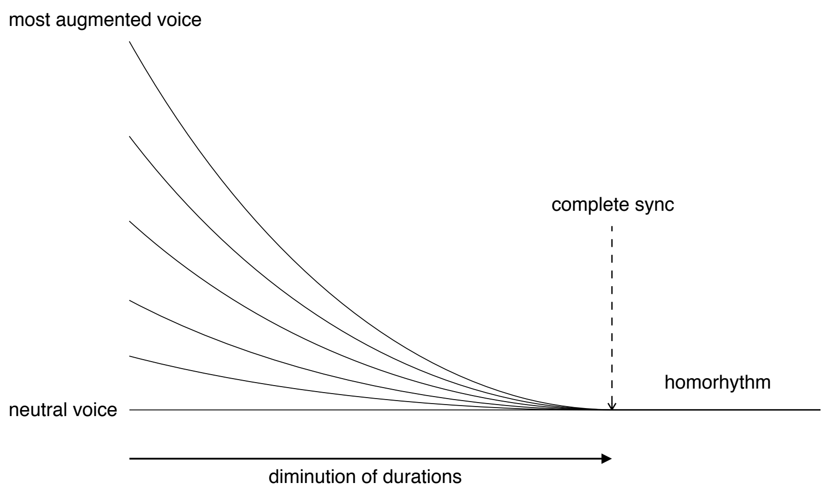

Figure II.2-9 – Rhythm-focusing process by diminution.

II.2.1.4 Microtonality

OpenMusic is very suited to work with microtones. This is, in part, due to the way in which pitch is represented inside it: the midicent.[20] The other reason is that OM can play back microtonal pitches, chords, melodies and polyphonic textures, thus enabling the composer to work aurally on a wide range of musical situations. The following four sections show how I explored different microtonal techniques algorithmically.

Bell-like Sonority and Variation

The final coda section of *Dégradé* is the arriving point of a conveyed "shift of composition focus from figure to sound" (see score's programme notes). The music was imagined as a simple sequence of harmonic sonorities that did not articulate any melodic figuration. I eventually designed a simple algorithm that would create:

[20] See footnote 5, page 41.

Figure II.2-10 – Last bars of the rhythm-focusing algorithm output showing the synchronization points of the voices.

1. A bell-like sonority.
2. A quarter-tone-based harmony.
3. A link of the sonorities with the harmonic series so as to prevent arbitrary quarter-tone-based chords.

4. Easy playability by the ensemble. Only the two string instruments would articulate quarter-tones, and so only two notes per chord (and not more) could be quarter-tones.

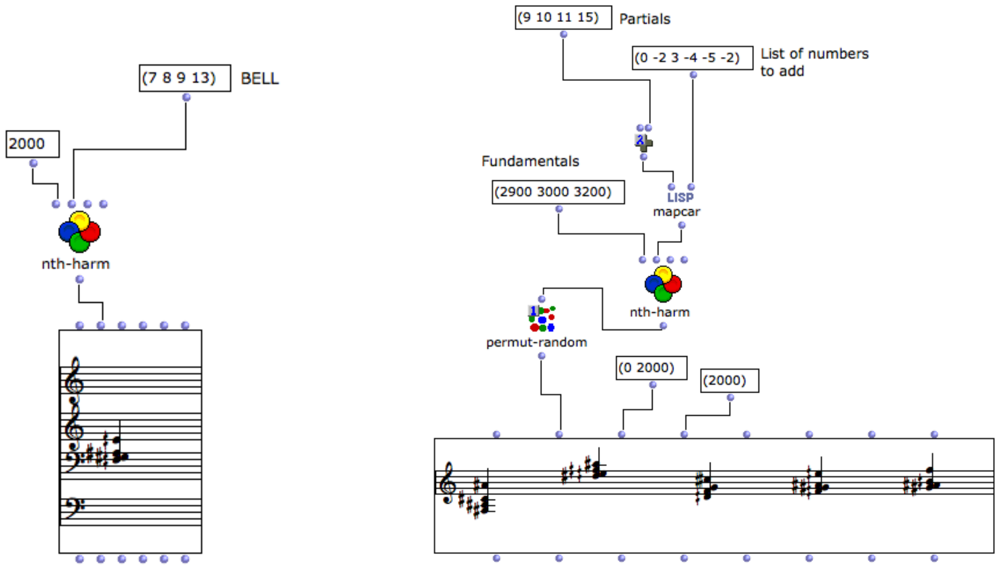

Figure II.2-11 – OpenMusic patch excerpt showing the construction of a bell-like sonority (left) and the generation of the chord progression (right).

I started with a combination of partials 7, 8, 9 and 13, to obtain a bell-like sonority and evaluated it by hearing the playback with a sampled piano sound. The algorithm is shown at the left side of Figure II.2-11. I felt the need to impart sonic diversity to the chords and developed the simple OpenMusic algorithm shown at the right side of Figure II.2-11: it created random sequences of strictly calculated variations of the initial bell-like sonority.[21] The selected progression is shown in Figure II.2-12, used as a raw material for composing bars 163 *al fine*.

[21] There is a partial-list (9 10 11 15) to which a given number from a different list (0 -2 3 -4 -5 -2) is added. This last list was chosen by trial and error so as to obey point number 4 above (p.57) but at the same time create different sonorities. We get the following results for the partials:

- (9 10 11 15), the result of adding 0 to the initial partials-list.
- (7 8 9 13), the result of subtracting 2 to the initial partials-list. It is the initial bell-like sonority, of course.
- (12 13 14 18), the result of adding 3.

  ... and so forth.

All these resulting partials-lists are then applied to the different fundamentals so that each chord is always a subset of a given harmonic series and never a mixture of partials from different

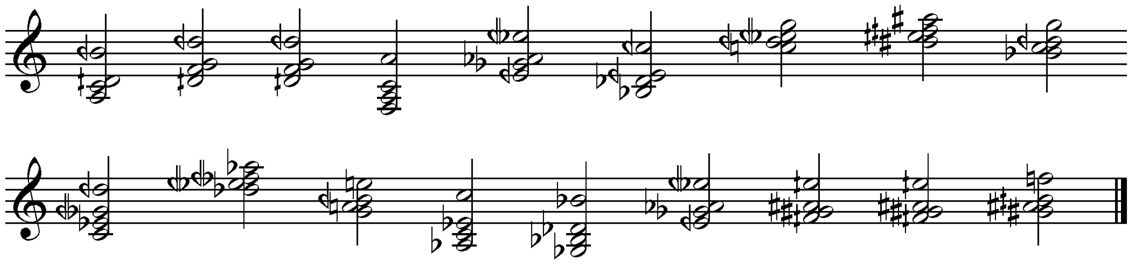

Figure II.2-12 – Algorithm output after being imported into music notation software. Enharmonic spellings were changed for clarity purposes. Accidentals apply only to the chord on which they appear.

Consonance and FM Synthesis

The only algorithm I used on the piece *Vacuum Instability* came as a result of previous experimentation with frequency modulation (FM) synthesis to create various degrees of consonance. That experimentation seemed to corroborate Murail when he wrote that "Frequency modulation provides a process rich in spectral synthesis. […] it can also serve to calculate frequency aggregates for instrumental synthesis." (Murail 2005, p.130), but Haas' *In Vain* (2000) was resonating much more inside my head than Murail's *Gondwana* (1980), a landmark piece where he used FM to create denser and more inharmonic sonorities (see Hirs 2009, pp.96–103).

A reflection on consonance can be found in Appendix IV.8, p.181. In spite of the topics I reflected on, the idea of a working consonance hierarchy persisted in my mind, and I was determined to establish it using FM synthesis.[22] I recalled the joy of discovering the harmonic worlds of Grisey, Murail and Vivier, and wanted to engage more with that kind of aesthetic.

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fundamentals. This relates to point number 3 above (p.57). As the list (0 -2 3 -4 -5 -2) has six elements and there are three fundamentals at work, we get 6 × 3 = 18 chords.

[22] The basis of FM synthesis is the addition and subtraction of two initial frequencies: the *carrier* (C), and the *modulator* (M). The results are what we call *sidebands*: C+M and C-M, C+2M and C-2M, and so forth according to the modulation amount/*index*. It is known that a parameter called *C:M ratio* — meaning the quotient between the frequencies of the *carrier* and *modulator* — controls the spectrum of resultant sounds in FM synthesis. In general, the simpler the quotient (1/2 or 2/3, for instance), the more harmonic the resultant sound is. Also, and generally, the higher it is (or the smaller the modulator), the more compact the resultant spectrum becomes. The generation of negative frequencies, which are reflected as positive frequencies with opposing phase, can distort this general tendency.

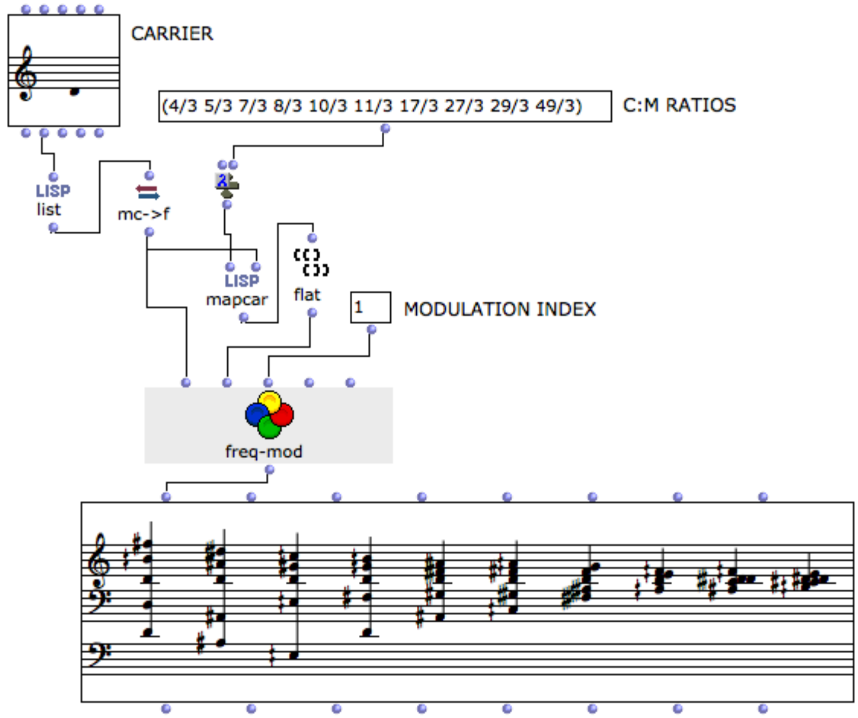

Figure II.2-13 – Algorithm for the generation of a series of sonorities using frequency modulation.

I tested the generation of a consonance scale resulting from a series of C:M ratios that increase *C* and maintain *M*. If this is carried out by adding 1 each time, then one observes a general contraction of the resultant chord, but this does not mean a sustained increase or decrease in consonance. For example, in going from 6/4 (=3/2) to 7/4, and to 8/4 (=2/1) consonance is firstly decreased and then increased.[23] I tried to make the ratio more complex, avoiding any arithmetic divisibility simplification (6/4 = 3/2, for instance). One way to guarantee that is to make sure *M* is a prime number and that *C* is never divisible by *M*.

The algorithm I used is shown in Figure II.2-13, using D4 as carrier and having the modulator always equal to the prime number 3. The quarter-tone-approximated chords generated can be seen more clearly after re-notating them (backwards, as they were actually used, Figure II.2-14). We can readily note the presence of the carrier D4 in all of them, which serves the function of a common tone facilitating harmonic linkage.

[23] Resultant chords for 6/4, 7/4 and 8/4 are the partials [1, 3, 5, 7], [1, 3, 7, 11, 15] and [1, 2, 3, 4] respectively.

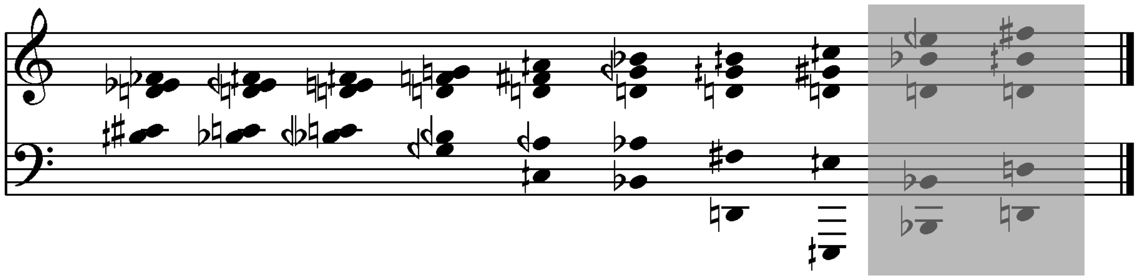

Figure II.2-14 – Sequence of sonorities used. The first chord was implemented at bar 9. Last two chords were not used.

Virtual Fundamentals

While I was trying to come up with techniques for dealing with the folk material I wanted to use to compose the piece *The Life is Ours*, I faced a challenge: how could I create complementary music to the diatonic folk tune *Chamarrita Preta* (*Grupo Folclórico da Casa do Povo de Bandeiras - 'Chamarrita Preta'* 2012)? How to create a harmony that is different from, but related to, the melody's pitch collection and that would enable some freedom and greater dissonance? I chose to explore techniques from spectral music to get two solutions:

A. Get the virtual fundamental of the diatonic pitch collection. Complementary parts would play partials of that fundamental.
B. Consider the diatonic melody's pitches as the same partial of various fundamentals to be calculated (for instance, suppose all five pitches are seventh partials of five fundamentals). Then, obtain other partials by transposing the pitch collection so that it makes an interval with the original determined by an integer-ratio in frequency.

These solutions were individually programmed and tested in OpenMusic.

The techniques related to the use of the virtual fundamental have been around for some time. In Lindberg's *Kinetics* (1989), for instance, an example can be identified:

> The acoustic properties of [these serially derived] chords are [then] analysed in relation to the overtone series, as group of partials issued from one fundamental. That spectral analysis allows all chromatic constituents to be viewed in relation to an underlying fundamental, which may be deployed in their re-harmonization; this can transform initial dissonance into sonorous chords (Howell 2006, p.239).

Exploring the same technique, I tried to achieve a good degree of harmonic amalgamation between the folk melody and the added partials while at the same time avoiding obvious and very consonant combinations. Here is the algorithm I used:

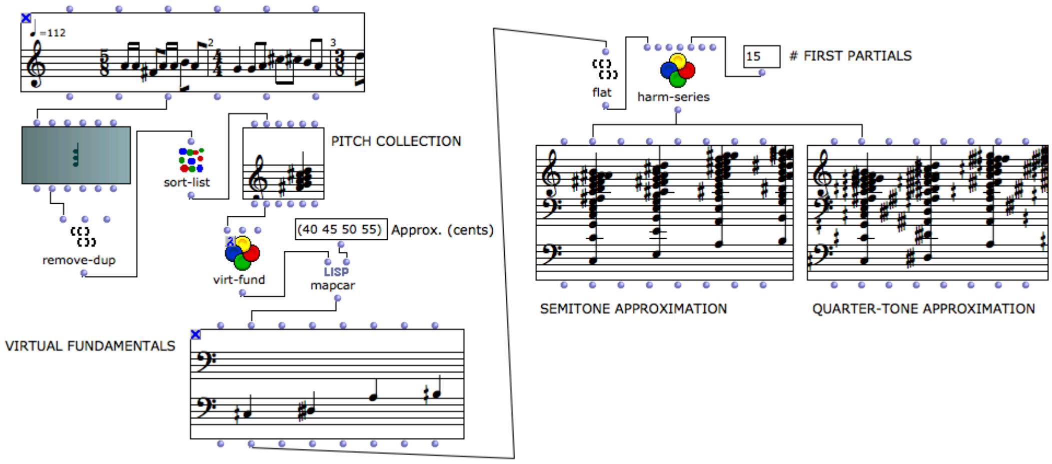

Figure II.2-15 – Algorithm for finding the virtual fundamental of a pitch collection and calculate *n* first harmonic partials.

I was after a sonority that would transfigure the folk melody's diatonic harmonic field. This perceptual shift was rehearsed and tried-out by using the playback functionalities of both notation software and algorithmic software (OpenMusic). The various calculated harmonic series were tested by superimposing them on the folk-melody-based heterophony. From the eight possibilities shown above, the second chord of the quarter-tone-based set was selected.

The same technical procedure used by Lindberg in *Kinetics* is used in *The Life is Ours* but to carry out the opposite perceptual transformation accounted for by Howell. As the folk tune's pitches begin to be superimposed on the added partials, their aural perception is changed: they become just part of a bigger sonority. Furthermore, as they do not conform precisely to the overtone series, they render the whole sonority slightly inharmonic. The result is that the initial diatonic sonority (arguably consonant) is changed into a new globally inharmonic sound entity. An analogy with a chemical reaction is almost irresistible: A + B → C, where A is the folk heterophony, B is the added partial collection and C is a new sonic entity.

Turning now to solution B mentioned above, I developed a simple algorithm to carry out (and test) the harmonic superimposition of the original pitch collection of the folk melody with its own transposition, the interval of which is given by an integer-ratio in frequency.[24] The integer-ratios used are listed in Table II.2-1 and an illustration of the calculations is shown in Figure II.2-16. The algorithm is shown in Figure II.2-17. The approximation used was the semitone so as to allow easier playability in the intervening parts. The output was a harmonic sequence, with each chord serving as a pitch reservoir from which the music would unfold. The score implementation is discussed in Section II.3.1.2, p.110.

Table II.2-1 – Integer-ratios for transposition.

Pitch collection	Added pitches
1	1
3	2
4	3, 6
5	4
5	3, 7
9	5, 12, 15
13	5

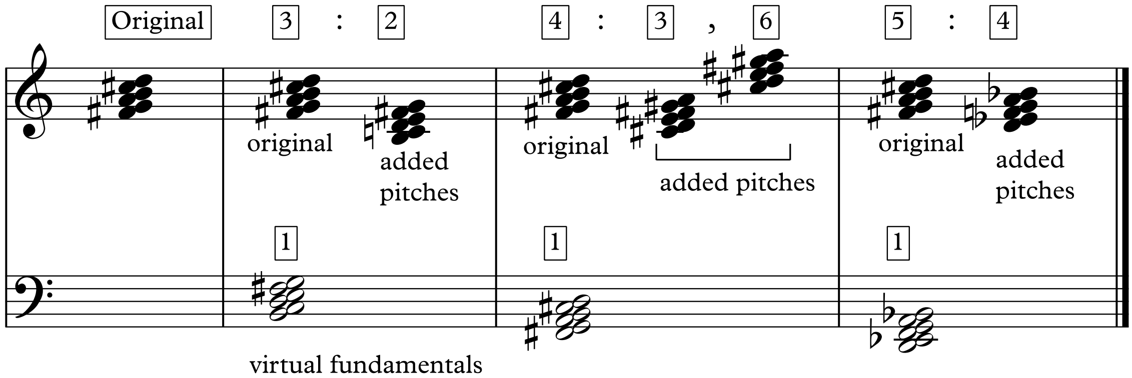

Figure II.2-16 – Calculation of the pitch collection transpositions using integer-ratios in frequency. Boxed numbers indicate partials of the virtual fundamentals (bottom staff).

[24] Integer-ratios in frequency correspond to partial relationships in the harmonic series. These define pure (as opposed to tempered) musical intervals. The ratio 5:4, for instance, corresponds to the relation between partial 5 and 4, a pure major third. As an example, if the pitch collection C+D is taken as 5 in a 5:4 ratio, the pitch collection taken as 4 is the A♭+B♭ immediately below (major third below). The same applies to pitch collections.

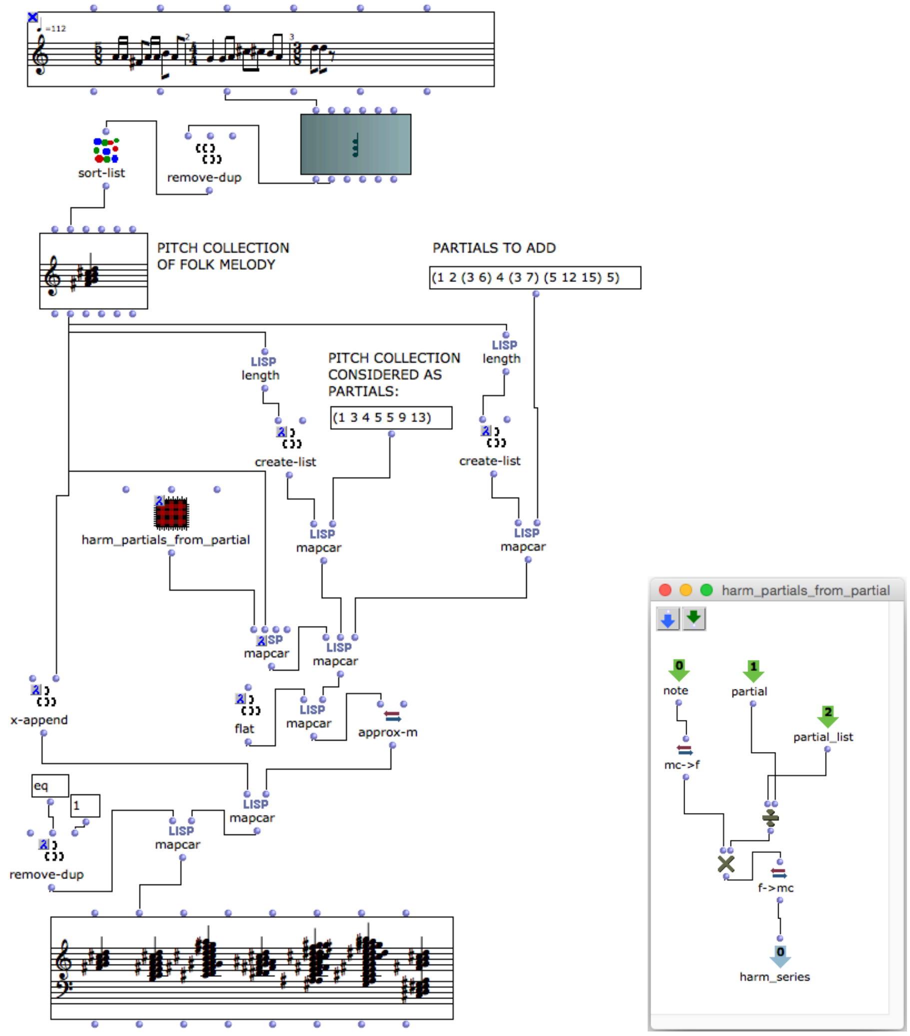

Figure II.2-17 – Algorithm for the calculation of pitch reservoirs related by integer-ratios in frequency.

Circular and Helicoidal Harmony

Circular and helicoidal harmony are personal techniques I have developed over the last years and their formulation can be found in Appendix IV.3 (p.157). Circular harmony starts *Agnostos*' first movement with the following progression:

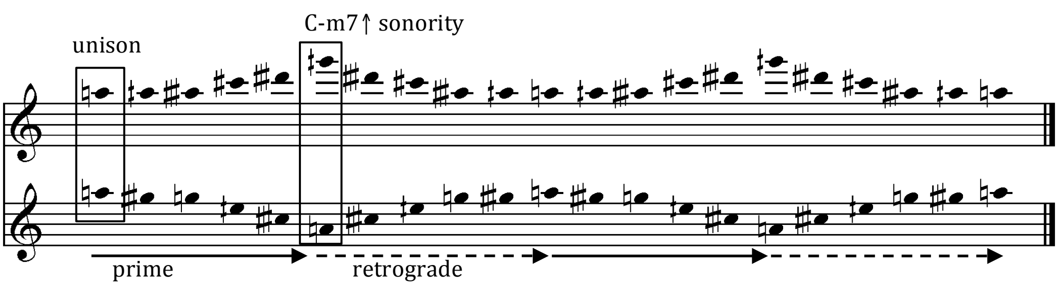

Figure II.2-18 – Circular harmony used for the beginning of the piece.

The wave-like shape shown in Figure II.2-18 occurred to me after making contact with architect Kengo Kuma's installation during the *Sensing Spaces* exhibition at the Royal Academy of the Arts in 2014 (Kuma 2014), an interpretative drawing of which can be seen in Figure II.2-19.

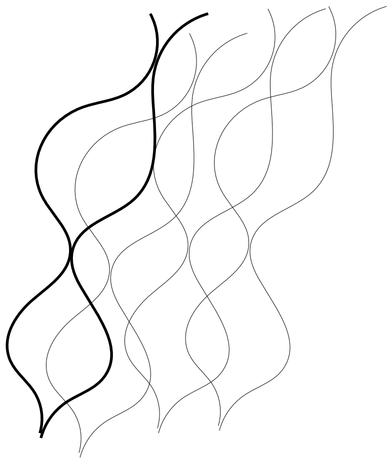

Figure II.2-19 – Interpretative drawing of Kuma's installation.

As Kuma's work is frequently about 'weak architecture' (Bognar and Kuma 2009, p.174) and the void (as opposed to the architectural structure), I tried to translate this into music by having just the necessary pitches (the structure) define an interval (the void). Subsequently the 'structure' would describe a path and the 'void' would be resized and filled in in various ways. One of them consisted in adding one more voice as shown in Figure II.2-20.

Later I would add partials from an estimated virtual fundamental so as to thicken the sonorities (Figure II.2-21). Later still, a whole manually-composed coda section would be based on 'filled void', using chromatic cluster harmony (letter E in the score). This connection with architecture obviously resonates with Xenakis' *Metastaseis* (1953-54) for orchestra, but strict (or mathematical) correspondence with the architectural structure was not something I aimed for.

The harmonic progressions were generated algorithmically by means of deterministic procedures. Shown in Appendix IV.4.9 (page 175), the algorithm is based on an interpolation from a unison to a given sonority, as is readily apparent in Figure II.2-18, as well as in Figure II.2-20 and Figure II.2-21. The addition of partials from an estimated virtual fundamental used only partials 3, 5, 7 and 9.

All the initial sonorities, as well as the progressions obtained, could be aurally assessed through playback. This meant that research was giving rise to actual knowledge: I began to have a good idea of how the progressions actually sounded and could intervene by changing some parts of the algorithm to achieve more satisfying results. Again, the analogy with pure manual composition being constantly assessed at the piano is irresistible and very much a valid one.

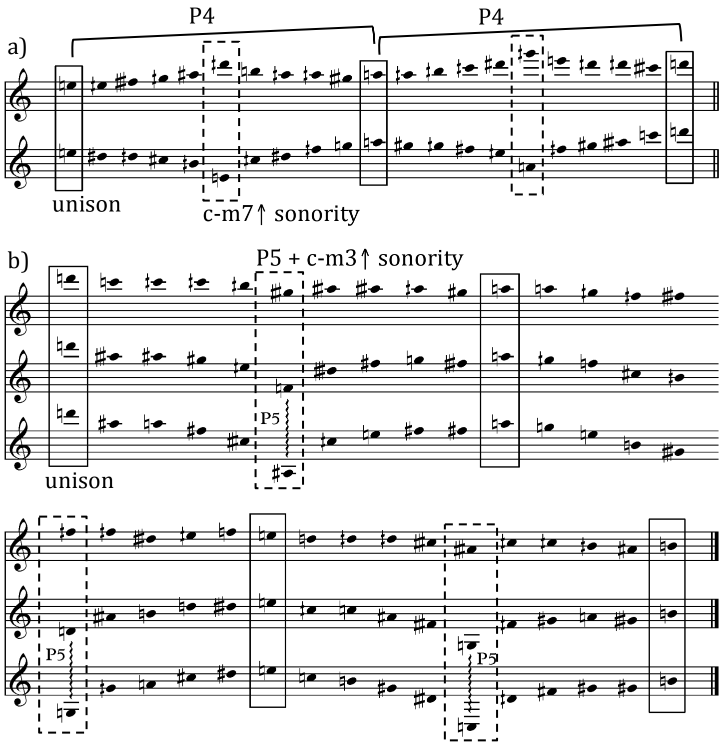

Figure II.2-20 – 2-part (a) and 3-part (b) helicoidal harmony. Implemented at bar 11 and 16 of the score, respectively.

Figure II.2-21 – 4-note helicoidal harmony in pure form (top system) and with harmonic rhythm plus added partials from virtual fundamental estimation (bottom system). Numbers to the left indicate voice number, boxed numbers indicate chord number and staff labelled 'F' shows the virtual fundamental. Bottom system was implemented at bar 88-98 of the score with anacrusis.

II.2.1.5 Fractal Research

The attendance of a live performance of Per Nørgård's *Voyage Into the Golden Screen* (1969), for chamber orchestra, had a great impact on me. On the second movement of the piece, the composer makes use of the so-called infinity series: a way of building a pitch sequence having fractal[25] characteristics. This interested me very much.

While composing *Agnostos*' first movement, OpenMusic allowed me to automate, test and explore the creation of fractal melodic sequences following Per Nørgård's procedures as described in the website dedicated to his music (Kullberg et al. 2015). I tried to generate a fractal melodic sequence by using my own starting materials, namely a melodic fragment taken from the 3rd trombone part just after the first climax at bar 33 (itself having the same intervallic sequence as clarinet 1 in bar 29). This way I maintained an organic relation among materials, something that worried me throughout the piece.

As illustrated in Figure II.2-22, the pitch sequence is created by interlocking the prime and inverted forms of the starting material. This instantly creates a first self-similarity feature: the intervallic sequence is recurred at half the speed. Other self-similarities were analysed later.

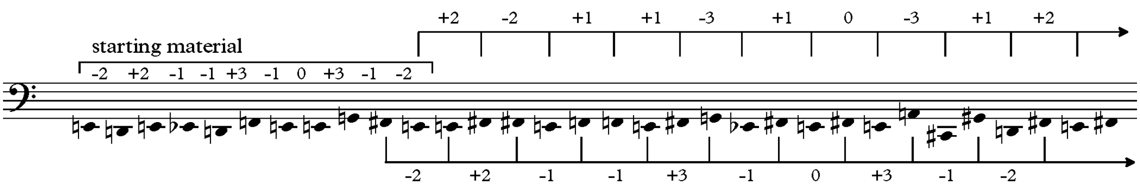

Figure II.2-22 – First step of fractal pitch sequence generation.

The algorithm I developed for generating the fractal is shown in Figure II.2-23. The initial pitch sequence is entered into the first score object. In the middle score object the fractal pitch sequence is obtained. In the score object at the bottom the melodic sequence is created after transposing 3 semitones up to fit the violoncello's range. The rhythm was obtained by concatenating random rotations of a sequence of durations — 1 2 1 1 1 1 1 1 1 2 — where the value 1 corresponds

[25] A fractal is "a curve or geometrical figure, each part of which has the same statistical character as the whole" (Oxford University Press 2013a). This means that in fractal geometry there is recurrence of the same structure at different scales, frequently designated by self-similarity.

to the semiquaver. The melodic sequence shown was doubled so that the rhythms became simpler to read and perform.

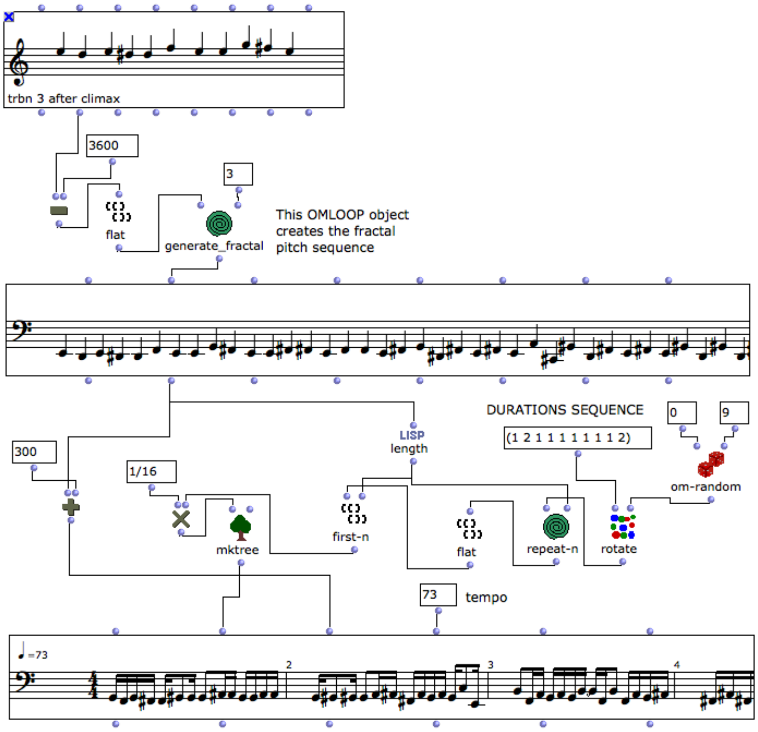

Figure II.2-23 – Algorithm for the generation of a fractal melodic sequence.

Figure II.2-24 – Musical analysis of the fractal melodic sequence showing the various internal pitch canons. Top staff shows the complete melody (having P1 as pitch sequence), with the starting material in diamond-shaped notes. Other staves retain every x^{th} pitch starting on *y*: labelled as *x,y* where 0 is the first pitch.

After generating the fractal, the internal self-similarities were analysed. OpenMusic helped calculate the sequence of intervals at various periodicities. The numerical analysis is shown in Appendix IV.9, p.183, the musical transcription of which is shown in Figure II.2-24. The material was implemented at bar 38 of *Agnostos*' first movement.

II.2.2 Indeterminism, Chance and Automatism

As defined in Section I.5.1, algorithm indeterminism refers to the automation of processes in which "action corresponding to one or more steps is dependent on a number of alternatives" (Basu 2013, p.133). In order to output a result when evaluated, the algorithm has to feature selection criteria; otherwise it could not *choose* a single result. The selection criteria can be looser or tighter, depending on how they are defined.[26] An equally effective programming strategy would consist in generating only the possible alternatives and then picking *any* one of them at random, thus avoiding validation tests.[27]

My programming practice with indeterministic algorithms is more biased towards *generating* the possible alternatives, and less towards applying selection criteria through validation tests. The latter strategy is commonly called *constraint programming*. Nevertheless, the idea of constraining possibilities holds true for both methods. For the purposes of this commentary, if an algorithm can output different and valid results each time it runs, then it implies chance.[28] It is up to the composer to select among the results coming from repeated evaluations and to choose how to go about doing it. This selection process can, again, be looser (any result) or tighter (only some results).

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[26] For instance, if an algorithm would have to pick *any* number from a list — 1 to 10, for instance — any given number would be output by pure chance. By contrast, if it would have to pick any *odd* number from the same list, a test would need to be carried out: is the picked number odd? If it weren't, it would have to pick another number and run the test again. Any number from the set [1, 3, 5, 7, 9] would finally be output.

[27] To get only odd numbers from 1 to 10 the algorithm would start with the number 1 and add the number 2 cumulatively until 9 (1, 1+2=3, 3+2=5, 5+2=7 and 7+2=9). Now that all the alternatives are odd numbers, it would just pick any of them.

[28] Some algorithms discussed before featured a limited number of simple chance procedures, but their significance was not very relevant for the process under discussion.

At this point one should also relate chance to automatism.[29] Pure chance is a form of automatism as unconscious intention relies on a mechanical device working randomly (dice, for instance). What if the composer is actively judging each result so as to select one out of many (commonly called *cherry-picking*)? He is now using *conscious* intention to *select* what was previously generated unconsciously. Could this still be called automatism? I believe it depends on how rigorous and strict the selection process is. Furthermore, it also depends on how the algorithm is programmed, and in particular how chance is constrained. The higher the constraints, the less adequate the term automatism becomes. Putting classification issues aside, and as will be made clear by the following sections, automatism through constrained chance in algorithm design gradually constituted a solid foundation in processes of *discovery*.

Cage's and Boulez's views on chance procedures are quite relevant and worth considering. Cage embraced chance operations quite early[30] and related them to philosophical reflections about the composing action. On this account, Pritchett writes that:

> In Cage's *Lecture on Something* of early 1951, he praised Feldman's graph pieces as having 'changed the responsibility of the composer from making to accepting' (Pritchett et al. 2015, sec.4).

Although, initially, chance controlled only the ordering of pre-composed events, soon chance would assume a more fundamental role:

> [In] *Imaginary Landscape No. 4* for twelve radios (1951) . . . coin tosses decided frequencies of tuning, dynamics, durations, tempos, and numbers of superimposed events (Griffiths 1981, p.24).

It became quite radical in the famous *4'33''* (1952) consisting of three movements, each completely silent: any sound from the environment could penetrate the performance.

Although one can say that Boulez embraced automatism in his early integral serialism pieces such as *Structure Ia* (1952) — in effect *accepting* the outputs of an

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[29] See p.27 for the definition and Gibson (2015) for a wider discussion relating to other art forms.

[30] In the third movement of his *Concerto for Prepared Piano and Chamber Orchestra* (1950-51).

elaborate system of generating materials[31] — later he emphasized the need for the composer to take responsibility by exercising aesthetic choice:

> It is all very well to talk about chance, but then you must consider what its intrusion into a work of art represents in general terms — and it was on this point that my article [*Aléa*] became relatively polemical — and that the aesthetic project itself can be annihilated by the admittance of pure chance. Chance, as such, is devoid of interest.
> [...]
> I think that aesthetic choice consists precisely in retaining the one interesting thing out of the million uninteresting ones.
> [...]
> But I am absolutely opposed to the abdication of the composer who introduces chance operations which have every likelihood of being uninteresting, and which moreover demolish any idea of a musical vocabulary (Boulez and Deliège 1976, pp.84–5).

Whereas Cage's use of chance would frequently aim at producing aimless (frequently static harmonically), intentionless music, my own use of chance is assisted by definite compositional intentions to generate novelty and variation, or as a discovery device. So what is really contrasting with Cage is the fact that he accepted the results, whereas I select, study, possibly change, and integrate them in scores. In this sense, I feel much more biased towards Boulez's views:

> Nevertheless, wouldn't the composer's ultimate ruse be to absorb this chance? Why not tame these potentialities and force them to render an account, to account for themselves? (Boulez 1964, p.45)

Constraints and Rules

Pierre Boulez's concept of *aléa* is very useful as an example of highly constrained chance in composition. In an article dealing with this concept (in Boulez's work *Constellation-Miroir*, one of the movements of his *Third Piano Sonata*), Trenkamp (1976) writes:

> [*A*]*léa* is the use of chance under highly controlled circumstances (p.1).

[31] See again Ligeti's analysis of the piece (Ligeti 1960).

and later on:

> [A] particular form of chance called *aléa*, in which the composer controls precisely the areas in which chance may enter into the composition (p.5).

clarifying how it is defined.

Boulez's application of chance is limited to highly controlled performance indeterminacy as exemplified by the *Third Piano Sonata*'s movements (*formants* as he called them) where the player constantly chooses between written down, alternative routes. This means that, in fact, chance never presents him with alternatives to select from while he is composing: he composes every alternative. This makes it hard to talk about actual (or true) constraints. Nevertheless, an analogy with my own practice can be drawn. Boulez, like myself, also generates the possible alternatives instead of applying validity tests to crude sets of materials. But while he composes the materials themselves, I *program the rules* so that an algorithm can generate and propose them to me.

II.2.2.1 Complexity and Randomness

The following discussion analyses two applications of the same algorithm, firstly to compose the first piece of the portfolio — *Shapes* — and secondly to create a sketch to be workshopped while I was composing *Vacuum Instability*, situated roughly at the middle of the research period. Different phases within the research period originated different aesthetic reflections.

While composing *Shapes*, I programmed an algorithm to construct a *rhythmic complex*: a superimposition of *rhythmic compounds* (see Appendix IV.5, page 178, for a definition of this terminology). In the present case, this complex is considered to be a superimposition of rhythmic figures,[32] which are nothing more than pulses (or *pulse trains*) of varying duration and separated by a varying amount of silence.

The onsets and durations of notes of a particular voice are obtained from time-domain contours for the following parameters:

1. Distance between note onsets (pulse attacks), or 'Δonsets'.

[32] These figures are not the durations commonly used in musical notation (crotchet, quaver, etc) but sequences of durations with a particular temporal evolution: the rhythmic equivalent of a melodic figure.

2. Duration of notes.

These contours are contained in *BPF* (break-point function) objects inside OpenMusic:

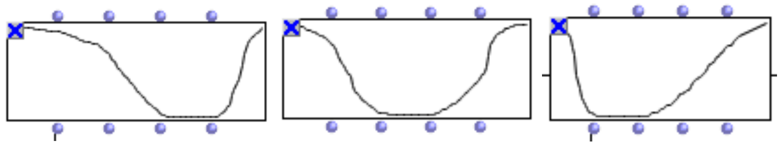

Figure II.2-25 – OpenMusic BPFs of Δonsets for voice 1 to 3. Vertical axis is the amount of time between two note onsets (Δonset) and the horizontal axis is the note order (i.e. first, second, third, and so on).

Each of the voices is based on a particular subdivision of the pulse: 5, 3 and 2. Therefore, we get a polypulsional texture of: crotchet quintuplets, crotchet triplets and eighth notes. This can readily be seen by looking at the algorithm output in Figure II.2-27, below.

Figure II.2-26 – Vectorial harmony underlying the rhythmic complex. Only sharps are used and they apply only to the chord on which they appear.

Regarding the harmonic content of the rhythmic complex, it was based on rotational vectorial harmony with vector v = (-2, +4, -1) as shown in Figure II.2-26. The first chord was chosen for its dissonant sonority: 'A4-M2-m2'.[33] The intervals are ordered by size from top to bottom, following the harmonic series model for resonance. Vectorial harmony, in this case, produces diverse sonorities — a 'M6-U-m3' chord, then a 'm3-M3-M2' chord, and then back to the first intervallic structure — but, interestingly, it maintains the smaller interval on top.

The algorithm and its description can be found in Appendix IV.4.2, p. 160. It is deterministic for rhythm — meaning that it will always output the same rhythm if the same set of initial values is used — but not for pitch. Pitch is random under a restricted set of possibilities: chord's notes from the harmonic progression.

[33] See interval notation on page 40.

The generated result is shown in Figure II.2-27 and was implemented at bar 72. Three moments can be emphasized — one for each part — where the notes are not separated by rests. This was controlled by the contours used for the rhythms. The aim was to create melodic moments that would break the monotony of a plain polyrhythmic texture being played and add some leading roles to the parts.

Figure II.2-27 – Raw algorithm output. Rectangles indicate leading roles for the parts.

A Sense of Failure

The piece *Vacuum Instability* started as a commission to write for a joint BBC Symphony Orchestra musicians plus Guildhall School of Music and Drama students octet. The piece began as a workshop for trying out compositional sketches.

One of the sketches I took to rehearsals was a texture created by the same algorithm used in *Shapes*: generating a polyrhythmic complex out of a harmonic progression. This time I used 6 voices, a different vectorial harmony progression and controlled, for each of them, the contours of the durations and of the distance between notes (Δonsets). The result is shown in Figure II.2-28. I found that the performance of this material was not satisfying. I felt it was too random, plain, static and undirected. Back when I was attending the rehearsals of the same kind of texture in *Shapes*, my judgement was, perhaps, more forgiving either because of the excitement of having accomplished the programming and trying its new outputs or because the texture was simpler, comprised of three parts only. But I still can recall the high level of 'undirectedness' and speculation present.

The sense of failure in trying out the sketch in Figure II.2-28 was a valuable experience because it made me clearly realize that, despite the large amount of parametric control built into an algorithm, it can produce music that lacks what I could call intentionality. This was, with all probability, due to an insufficiency in creating stimulus for auditory memory; a lack of resemblance relations important in creating a coherent musical discourse. I now understand that, in terms of algorithmic design, this was due to the use of randomness in calculating pitch (in spite of the underlying harmonic progression) plus too much complexity in calculating rhythm. In general, too much complexity can often produce similar results as total randomness. The reason for this is that human cognition can be *saturated* with too much information. In *Shapes*, I used total pitch randomness coupled to a very directed rhythmic process (pulse unfocusing, Section II.2.1.3), and, in that case, I think the texture worked well.

To conclude, the workshop was kept in my memory as a serious warning that the use of random procedures and/or very complex processes can produce nonsensical music. In spite of being carefully worked out algorithmically, the performance of that music exposed very clearly the dangers algorithms enclose: a fascination with a process efficiently (and perhaps elegantly) automated, but that is not properly understood or assessed in terms of its musical implications. Again, this can be related to automatism and Ligeti's reaction against some of its forms.

Figure II.2-28 – Rejected excerpt from the workshop score used while composing *Vacuum Instability*.

II.2.2.2 Simulated Creativity: Novelty

If chance is present but constrained in an algorithm, then it still means that each evaluation can produce a new result. This novelty — "the quality of being new, original, or unusual" (Oxford University Press 2013a) — constitutes what I could also call simulated creativity: the algorithm not only relies on rules that enable its successful evaluation, but, in doing so, *creates* different materials each time it runs. It is as if it could improvise and create one result out of a set of limited possibilities. Pritchett, writing about Cage's use of chance procedures points out that:

> Chance, by helping to avoid habitual modes of thinking, could in fact produce something fresher and more vital than that which the composer might have invented alone (Pritchett et al. 2015, sec.4).

Being able to produce new results with each evaluation is also one of the reasons why algorithms can work as testing devices for compositional techniques: being based on the rules that formulate them, and being given a starting material, they allow the composer to quickly scan through all possible products and check if there is any case where the technique fails, indicating that it needs further adjustment.

The following sections show various ways in which novelty was sought and used as a viable solution in various creative scenarios.

Juxtaposing Melodic Figurations

During the initial stages of the composition of *Dégradé*, an algorithm was designed to create a long melodic 'skeleton' for further manual elaboration. It produced a large and uninterrupted melodic line made up of an alternation between two elements:

A. A wave-like melodic figure defined by its contour, range and number of notes.
B. A trill defined by its interval, initial direction, and number of notes.

The contours (or shapes) of the melodic figures can be seen in Figure II.2-29. Any figure could be retrograded (r), inverted (i), or retrograded and inverted (ri).

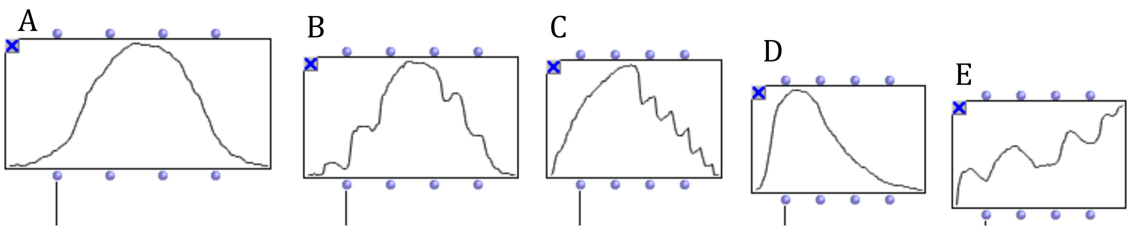

Figure II.2-29 – Contours for the wave-like melodic figures used in *Dégradé*.

In terms of pitch, these melodic figures were constrained to all the semitones contained within the ranges shown in Figure II.2-30. Rhythm was derived from a reservoir of small segments: 2 quavers, 3 quaver triplets, 8 semiquavers, 2 demisemiquavers. These segments were then concatenated and notated in 4/4 meter by OpenMusic.

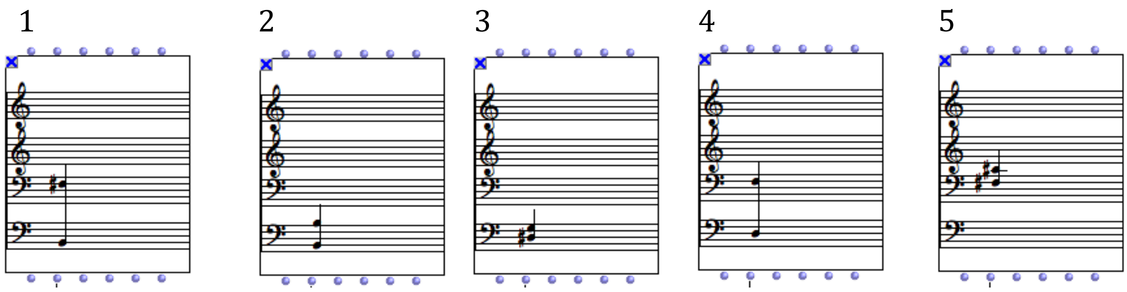

Figure II.2-30 – Ranges constraining the melodic figures. Lower staff sounds two octaves lower.

Chance is an integral part of this non-deterministic algorithmic strategy. It affects choosing the melodic contour, the range in which it unfolds, the amount of trill notes, and the rhythmic segments. The constraints for these elements are promptly defined by a set of possibilities and, therefore, exert control over what would otherwise be absolute chance. The OpenMusic programming is described in Appendix IV.4.3, p.161, and produced, with each evaluation, different sequences of figures having different lengths. I selected the output shown in Figure II.2-31, after being satisfied with how it played back.[34]

[34] Although the design was rooted in the idea of melodic morphology, it also considered cognitive factors. The melodic figures — or waves — can be said to constitute a *Gestalt*, a form, because the trills always surround them. This means that the serial-like transformations (r, i and ri) are not as abstract as when applied to transform a 12-tone (class-set) row. The transformations used here are tied to a particular musical idea (a melodic contour, shape), not to an underlying ordered pitch row as in 'classic' dodecaphonic music. Furthermore, the fact that there are always two recurring elements (the 'wave' and the trill) makes a strong stimulus to auditory working memory (see Levitin 1999). This helps create coherence by similarity and elaboration. See the music analogy with 'Cognitive Aspects of Discourse Coherence' (Patel 2008, pp.337–340).

Figure II.2-31 – Raw algorithm output implemented in bars 1-33 of *Dégradé*. Rectangles indicate melodic figure source with reference to Figure II.2-29 and Figure II.2-30.

The result was used to build the piano part from bars 1 to 33 of the score, which constituted the basis for further manual intervention and elaboration (see Section II.3.2.2, p.128).

From bar 45 to 83 of *Dégradé*'s score, another instance of the same melodic line shaping algorithm was implemented. This time it used different ranges for the melodic figures (Figure II.2-32) but relied on the same contours as shown in Figure II.2-29. The output is shown in Figure II.2-33.

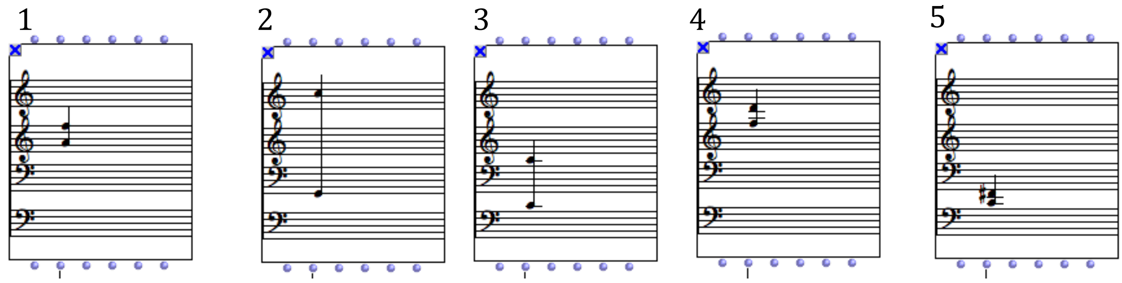

Figure II.2-32 - Ranges constraining the melodic figures. Top and bottom staffs sound two octaves higher and lower, respectively.

The use of different starting materials provides an example of how one could use the same algorithm to produce a variation of the same basic musical material: the technique is the same but it is applied to different starting materials. Given that it was used to build a new section within the piece, these differences in configuration are the main source of formal novelty. At the same time, as the algorithm relied on the same basic ideas, formal coherence was obtained.

Some time after *Dégradé*'s premiere, and as I got more and more aware of the various issues affecting CAC, I realized that, despite the amount of control applied in the chance procedures just discussed, one important aspect remained uncontrolled: harmony. Melody always has harmonic implications. The programmed algorithm generated various melodic figurations based on the same set of shapes, but with diverse and quite random harmonic implications. Some of these unwelcome implications were counteracted through manual intervention, as discussed in Section II.3.2.1–Unwelcome Aspects (p.126), or by means of manual elaboration.

Musical Object Generators

Still while composing the piece *Dégradé*, I programmed two closely related algorithms for creating musical objects based on a given harmony and called them 'musical object generators'. I will discuss the first one and point the reader to Appendix IV.4.4.2 (p.163) for a discussion of the second.

Figure II.2-33 – Raw algorithm output implemented in bars 45-83 of *Dégradé*.

The first musical object generation algorithm created a three-part texture based on a predefined harmonic progression and a reservoir of possible sub-divisions of the beat. The total notes within each voice could be controlled but all other parameters were randomized. The result was a raw musical material for further manual intervention and elaboration (discussed in Section II.3.2.2).

The main compositional idea was to create very diverse ways of distributing a given chord's notes inside a time interval — like a container where notes would be put — so as to create 'musical objects' with a particular harmonic colour. One could define how many parts and how many notes there would be in total on the final object but note onsets, durations, and melodic sequence would be arbitrary.

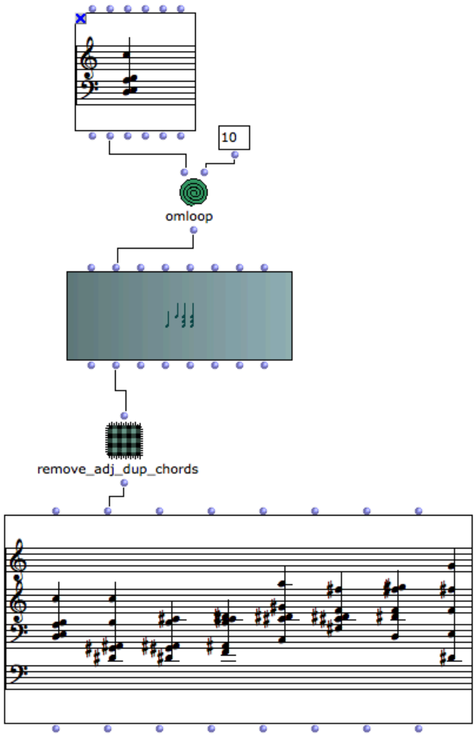

Figure II.2-34 - OpenMusic patch for the automation of modular harmony. The harmonic sequence is shown just for illustrative purposes, not corresponding to the piece's actual harmony.

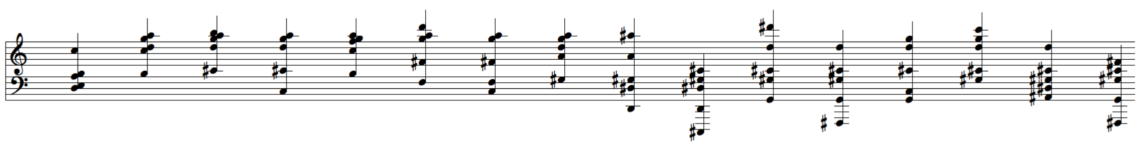

Figure II.2-35 - Harmonic progression used to build the musical texture. Sharps affect only the chord on which they appear.

The first part of the algorithm dealt with the generation of harmony (Figure II.2-34), creating an example of modular harmony, a personal technique defined in Appendix IV.2 (p.156). The module was comprised of a set of adjacent pitches and the rule for adding notes was as follows:

1. The pitches could be added above or below the module, not inside;

2. The intervals that the new pitches create with adjacent module pitches or with other new adjacent pitches have to be contained in the initial chord's adjacent intervals;
3. Intervals smaller than a P4 could not be in lowest position (i.e. in the bass) for resonance reasons.

The complete harmonic progression used in the piece (Figure II.2-35) was based on an initial chord of M2s, P4 and m9 (measured between adjacent pitches[35]). These constituted the intervallic universe (the genetic material) of the progression. As this kind of harmonic composition is obtained through a non-deterministic algorithm, each time one evaluates the patch the output is different. An interesting thing that can happen is a gradual prevalence of certain intervals: looking at Figure II.2-35, one can see that, although the first chord only has one P4 (between adjacent pitches), towards the end of the progression that interval becomes more prevalent. It conveys a kind of harmonic modulation that is based on intervallic content.[36]

After building the harmonic progression, the actual musical texture was constructed. This was carried out using the algorithm shown in Appendix IV.4.4.1, p.162. It retrieves the pitches from the modular harmony progression — each chord used as a pitch reservoir for each time interval of the total duration of the texture — and constructs the rhythm of the parts based on a set of predefined subdivisions of the beat.[37] Thus, the algorithm can be said to generate a large musical object, or various smaller juxtaposed objects, tied to the idea of generating unforeseen possibilities of pitch and rhythm that conform to a given harmonic progression. This is, in fact, one of the main advantages of algorithmic indeterminism: forcing musical novelty out of a constrained compositional scenario. The algorithm output is shown in Figure II.2-36.

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[35] The reason I work this way is rooted in cognition. Although every note of a chord interacts with every other note, pitches that are closer in register interact more due to proximity.

[36] This is very much how I tend to think about harmonic modulation in atonal music.

[37] These subdivisions work to define the kinds of minimum durations and tuplets allowed *ab initio*, preventing errors of quantization frequently present in quantize functions. These errors would appear if, for instance, one wanted to juxtapose a semiquaver (1/16) to a triplet of quavers (1/12) at the beginning of a beat.

Figure II.2-36 – Algorithm output after being imported into the music notation software. Some clefs were added for visual clarity, avoiding many ledger lines. Accidentals last one bar. The large amount of rests comes from the beat subdivisions, which are written into the parts.

Folk Analysis and Resynthesis

As I tried to characterize the folk tunes that interested me during the composition of the piece *The Life is Ours*, I developed analytic procedures that would extract information from them:

1. the set of melodic intervals they contain.
2. the set of rhythmic cells used in melodies and in percussive accompaniments.

These two procedures (rather like dissections) produced materials I could then elaborate algorithmically, drifting away from the folk reality but, nevertheless, maintaining a relationship with it.

Figure II.2-37 – Transcription of the folk melody *Senhora do Almurtão*.

As an example, consider the folk melody *Senhora do Almurtão* shown in Figure II.2-37, which I transcribed from an online video of a Portuguese folk group called *Adufeiras de Monsanto* (*Adufeiras de Monsanto - 'Senhora do Almurtão'* 2011). There are clearly two parts, the second starting on the twelfth bar. The analysis of the melodic intervals produced Table II.2-2. One can say that, although +2 is only present in the second part, both parts share the same set of interval moduli: 0, 1, 2 and 5 semitones. This set can be considered a characteristic (one among many) of the melodic line.

Table II.2-2 – Intervallic analysis of *Senhora do Almurtão*.

Part	Melodic Intervals
1	0, -1, -2, +5
2	0, -1, -2, +2, +5

In much the same way as an interval set can denote intervallic properties of a melody line, so can rhythmic cell sets denote properties of a rhythm. Thus, a rhythmic *polymerization*[38] can be created by concatenating cells in any given degree of ordering randomness, the results of which are comparable to rhythmic

[38] A term imported from Chemistry which means the synthesis of a compound (polymer) "built up chiefly or completely from a large number of similar units bonded together" (Oxford University Press 2013a).

improvisations carried out by folk players. This formed the basis of the algorithm used for the rhythm (see Appendix IV.4.6, Figure IV.4-9, p.168) of the melody shown in Figure II.2-38. The pitch sequence was obtained through a patch named 'intervallic_melody_range' (see Appendix IV.4.6, Figure IV.4-10) which accepts an interval set from another folk source, a register range and the total number of notes. The melody obtained is very far from the original folk materials' grammar but remains, nevertheless, related to them: it *derives* from them.

Figure II.2-38 – Initial brass melody showing the rhythmic cells in parenthesis.

An analogy can be drawn with the cross-synthesis technique in digital audio processing. It implies the combination of analysis data from two sounds (Roads 1996b, p.208). By analogy, one can term *cross-resynthesis* the process by which the initial low brass melody of *The Life is Ours* was obtained: combining intervals from the interval set shown in Table II.2-2 — altered so that all intervals could be upward or downward — with percussive rhythmic cells from another folk source: a *Viola da Terra*[39] performance (*Décio Leal toca Viola da terra* 2012). If the exact upward and downward interval sets were to be used, the results would be less varied and closer to the original folk melody. Instead, the chance for intervals to be either upward or downward created more varied melodies with each evaluation.

Another use of the 'rhythmic polymerization' algorithm created the initial woodblocks part of the score. In that case, rhythmic cells from the percussion instruments (*adufes*) played by the *Adufeiras de Monsanto* were employed.

One of the beautiful and elegant aspects of algorithmic composition of this sort lies in the fact that it enables the composer to shift his attention from algorithmic design to the aural selection of materials, provided that he/she is sure the algorithm reproduces the compositional technique he/she is after. Drawing an analogy with the common use of the piano to try out compositional ideas, the algorithmic tools constitute a kind of intelligent piano; a kind of musical

[39] A local string instrument from Açores, Portugal.

laboratory. This significant and underlying aspect is one of the main reasons I use algorithms.

Percussive Ostinati

The piece *Stochafrica* started as a commission from percussionist and jazz drummer Pedro Segundo. After two meetings to discuss and try out instrumentation and playing techniques, I began the composing process. I wanted to create music with irregular meter, but relying on repetition and variation. This was something I agreed with Pedro. Given the simple instrumentation, I decided, at first, to compose the piece manually, starting by devising ostinati, which would work as thematic ideas. This focus on repetition is common in percussion pieces such as Xenakis' *Rebonds* (1988), from which I drew influence. I was also strongly influenced by jazz drummer Dan Weiss' *Jhaptal Drumset Solo* (2011) album, where he bases his improvisations on Indian beat cycles. The piece's title, nevertheless, came from the prefix *stoch*-, alluding to Stochastic methods, and the suffix *africa*-alluding to Mozambican (Africa) timbila rhythms. The piece starts with the mbila instrument (the singular of timbila).

Although initial sketching began manually, soon algorithms would reveal their adequacy for the artistic project at hand: a search for possibilities of creating irregularly metered percussive ostinati. The unpitched percussion medium, not being able to articulate pitch, relies heavily on rhythm, timbre, register and dynamics. This means that it does not run the 'dangers' present in pitch-based melody and harmony. The ear is much more forgiving of the horizontal and vertical combinations,[40] and so they are much less significant compositionally. As rhythm is the most imposing element, it follows that rhythmic recurrence is arguably the most important device used to achieve musical discourse coherence, guaranteed from the outset by choosing to compose ostinati. Thus, the relatively unconstrained indeterminism present while creating each ostinato would not pose any great threats.

[40] As a clear and definite pitch is not an attribute of unpitched percussion sounds, there are no such things as musical intervals, modes, chords and harmony (in their usual sense).

The main algorithm I used for ostinato generation is shown in Figure II.2-39.[41] The outputs were aurally assessed, cherry-picked and exported to MusicXML files that could be imported into notation software. I began to build a library of different sized ostinati.

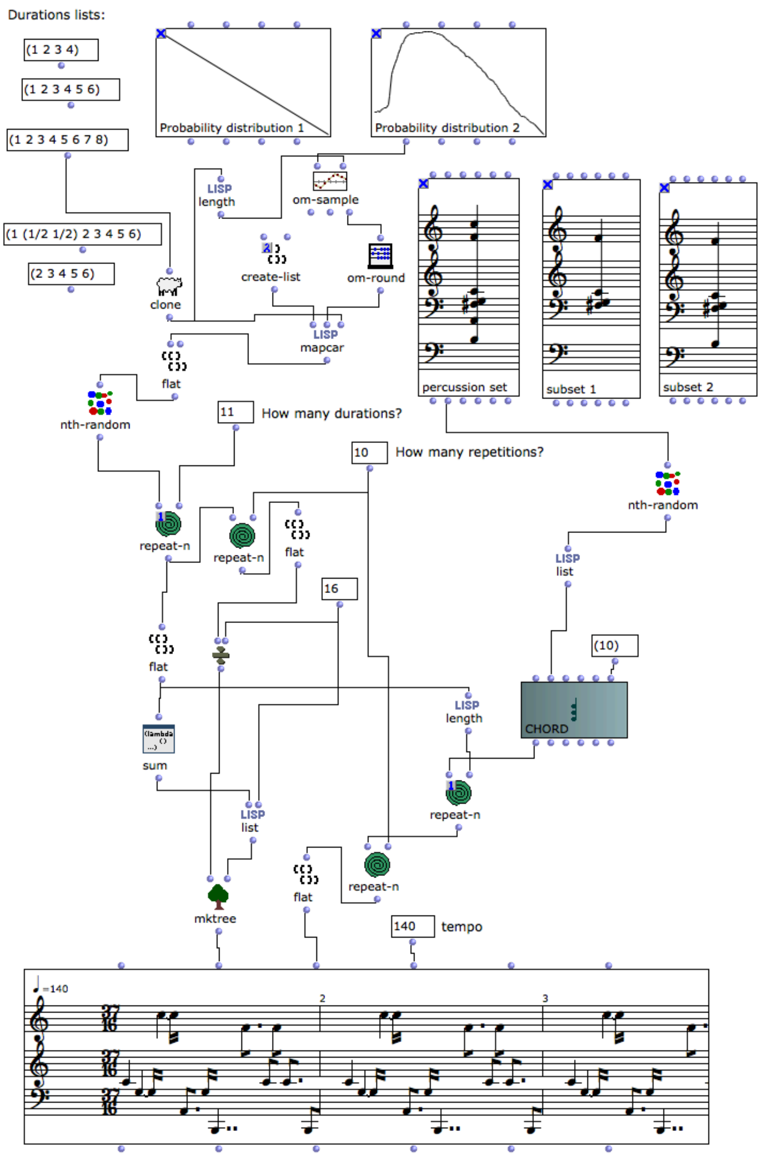

Figure II.2-39 – Ostinato generator algorithm.

In Figure II.2-40, a raw 21-note ostinato is shown along with its final score notation clarifying instrumentation and meter.

[41] Durations lists could be fed and have their frequency of occurrence weighted by a probability distribution graph. The number of durations to be assembled into an ostinato could be specified, along with the instrumentation (the *CHORD* objects shown at the right, the pitches of which represent instrument samples). The result could easily be heard through playback at the bottom object, which outputted MIDI into an external sampler application (not shown).

Figure II.2-40 – The raw 21-note ostinato and its score notation.

In Figure II.2-41 another raw ostinato is shown. Notation and score implementation is discussed in Section II.3.2.1–Percussion Notation, p.121.

Figure II.2-41 – Raw 5-note ostinato.

II.2.2.3 Counteracting Mechanicalness

Algorithm outputs, if implemented automatically, can impart a certain amount of mechanicalness to the music. This constitutes one of the reasons why further manual procedures can be necessary (see Section II.3.2). The following discussion describes an attempt to counteract mechanicalness during algorithm design by resorting to a perceptive effect — stream segregation — and distortive processes, working very much as local melodic variation devices. The algorithm was used to compose the piece *Duet*.

Gradual Stream Segregation and Distortion

Gestalt auditory grouping principles (see Appendix IV.7, p.180) can give rise to an effect known as auditory stream segregation (see Shepard 1999b; Bregman 1994). In the presence of varied stimuli, the human brain parses information into discrete streams in order to simplify the external world. If the composer can have some control over the factors that contribute to the grouping of auditory stimuli, then he/she can control the possibility of their segregation, creating a richer musical texture. I've used this principle to create a gradual segregation of one melody from another by gradually transposing pitches.

The algorithm starts with a melodic fragment, from which it randomly chooses groups of adjacent pitches. These groups are the elements on which transposition and distortion operations will occur. For each group, a set of intervals of transposition (i.e. a vector of intervals) is chosen and applied repeatedly. This same set is used for the different groups but with alternating sign. Figure II.2-42 illustrates this: the application of the vector proliferates the initial melodic fragment and creates a gradual separation of the inner groups in register.

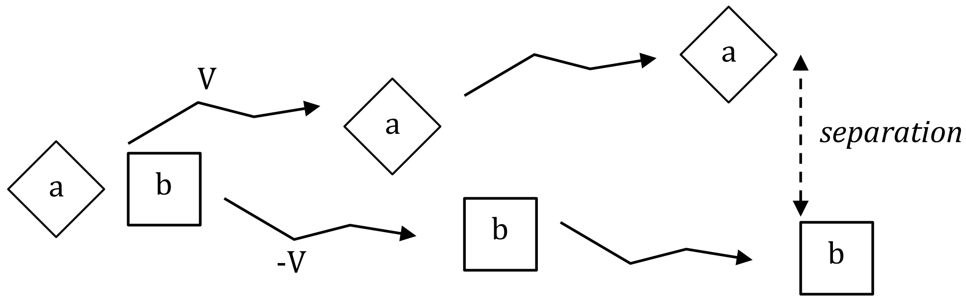

Figure II.2-42 – Illustration of the algorithmic idea. *a* and *b* are groups of pitches. *V* is a vector of intervals.

Distortion is then applied to every group each time after transposition and is defined as follows:

1. Randomly pick a defined number of pitches.
2. Transpose each one of them up or down a semitone.

Distortion works as a melodic variation process. It retains some of the identity of the group of pitches — mainly contour if the group has a large enough range[42] — and effects small changes (the smallest pitch change the piano, as a tempered instrument, can allow). Being able to retain the main traits of a given musical object but at the same time give it a new appearance is very appealing as it is linked to cognition through the notion of prototype.[43] By changing some — but not all — perceptual attributes of a given musical material, a composer can maintain its recognizability[44] (see Levitin 1999, p.214). After some experimentation, a

[42] I.e. distortion could destroy a contour if intervals are already quite small.

[43] The first, original, or typical form of something (Oxford Dictionaries 2010b).

[44] One classic example is the transposition of a melody where only *register* is changed, thus enabling the listener to recognize the original melody.

distortion of two notes per group was found to be most satisfying as it was enough to break some of the mechanicalness (and therefore monotony) of the process.

Figure II.2-43 – Algorithm output. Solid rectangles show the groups subjected to transposition and distortion. Dashed rectangles show results of those operations. *D* stands for distortion, T_i stands for transposition by interval *i*.

The final output is shown in Figure II.2-43. The initial melodic sequence was obtained by considering the musical context: the music material that preceded the score implementation location (bar 176) was a melody with regular rhythm and so this was what was initially fed to the algorithm.

A Critical Reflection on *Duet*

In line with the effort to counteract mechanicalness by relying on cognitive principles, and critically looking back at the piece *Duet*, I believe that, after all, and in spite of the cognitive concerns which played so great a role while composing it, a great deal of mechanicalness and/or plainness still remained in the final score. Probably the reason for this is that if one decides to exert too much control in terms of perceptive and cognitive impact, the results can end up being simple perceptive and cognitive *mechanisms* on display, instead of imaginative, expressive and poetic artistic outputs. Or perhaps due to the effort in trying to automate cognition-based processes I ended up turning them into mechanical processes. This aspect of *programmability* of compositional procedures is, after all, one of the fundamental problems in CAC.

II.2.2.4 Processing Found Material and Preparing Manual Composition

The piece *Canti Firmi* was based on Gesualdo's madrigal *Gioite voi col canto*. This was a request from James Weeks, conducting at the time the Guildhall New Music Ensemble. As the madrigal was available online in Sibelius format (Harmer 2009), I could import it into notation software and then export it to MIDI format so as to be able to finally import it into OpenMusic. This rendered the 'raw material' subject to algorithmic manipulations I could envisage and develop, starting as it did the composition process.

I devised simple principles that would define the algorithms but also, and importantly, their scope of action — from the beginning I wanted to leave a lot of space for manual composition. As stated on the programme notes (see score), "I started by segmenting the madrigal in seven parts of different lengths. Each segment was then filtered in various ways to obtain 7 different *canti firmi*" (hence the piece's title). Filtering procedures eliminated some of the madrigal's pitches so as to make room for my own elaborations and complementations. There were two ways of filtering: randomly and by using a register range.

Figure II.2-44 – Production of *cantus firmus* 1 from Gesualdo's madrigal *Gioite voi col canto*. On top, an excerpt of the original madrigal is shown (Harmer 2009).

Figure II.2-44 shows the production of the first *cantus firmus* from its madrigal segment. The algorithm is shown in Figure II.2-45, where one can see the original MIDI version of the entire madrigal (top), together with a graph controlling segment length, the various register filters (rightmost part), the resulting filtered segment and a final segment (the *cantus firmus*) obtained by additional random filtering.

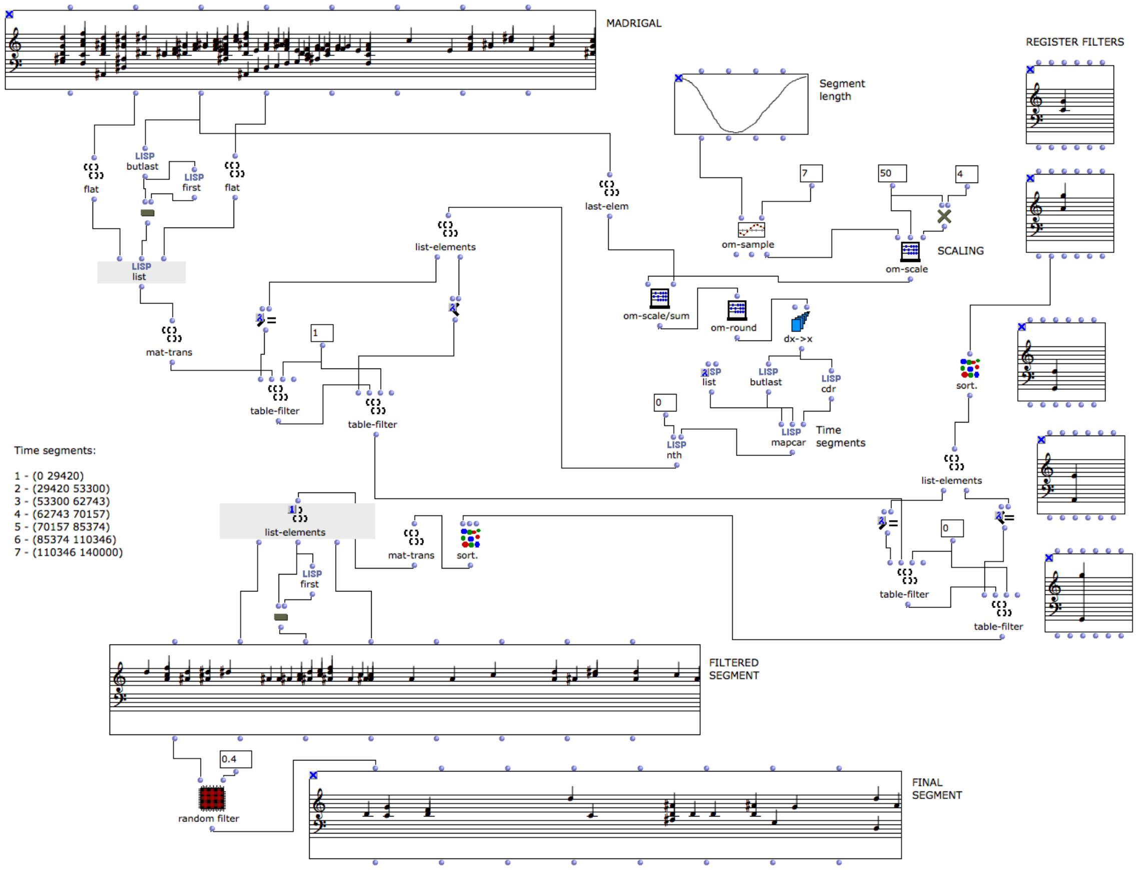

Figure II.2-45 – Algorithm for the generation of *canti firmi* from segmentation and filtration of the madrigal.

After obtaining the 7 *canti firmi*, I devised a way of building algorithmically, for each of them, a sequence of modes. These modes always contained the pitches of the corresponding *cantus firmus* plus new pitches added according to a set of possible intervals. The final result of the algorithmic calculations can be seen in Figure II.2-46. I based all subsequent manual procedures on the modes, working around the *canti firmi*. Thus, algorithmic calculations solidly prepared manual composition by providing an underlying system, something I would further develop in *Agnostos* (Section II.2.2.5–Sonority/Mode Relationships and Microtonality). In Section II.3.1.3, p. 112, the score implementation is discussed.

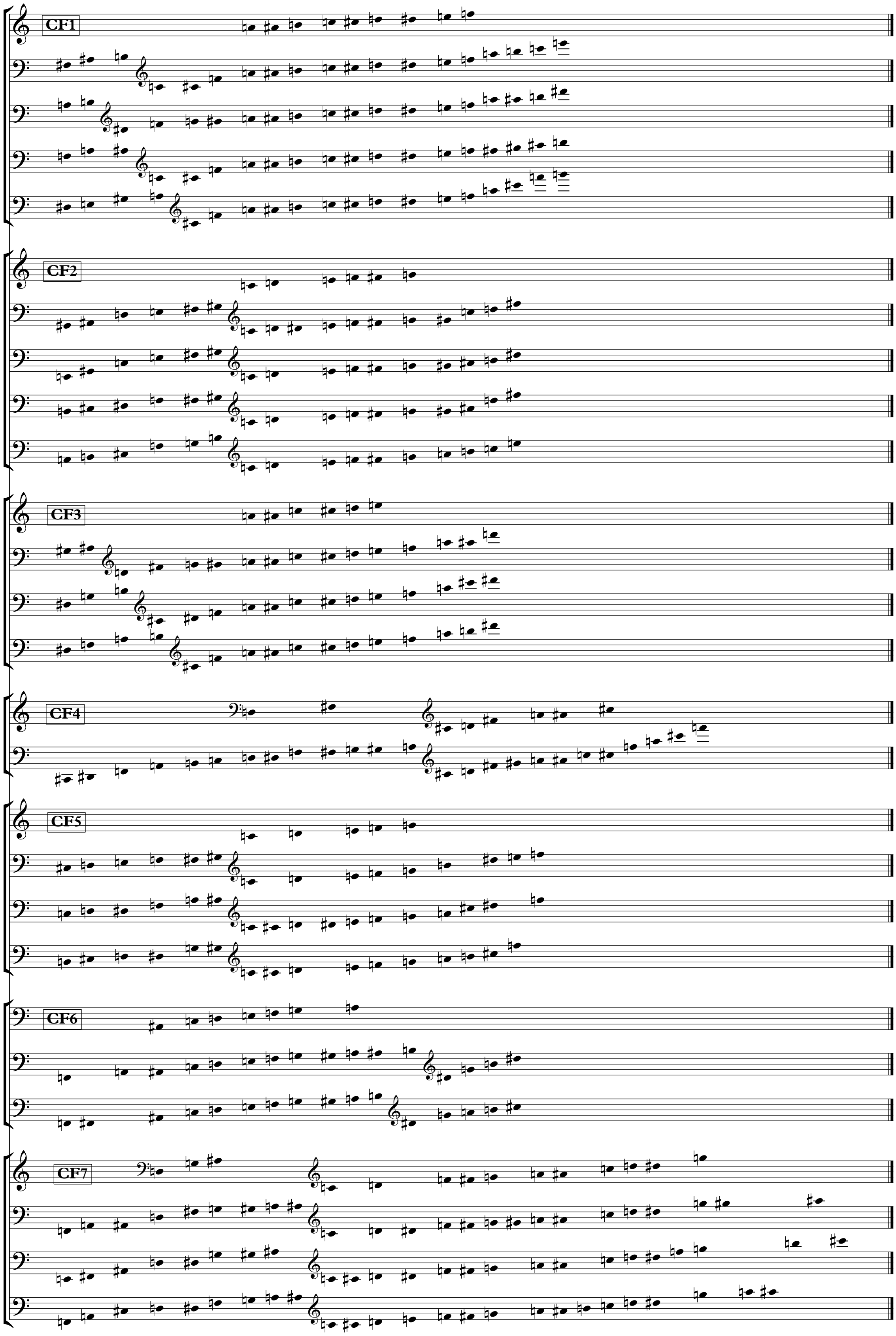

Figure II.2-46 – Pitch sets of the seven *canti firmi* and corresponding modes.

II.2.2.5 Discovery

To discover means to:

> find unexpectedly or during a search
> • become aware of (a fact or situation)
> • be the first to find or observe (a place, substance, or scientific phenomenon)
> • show interest in (an activity or subject) for the first time
> • be the first to recognize the potential of [someone or something]
> (Oxford University Press 2013a)

What I want to emphasize by using the word discovery is the action by which I produce something I could hardly have *known* before.

In the following discussions I will analyse two compositional situations in which discovery became quite important. Firstly, I'll describe how a creative accident can affect algorithm design and give rise to a new technique. Secondly, I'll describe indeterministic procedures used to create a rich sound world whose elements I couldn't have conceived beforehand, in effect turning algorithms into discovery devices. As I progressed, there was a sense of a new world being discovered, aided by the playback functionality of OpenMusic: what, at first, I did not know how it would sound, became something I eventually got to know and selected after careful and repeated playback.

Creative Accidents

Some time before working on *The Life is Ours*, I had done some initial programming of an algorithm that would generate a series of melodies by gradually developing an initial one. Each melody would randomly retain a melodic fragment of the previous one and append notes based on its universe of intervals and durations. The number of notes to add each time could be controlled. I developed and refined the programming, fed a folk melody, and operationally decided[45] to display the results from subsequent cumulative evaluations[46] on a *POLY* object, which superimposes the several *VOICE*s obtained (Figure II.2-47).

[45] Decisions can be broadly classified as operational or aesthetic.

[46] Using a feature of OpenMusic loops called 'accumulation', meaning that a process can be applied several times by acting on the previous result each time.

This was meant only for organizing the results in a logical manner, but I could not resist playing it back!

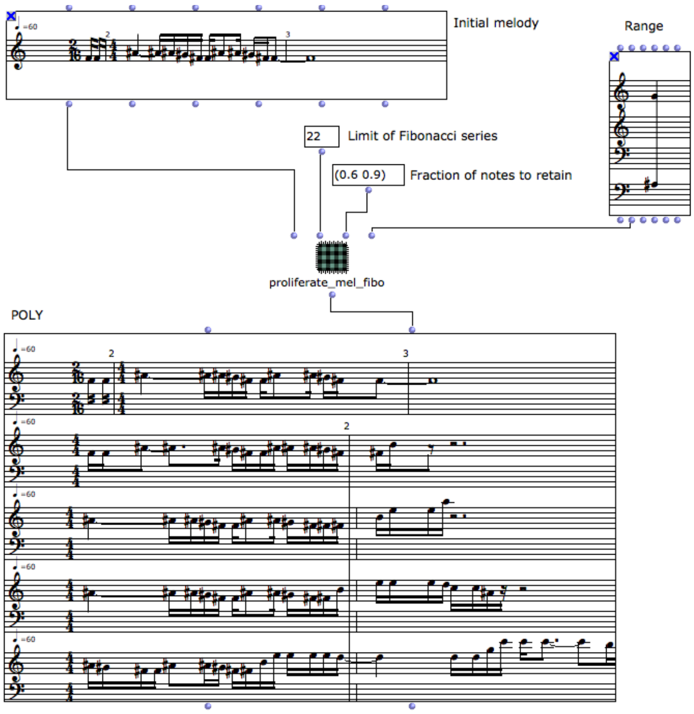

Figure II.2-47 – The algorithm for the proliferation of a melody. The number of notes to retain is defined by a fraction interval (0.6 to 0.9 as shown) and the number of notes to add is defined by the Fibonacci series.

After being pleased with the aural results, I made the aesthetic decision of turning this ‘accident’ into one of the core techniques of the piece. It created a kind of heterophonic/canonical texture: imitations being created from the same melodic fragments on different voices at different times. This also means heterophony if the onsets are close enough.[47] The superimposition creates harmony from the folk melody's pitch set but also chromatizes it because of the newly calculated pitches.

After several evaluations of this indeterministic algorithm, one solution was selected (Figure II.2-48) and implemented at letter A in the score.[48] One of the important characteristics, which was very noticeable aurally, is that voice activity

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[47] Ligeti's *Lontano* (1967) is a good example as heterophony therein is also created by canons.

[48] Different outputs from the melodic proliferation algorithm were used at various locations on the score. The technique thus created one of the main defining syntaxes of the piece:

- Letter A and J – based on part 1 of *Senhora do Almurtão* (see Figure II.2-37, p.85)
- Bar 37 and also at letter B – based on part 2 of *Senhora do Almurtão*
- Letter F, G and H – based on the folk tune *Chamarrita Preta*

occurs by waves: increases and decreases of the local density of short durations, separated by moments of relative relaxation through longer durations as tied notes. It has a light and *cantabile* quality in the melodies that occur from bar 4 onwards. I was struck by the ability of this algorithm to create such melodic lines.

Figure II.2-48 – Algorithm output selected and implemented in the score at letter A. Rhythmic notation and accidentals are shown in raw, unprocessed form. The brackets show retained segments, which begin the next voice.

Important CAC-related reflections arose during and after the composition period. If algorithm design can be considered creative work and an integral part of composing — as it naturally is — then, as I just showed, it can allow space for a lot of discovery to take place, not being reduced to just straightforward programming of a given technique or process. It is the interaction between the algorithmic tools and the composer's thought, manifested through decisions, which makes CAC such a rewarding activity. Decisions restrict possibilities, helping shape the workflow, but also make certain phenomena more likely to happen. This resonates with famous writings by Boulez:

> A musical universe cannot exist without law: it is, under another name, coherence, so dear to Webern; but law alone does not allow an accident to exist, and thus deprives music of the most spontaneous aspect of its means of expression (Boulez 1986).[49]

Furthermore, there is fundamentally no reason why algorithmic composition shouldn't feature, or deal with, the same aesthetic issues of pure manual composition. This frequently can mean reacting against excessive rigidity of the techniques and/or mechanicity of their results, either through careful algorithm redesign or through the use of subsequent manual procedures (intervention, elaboration or complementation) assisted by aesthetic judgment.

Sonority/Mode Relationships and Microtonality

Working on harmonic sonorities generally means focusing only on the vertical aspect of music. Textural sonorities, on the other hand, imply a certain horizontal dimension to be taken into account: melodic invention and counterpoint. Timbre composition, although involving vertical harmonic sonorities, is greatly sensitive to the onsets and dynamic evolution of constituent pitches in time. Therefore, and importantly, the harmony involved in a certain timbre can sound very awkward if it is used as a pitch reservoir for some arbitrary texture. This is because the fusion of the pitches (into a timbre) is broken down, producing a pseudo-melodic dimension that can expose intervals sequentially.

I tried a solution to this 'vertical sonority vs. horizontal freedom' problem whereby sonorities could become part of modes, thus giving the texture an emancipated melodic freedom. This marked, perhaps, an important new phase for my composing aesthetic, the first steps of which having been taken while composing *Canti Firmi*. That piece did not build so much on vertical sonority as on melody and counterpoint (mainly horizontal techniques), but the reliance on

[49] Translated from the original in French. On the same topic, and relevantly, Jonathan Goldman writes that "in fact, the acceptance of the accident is what allows Boulez to reintroduce the present moment of composition, the spontaneity of the gesture and even irrational elements as a welcome tonic to the implacable reason of compositional logic. In the encounter between accident and system, neither of the two elements is left unchanged" (Goldman 2011, p.60).

modes was already very apparent. The pitch stability of a modal space was something that I felt my music needed so that it could accommodate more daring melodic figurations, textural effects and gestural expressions. Sonority/mode relationships began to gain a prominent importance.

The first harmonic process I used was based on building modes that contained a given sonority. An initial sonority was created manually and assessed aurally. Each succeeding sonority of the progression would have the same pitches as the first plus other ones filtered out of newly calculated modes. Different sonority densities were obtained by using different magnitudes of filtering, the evolution of which was modelled on the geometrical curve employed by the Portuguese architect Siza Vieira in the striking 'concrete canopy' of the Portuguese Pavilion. Built for the 1998 Lisbon World Exhibition, it's a monumental building I'm passionate about. I used a hyperbolic cosine mathematical function (depicted in Figure II.2-49) and calculated 25 symmetrical points using spreadsheet software. I then imported the values into OpenMusic and used them to define points inside a *BPF* object.[50]

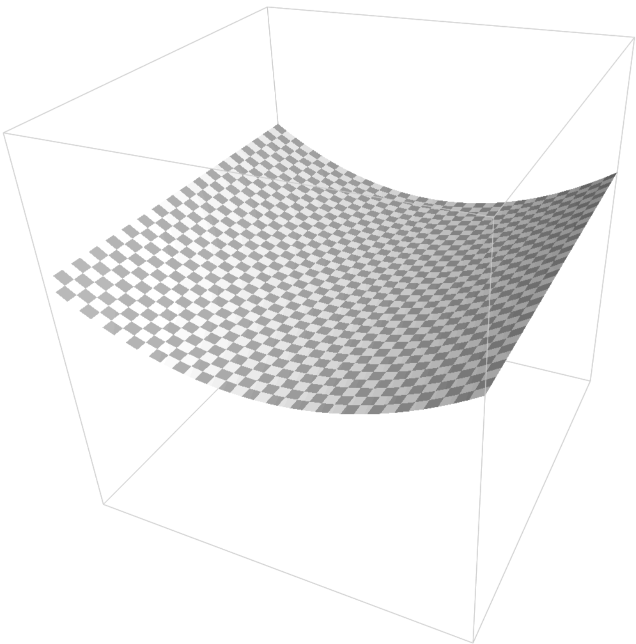

Figure II.2-49 – Hyperbolic cosine 3D shape inside a hollow reference cube.

The resulting sonorities and modes are shown in Figure II.2-50. The increase in density sets an analogy with the sensation of massiveness/weightiness as one moves towards the lowest point (centre) of the architectural shape.

As one can readily see from Figure II.2-50, the modes are built from the sonorities by adding only the intervals 1, 2 and 4 (in semitones), and the evolution of sonority density describes an arch (increasing until the middle sonority and decreasing afterwards). This process was entirely automated and the progression was chosen by cherry-picking the results aurally: I could listen to the sonority progression slowly and with each chord arpeggiated, an important feature that

[50] A 'break-point function' object that graphically depicts points or curves on the Cartesian plane.

improved the listening of the intervallic content, very much mimicking the action of arpeggiating chords at a piano. After I arrived at a satisfying result, I printed it for reference and began composing the score manually (see Section II.3.1.4, p.114). I did this two times creating two sonority/mode families: A and A', the first sonority of the A' family having been created by filtering 60% of the pitches of A2 (the second sonority of family A).

Figure II.2-50 – The first harmonic and modal progression used: family A. Each mode contains its corresponding sonority. The vertical lines show how the initial sonority is maintained throughout. The curve illustrates the correspondence between density and architectural shape.

Building on the sonority/mode procedures described above, I developed yet another process, this time cyclical, for controlling the musical flow. Let's call it Cyclic Harmonic Process, illustrated in Figure II.2-51.

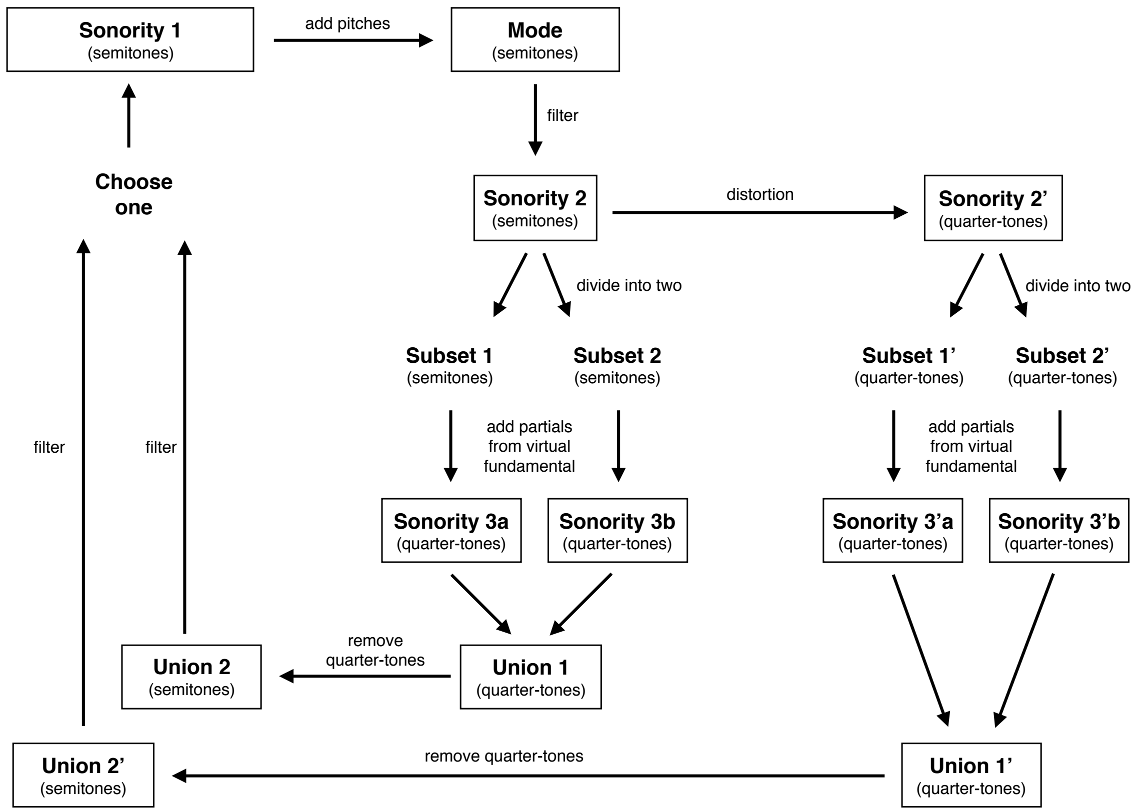

Figure II.2-51 – Diagram of the Cyclic Harmonic Process guiding the generation of the pitch reservoirs. Numbering of sonorities applies only to this diagram, not to the sonorities used throughout the piece.

It starts with a given sonority in semitone space. Pitches are then added according to a set of possible adjacent intervals (semitone and whole-tone, for instance) to build a mode where melodic development can occur. By filtering the mode, we get a new sonority — *Sonority 2* — which is divided into two subsets, or distorted to produce a similar entity (*Sonority 2'*, which will follow the same steps in parallel). To each of these subsets, we add partials (from a possible set comprising partials 4, 5, 9, 11 and 13) from a calculated virtual fundamental. What we get is two sonorities — *3a* and *3b* — which work as 'oscillating spectra' in quarter-tone space. Their union — *Union 1* — can form a more complex sonority, from which we can eliminate only the quarter-tones to form a large pitch reservoir (*Union 2*, a kind of mode also). By filtering this union we can arrive at a new sonority that enters the cycle again.

In Appendix IV.4.10, page 176, the algorithmic environment for automating the Cyclic Harmonic Process is shown. It provides a vivid illustration of the notion of musical laboratory, for me an indispensable concept of CAC. It is quite dense in terms of resources and this allowed me, both aurally and visually, to assess every single music material being developed. The diagram of the technique shown above, although prescriptive in terms of procedures, does not imply determinism. Many steps depend on a number of possibilities. As I repeatedly evaluated the algorithm to get new solutions I would then assess aurally, this meant progressing from research into actual knowledge: from not knowing to knowing. Throughout this discovery process, I was building an aural model of all the materials involved; materials that would be implemented in the score. The adequacy of algorithms could, in this light, be found in their powerful ability to devise, test and assess a system that would underlie manual composition, even if that subsequent composition would, after all, be very spontaneous.

In Figure II.2-52 and Figure II.2-53 the results of automating this principle are shown for a given initial sonority (A''2). Adding partials from a virtual fundamental creates a virtual spectrum, and hence the designation 'spectrum' in the figures. That means that the sonorities can be said to arise from an analysis of an imagined/virtual sound. Again, I printed these results so that I could later refer to them while composing the score.

After the main climax of the movement at bar 106, a different harmonic process was used to complete what could be considered a coda section (b. 106 *al fine*). I created a modular harmony[51] progression and a mode for each chord as shown in Figure II.2-54. This continued the composing attitude laid out before: a carefully defined system proposing materials to be cherry-picked aurally and manually implemented subsequently.

[51] See Appendix IV.2, p.156, for the definition.

Figure II.2-52 – Cyclic Harmonic Process (no distortion) at work on one of the sonorities used (A''2).

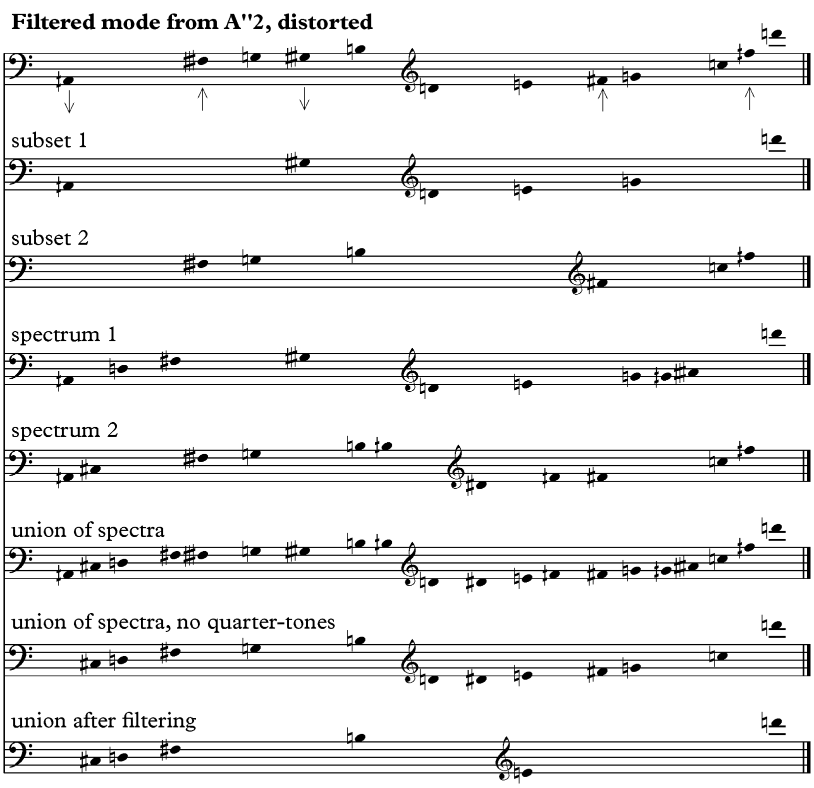

Figure II.2-53 – Cyclic Harmonic Process at work on the distorted branch of sonority A''2. Arrows indicate whether the distortion raised or lowered the corresponding pitch.

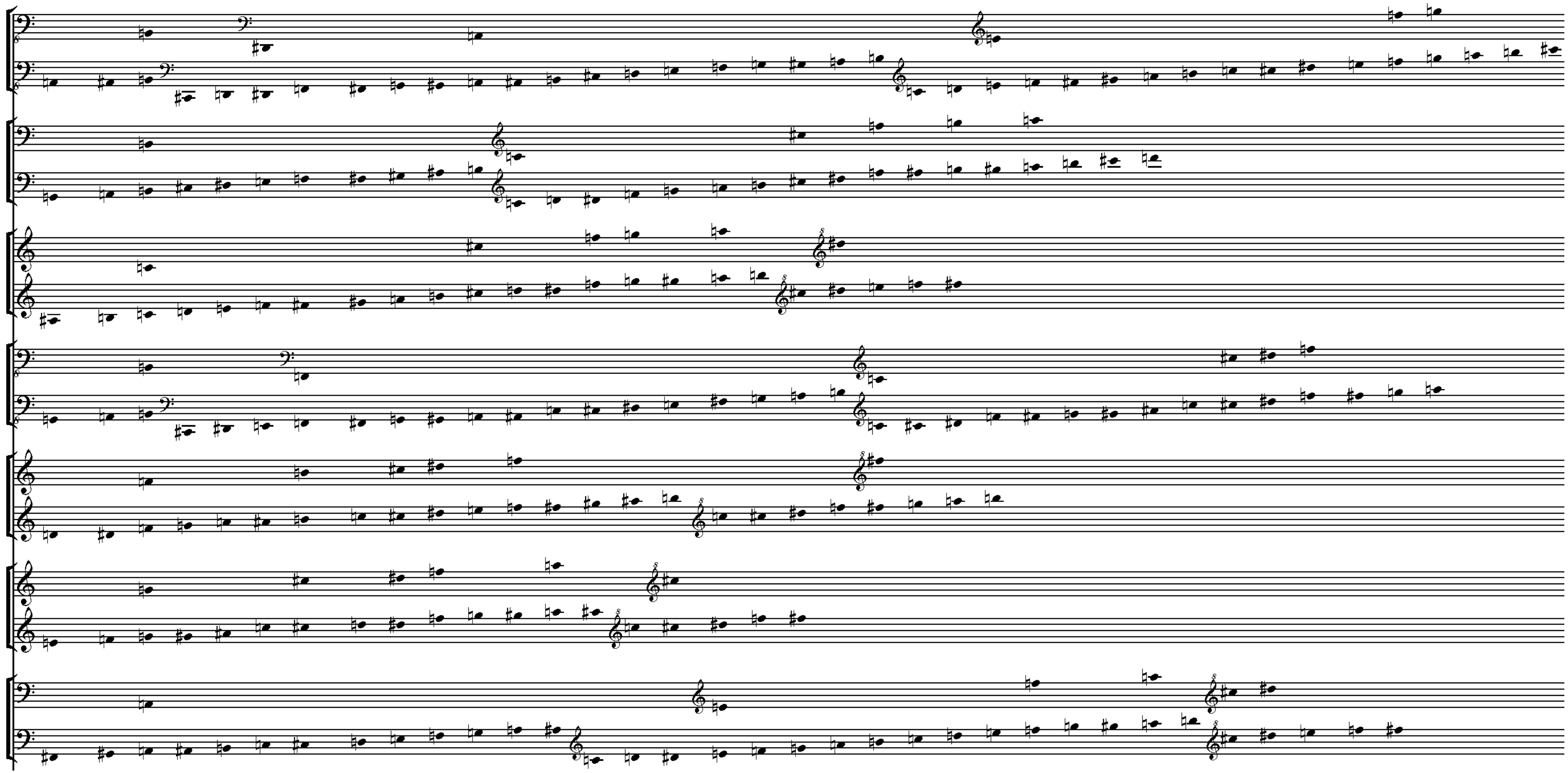

Figure II.2-54 – The first 7 (out of 19) sonorities and modes of the modular harmony progression.

II.3 Score Implementation

Score implementation is one of the fundamental stages of CAC, yet it is one of the less discussed areas. How do algorithm outputs make their way into musical scores? What aesthetic implications are to be found in the way I choose to implement those outputs? The following two sections discuss two broad categories: manual and automatic implementation.

II.3.1 Manual Implementation

Manual implementation means using an algorithm output as reference, so that the musical materials can be transferred to the score by hand. It is usually carried out if a given algorithmic process does not deal with durations, outputting materials such as a pitch sequence, a chord, a chord sequence, a mode, or other atemporal musical elements that cannot, as such, constitute part of a typical metered score.[52] Durations and their sequence are, of course, sufficient to create rhythm and, if notated as note values, constitute typical metered notation.[53] Section II.3.2 discusses the implementation of such algorithm-generated materials.

To be sure, manual implementation implies a break in the continuity between algorithm output and score: the outputs are not copied into the score automatically. This means that it is up to the composer to read and interpret the algorithm outputs and somehow integrate them into the score by hand. Naturally, this usually implies manual composition since further decisions need to be taken. One of them relates to whether the composer wants to completely follow the output's prescriptions as he/she is considering a given musical idea. Other decisions relate, in various ways, to instrumentation, rhythm, dynamics, context,

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[52] Other kinds of scores, in which duration of events is more loosely notated (such as graphical scores), could potentially integrate such materials provided that they correspond to a compositional intention.

[53] Inside OpenMusic, if a user wants to represent a musical element so that it can be played back, he/she would use *score classes*: NOTE, CHORD, CHORD-SEQ, and MULTI-SEQ, based solely on time duration, plus the VOICE and POLY classes featuring note value, metered rhythm. This means that, operationally, the user would use these objects for atemporal elements in spite of their durational specification, which enables finite playback duration. Otherwise, playback could not be achieved. For instance, a mode could be played back by using the CHORD object in arpeggio mode, or the CHORD-SEQ object configured so that each note is taken as a chord with finite duration.

musical complementation, among others. Manual implementation thus, and generally, means that more space is allowed for manual composition to take place.

It is important to note that, as discussed in Section II.2–Completeness of Results (p.45), if a given algorithm does not output complete musical results to be incorporated automatically into a score, it does not mean that it has insufficiencies, or that its programming could have been further developed. In relation to my practice, it usually means that I consciously decided that some aspects of composition would be left out of automation. The reasons for this are to be found in decisions that relate directly to the purpose, adequacy and nature of each composing method (manual vs. algorithmic).

II.3.1.1 Harmonic Progressions

Cognitive Principles and Spontaneity

As a first example, I will discuss the implementation of the results coming from the first algorithm discussed: the generation of vectorial harmony discussed in Section II.2.1.1 (p.47) and used to compose the piece *Shapes*.

The results were manually implemented in the score from bar 1 to bar 23. One of the main reasons for doing this manually was the idea I had for meter: I wanted to have short, contrasting, insertions of music with different tempo and time signature so as to provoke a temporary sense of 'not being able to follow' the rhythm in the listener. Hence, one of the main reasons for not automating more than just the underlying harmonic progression was a cognitive one. The phenomenon in question is called beat induction and corresponds to “the cognitive skill that allows us to hear a regular pulse in music and enables our synchronization with it” (Honing 2012). Accordingly, from bar 1 to 5 the listener is 'beat-inducted' by placing some musical stress on the beats of a 2/4 time signature and then, in bar 6, a different tempo and meter is immediately presented causing something we could call a 'cognitive processing delay', an element of surprise.

Finally, if the main reason for not automating beyond a certain point was a pre-existing idea for the meter and its cognitive impact, the other reason was tied to spontaneity: I wanted to write the music freely, choosing what I thought was appropriate in every step of the process. I thought that composing should be enjoyable and exciting, and hypothesized that this would mean a balance between algorithmic work and manual spontaneity. Too much algorithmic work would mean too much focus on algorithm design. That can, on the other hand, also be a source of enjoyment, but the more challenging the programming is, the more it can drift the attention away from the actual musical reality; in effect, turning the composer into a (temporary) programmer.

Intuition and Aesthetic Choice

While composing the piece *Dégradé*, the algorithm-generated progression shown in Figure II.2-12 (p. 59) was subjected to some alterations in its ordering in a quite intuitive manner. Some chords had unique sonorities that I wanted to keep isolated and not close together because that would weaken their uniqueness. In terms of durations, the following sequence of numbers was used as multiples of the quaver: 7 8 7 9 6 10 5 11 4 11 3 12 2 12 2 13 1 14. If plotted, this creates the shape shown in Figure II.3-1. This shape created unpredictability in the durations, but also a sense of bi-directionality. Durations get bigger and, at the same time, smaller, which I found very exciting.

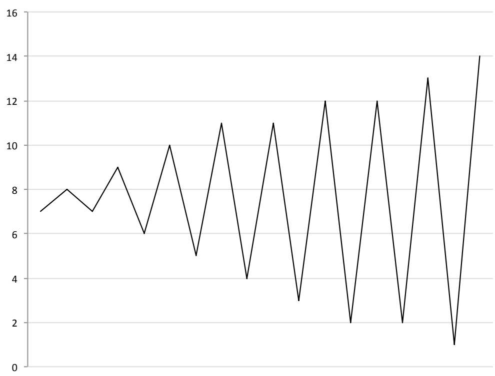

Figure II.3-1 – Duration contour for the chord sequence.

Orchestration was pretty straightforward since, from the beginning, the instrumental choices were fixed: flute, clarinet, violin and cello. Occasionally, the piano plays the same notes as the flute and clarinet to add timbral variation. Articulations were varied and dynamics were subjected to various envelopes, the prevailing one being the fade-in at the attack of a new chord.[54]

To confirm identity traits of the piece, a different stream is added on the piano part at bar 164 (manual complementation). It continues the descending

[54] Also called inverted dynamic envelope. Varèse (1883-1965) was probably the first composer to use them consistently.

melody contained in previous bars and based on the intervals of m2, M2, m7, M7, m9 and M9. It enriched the aural stimulus by constituting an additional perceptual stream.

Chord Articulation and Musical Complementation

A somewhat similar situation occurred while composing the piece *Vacuum Instability*, using the chord progression shown in Figure II.2-14, p.61. I decided to orchestrate the chords as subtly as possible, maintaining their sonic elegance and creating gradual emergences and extinctions: using dynamic envelopes equal to the shape '<>' as well as having the chord tones enter and leave at different times on different instruments.

Figure II.3-2 – Score extract from *Vacuum Instability*. Notated in C. First chord of the FM progression is at bar 9 and chromatic lines are indicated by rectangles.

As having solely the progression of sonorities would render the music very univocal and monotonous (in spite of the harmonic interest), I decided to add ascending chromatic lines as shown in Figure II.3-2 (manual complementation).

Adding another element to the texture creates auditory stream segregation,[55] and its recurrence throughout the passage stimulates auditory memory. Harmonically, the chromatic line develops the local harmony gradually by playing new pitches, working as passing notes, and formally anticipates the next sonority by arriving at one of its pitches. These lines are, thus, an additional element that enriches the aural experience and adds directivity to the music.

II.3.1.2 Mixed Complementation and Elaboration

Manual complementation and elaboration were defined in Section I.5.1 (p.39). When these kinds of manual procedures constitute the implementation of yet another algorithm output, a mixed situation arises:

- *Mixed complementation* corresponds to the complementation of an algorithmic material carried out as manual implementation of another algorithm's output.
- Similarly, *mixed elaboration* corresponds to the elaboration of an algorithmic material carried out as manual implementation of another algorithm's output.

In the piece *The Life is Ours*, examples of mixed elaboration and complementation can be found. I will discuss two of them, carried out to coexist in the score with the implementation of the output coming from the rhythm-focusing heterophony algorithm discussed in page 55. This heterophonic texture, based on the folk melody *Chamarrita Preta*, was implemented and scored for an instrumentation comprised of 2 oboes, 2 clarinets and 2 alto saxophones at rehearsal letter C. As I conceived it, the instruments needed to be from the woodwind section — I wanted a soft and stable dynamic and some timbral heterogeneity — and have compatible registers.

The mixed complementation that occurs at letter D relied on the output coming from the algorithm that calculated the partials from a virtual fundamental of the pitch set involved in the heterophony (see Figure II.2-15, p.62). I placed some of the calculated partials on the brass, making use of the easy accessibility of quarter-tones on the trombones (Figure II.3-3). As these partials arise out the E-quarter-tone-flat fundamental, they are of a different conception from the folk melody-based heterophonic texture.

[55] See page 89 for the definition.

Figure II.3-3 – Excerpt from *The Life is Ours* showing mixed complementation (indicated by the brace).

Figure II.3-4 – Focusing region of the rhythm-focusing heterophony (unboxed) and mixed elaboration (boxed). First bar shown is bar 88. Dashed line indicates the point from which the texture becomes homorhythmic.

A bit further on the score, the same heterophonic texture was elaborated with material coming out of the second technique based on virtual fundamentals (solution B, p.63). This mixed elaboration is shown in Figure II.3-4. As the generated pitch sets always contain the folk melody's pitches plus a transposition, they share the same conception.

II.3.1.3 Modes and Gestural Spontaneity

While composing the piece *Canti Firmi*, algorithms produced fixed materials (*cantus firmus*) coming out of madrigal's filtration, but also modes on which the manual procedures would be based on (see Section II.2.2.4, p.92). I printed the modes (p. 95) and began composing manually around the *canti firmi* using them as pitch reservoirs. The piece would end up adhering almost exactly to an arch form as shown in Table II.3-1, section length being strongly influenced by the length of each *canti firmi*.

Table II.3-1 – Formal plan of the piece *Canti Firmi*.

Section	**Bars**	**Cantus Firmus**	**Character/Movement**
A	1-31	CF1	*Vivo*
B	32-44	CF2	*Sereno*
A’	45-54	CF3	*Teatrale*
	55-62	CF4	
C	63-75	CF5	
B’	76-90	CF6	*Sereno*
A’’	91-108	CF7	*Teatrale*

Implementation of algorithmic results was automatic for the generated *canti firmi*, but totally manual for the modes. Thus, the manual procedures could be viewed as a case of mixed complementation and, to a limited extent, mixed elaboration of algorithmic materials (the *canti firmi*) given that, sometimes, local elaborations of the *canti firmi* occurred. Given the stronger significance of manual composition in general, I believe it makes more sense to consider the composition of the piece as a case of manual implementation (of the modes).

The solid foundations given by the modes and their progressions enabled a great deal of freedom and spontaneity, comparable to the levels present on the exclusively manual composition projects. *Gestural* is, perhaps, the most appropriate term to describe the composing that eventually completed the score. In this line of thought, Boulez can corroborate the whole composing layout when he says that:

If the system does not rest on solid foundations, then the musical gesture will also not be adequately formulated; the gesture needs to be preceded by some kind of pre-compositional reflection (cited in Goldman 2011, p.61).

The pre-compositional reflection that Boulez mentions was obviously the entire strategic approach and planning described in Section II.2.2.4 (p.92).

While composing, invention manifested itself, thus, through gesture, which started forming the piece's discursive material. But gestural formations were at the same time coalescing into a working hypothesis of musical form. Section content was, therefore, not conceived *a priori* (unlike section length and number) but relied on the characterization and development of sonic materials, which contrasted from section to section.

Figure II.3-5 – The first *cantus firmus* coming out of algorithmic filtering and score implementation at bar 1.

II.3.1.4 Discovery and Human Creativity

While composing the piece *Agnostos*[56] I tried to achieve a synthesis of all the things I learned with the pieces I composed before. For that reason, if there was a lot of algorithmic work involved, this was only to pave the way for imagination to take the lead afterwards (through manual implementation). Similarly, if the piece features more freely imagined passages, this is only because I was relying on solid ground given by the underlying harmonic control devised through algorithms.

Boulez's writings remain remarkable in that they outline and clarify quite well the configuration of resources that prepare the composing action. In his own words:

> This amounts to considering the system as an aid, a crutch, an exciter for the imagination which, without it, would not be able to truly conceive of a dreamed up world: I choose, therefore I am; I only invented the system in order to supply myself with a certain type of material; I must then eliminate or modify it as a function of what I judge to be good, beautiful, necessary (cited in Goldman 2011, p.60).[57]

Composing needs opposing forces, which leads me to postulate that algorithmic composition needs its opposite: the non-programmable. In this Hegelian dialectic,[58] we find, and indeed we strengthen, the importance of the composer as an intellectually resourceful being.

Kaija Saariaho and Magnus Lindberg exerted a strong influence during the composing period. Saariaho's article *Timbre and harmony: Interpolations of timbral structures* (1987) was particularly relevant, as was her later piece *Orion* (2002), the score of which I studied. I was concerned with sonority and, to a certain extent, the compositional attitude was biased towards the mental framework of electroacoustic composition. This 'way of composing', being historically rooted in the technical exploration of sound properties, typically does not rely so much on concepts such as notes, melodies, rhythms, progressions and variations, as on

[56] The Greek word for unknown.

[57] Original source is the text *Le système et l'idée* (Boulez 1986).

[58] "Hegel applied the term [dialectic] to the process of thought by which apparent contradictions (which he termed thesis and antithesis) are seen to be part of a higher truth (synthesis)" (Oxford University Press 2013a).

sonorities, textures, 'colours', layers, shapes and transformations. So it is only natural that Saariaho would write:

> Working with the computer has given me ideas which are equally applicable to instrumental music. [...] even the simple fact of noting how much one can vitalize a sound by adopting a constant micro-variation to complete its construction (Saariaho 1987, p.105).

Building on previous research projects and findings, I reflected and kept notes such as the following:

> I'm starting to question the notion that the composer should always hear and calculate inside himself what he is writing. This method can prevent that previously unheard, surprising, fantastic and truly unique music be written. It also can imply that the composer remains attached to his technique and compositional strategy (March 2014).

Could a composer hear inside himself something that he/she doesn't know yet how to formulate, how it works? For instance, can a composer know exactly how *every* possible vertical combination of *n* pitches (microtones and dynamics included) will sound? Surely for some combinations but, I believe, not for every one of them. I think the same applies to progressions. In this line of thought, inner hearing can only work if the composer is basing his/her writing on procedures he/she is familiar with.

This exploration/discovery attitude was a bit daunting, although exciting, but philosophically it made sense, resonating with Plato's writings:

> I am wiser than this man; it is likely that neither of us knows anything worthwhile, but he thinks he knows something when he does not, whereas when I do not know, neither do I think I know; so I am likely to be wiser than he to this small extent, that I do not think I know what I do not know (Plato 2002, p.26).

This explains the Greek title of the piece. I would later write:

> Creativity implies discovery; a mental state unafraid of doing what one does not know yet. [But this calls for] Underlying control of musical evolution (April 2014).

This "underlying control of musical evolution" is indeed where most of the algorithmic work resided.

With Magnus Lindberg, and in particular with the pieces *Feria* (1997) and *Cantigas* (1999), I was influenced by the exuberance and efficacy of orchestration, as well as by the formal control. I needed models that would enable me to create strong focal/arrival points but also effective orchestral passages that would punctuate and organize the piece's content as I gradually added the musical materials arising out of algorithmic explorations.

Table II.3-2 – Key developments for creating the underlying harmony of the second movement.

Sonority	**Development**	**Bars**
A.	Family of 7 sonorities — A1 to A7 — and corresponding modes: M(A1) to M(A7).	1-25
A'. Obtained by filtering A2.	Similarly, a family of 7 sonorities but now also a family of those 7 sonorities distorted.	26-52
A''. Obtained by the principles of modular harmony from A'.	A'' entered the Cyclic Harmonic Process to produce materials as described in Figure II.2-51. Each new sonority obtained that started the process again was labelled A''1 to A''4.	53-105
A''5. Obtained by manually filtering A''4's union of spectra, quarter-tones excluded.	Modular harmony produced 19 sonorities and their corresponding modes.	106 *al fine*

Table II.3-2 sums up the score locations of the harmonic materials whose algorithmic generation was described in Section II.2.2.5–Sonority/Mode Relationships and Microtonality, p.99. These mainly manual implementations of algorithmically generated pitch materials[59] (sonorities and modes) constituted the main part of the piece where I have relied the most on exclusive aspects of human creativity.[60] Personal involvement, imagination and a 'not knowing', questing attitude, along with a reliance on previously acquired musical knowledge (musical training and composing experience) were paramount aspects manifesting

[59] With the exception of woodwind textures starting at bar 26 — ostinati based on the pitch sonorities but generated algorithmically and implemented automatically — and also the ones contained in bars 123-133, which were based on algorithmic arppegiation of modular harmony (p.105), manually complemented by melodic ostinati on the strings.

[60] Aspects which are harder, or impossible, to simulate algorithmically. See Section III (p.147).

throughout composition. Perhaps a more adequate term would be ‘manual sculpting’ as it implied a great deal of imagination to create the gestures that emerged. It was indeed a very exciting process to begin drafting ways of articulating the algorithmically generated harmonic materials. Later I would become more judging and worked to further characterize the ideas I had sketched, thus progressing to more and more definite versions of the score.

II.3.2 Automatic Implementation

If an algorithm output features specified durations — either time-based or metered in the form of note values — it can be successfully imported into a sketch or developing score inside music notation software.[61] In OpenMusic, this usually implies exporting materials into a MIDI or MusicXML file. MIDI files do not support microtones and have to be quantized before being imported into music notation software. MusicXML files contain note value, metered notation and support microtones, but imply a more demanding programming strategy to deal with rhythm before they can be produced.

If an algorithm output is automatically implemented into a sketch or developing score, it can prevent errors which are known to occur while composers write a score passage based on a given compositional technique by hand. This is one of the advantages of automatic implementation. Another advantage is that it can speed up procedures, which would otherwise be very time-consuming to carry out by hand.[62] These aspects, among others, are frequently tied to more general advantages of using algorithms,[63] which means that, sometimes, automatic implementation is the only reasonable option.

Manual procedures usually follow automatic implementation and are needed for various reasons as described in the following sections. Underlying all of them is usually a concern with the *mechanicalness* present in raw algorithm outputs. Only very rarely did I leave the algorithmic materials virtually unchanged. I felt that it was up to me and to my 'composing hand' to guide and exert control over the composition process, taking all available measures to make the music I

[61] If a composer writes his/her score by hand, automatic implementation is never an option due to the digital/analogue (computer-based to paper-based) discontinuity.

[62] The speed aspect of algorithmic composition is further discussed in Section III.

[63] See page 32.

was more satisfied with. This stresses the importance of aesthetic judgement, self-criticism, and willingness to take decisions.

II.3.2.1 Manual Intervention

After an algorithm output is imported into a sketch or developing score through automated steps, it usually needs subsequent manual intervention. This is fundamental so that aspects such as articulation, dynamics and metre, among others, can be applied to the raw material. Some of these aspects represent limitations of OpenMusic: it cannot currently automate articulation, nor can it export dynamics (although it allows their automation). Sometimes, other manual interventions can be carried out which change the material itself: duration adjustment, note deletion, pitch changes, insertions, etc.

Instrument Range, Articulation, Dynamics, Rhythm

As shown in Figure II.3-6, the output that came out of the pulse unfocusing algorithm (p.51), used to compose the piece *Shapes*, was implemented into the score quite literally in bars 37-46. Instrumentation constraints led to the adaptation of the pitches by transposition so that no note was outside a given instrument's range. This can be readily seen by comparing the first notes of the algorithm output with the first notes of bar 37 of the score. Rhythm notation was simplified to improve playability. For instance, a quintuplet, which only has a semiquaver at its beginning, can be simplified to a single semiquaver, which is similar to a staccato quaver.

In bar 43 a gradual change of articulation to pizzicato begins to occur. The intention was to add a timbral shift to the ongoing pulse unfocusing process. If tempo can be regarded as a perceptual attribute,[64] then so can timbre. By adding change to another perceptual attribute, I wanted to enrich the auditory stimulus and therefore the listening experience.

[64] See Levitin (1999) for a discussion of perceptual attributes related to auditory stimuli.

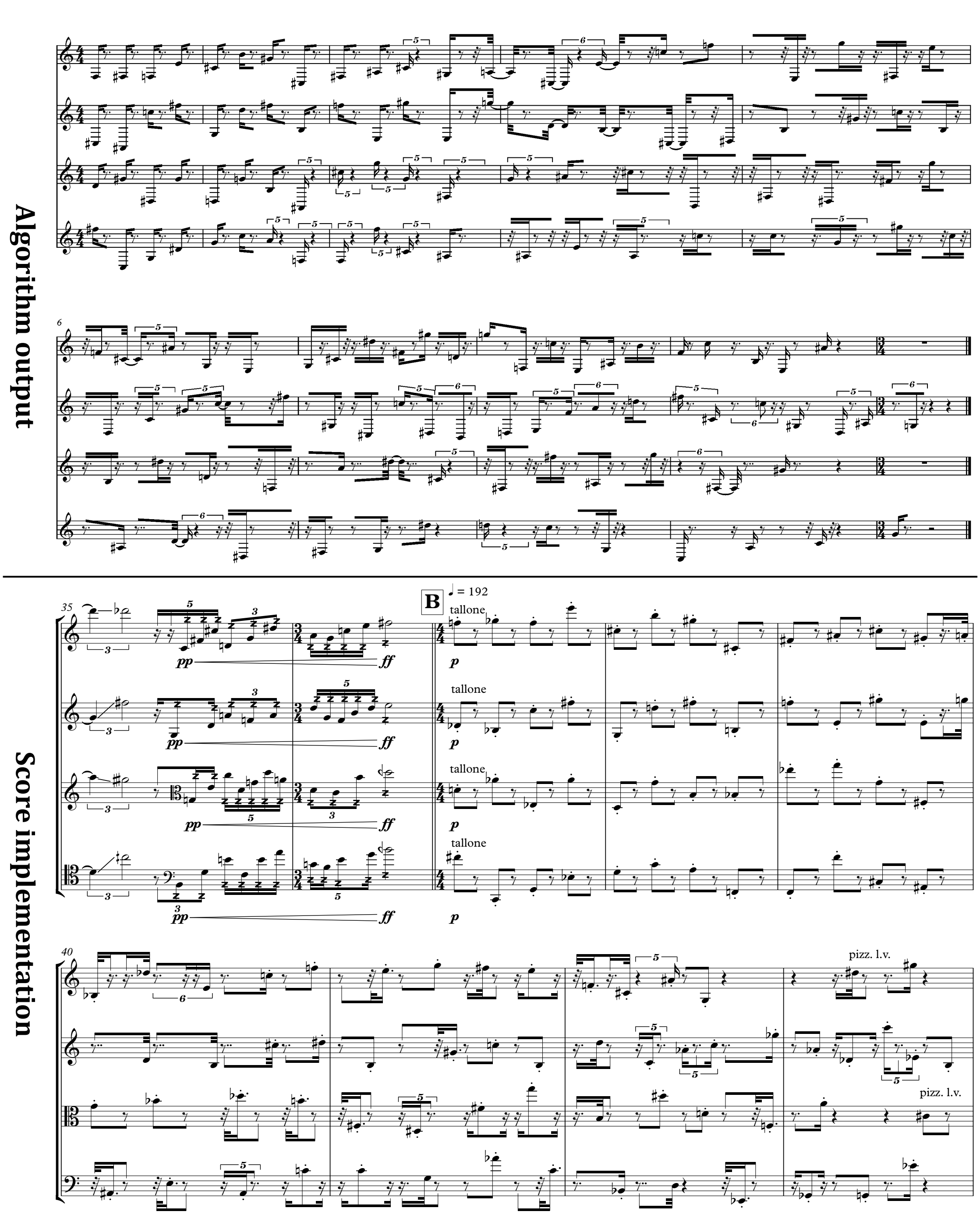

Figure II.3-6 – Raw algorithm output of pulse unfocusing and implementation in bars 37-43 of *Shapes*.

Metre

A rhythmic nesting algorithm, the description of which can be found in Appendix IV.4.5, was used on two pieces of the folio: *Duet* and *Stochafrica*. A first example of its output and implementation is shown in Figure II.3-7.

The score implementation was literal and automatic but involved some decisions regarding metre, rhythm notation, dynamics and articulation. I decided that the different rhythmic interventions should begin and end at bar lines, i.e. fit exactly on one or more bars. This helped stress the two interventions and reflect the sharp rhythmic juxtapositions derived from the quantitative nesting process. This was enhanced by the different dynamic and articulation of the rhythms, which contributed to a sense of mosaic-like contrast.

Figure II.3-7 – Excerpts from the rhythmic nesting algorithm output and its implementation at bar 78 of *Duet*.

Figure II.3-8 – Excerpt from the rhythmic nesting algorithm output (top) and score excerpt (bottom) showing the implementation of rhythmic nesting in *Stochafrica*. Solid and dashed boxes represent starting and arriving rhythmic material respectively. The first duration of the raw algorithm output was deleted.

The rhythmic nesting algorithm was improved before being used again to compose the piece *Stochafrica*. Although it now exported meter, which coincided with the different parts' interventions, its output still had to be subjected to manual interventions in order to improve playability (Figure II.3-8). As musical situations changed and presented themselves to me, I had to constantly judge the outputs of automated procedures, always caring for the production of an efficiently notated musical score.

Percussion Notation

Percussive ostinati produced by the algorithm discussed in Section II.2.2.2–Percussive Ostinati (p.87), had to be re-notated on a percussion staff. In Figure II.2-40, a raw 21-note ostinato is shown along with its final score notation clarifying instrumentation and meter. Because of sample positions on the chromatic scale the raw ostinato features large skips and many ledger lines. After choosing proper instrument location on the 5-line staff, meter was added after considering the ease of playability together with implied or imposed accents, noting that durations placed at the beginning of bars tend to have more of a downbeat character.

Figure II.3-9 – The raw 21-note ostinato and its score notation.

This ostinato constituted the first musical material I selected and was implemented at bar 317, which means that the composition progress did not generally follow score order.

In Figure II.3-10 another raw ostinato is shown, along with its score implementation at the first bar. The *mbila* (singular of *timbila*) is a pitched percussion instrument from Mozambique, similar to a marimba. As the tuning varies from instrument to instrument and does not conform to equal temperament, nor to a standard chromatic scale, I decided to use a 3-line staff, the lines of which delineate the registers. The tuning contributes to the characteristic general sonority of *timbila*, so that notating only the pitch contour and register made sense musically. I did not want to research the exact pitch potentialities of the instrument.

Rhythm was precisely notated after deciding which meter fitted best and slowing the tempo. The fast tempo of the raw output (♩ = 140, or ♪ = 280) was not considered adequate to start the piece because of the tension it carried. The ostinato served as a theme, to be gradually developed manually either through variation of pitch contour, or through alternation with new material.

Figure II.3-10 – Raw 5-note ostinato and its 3-line staff score implementation.

MIDI Limitations

While composing *Dégradé*, I programmed an additional algorithm for producing musical objects similar to the one described in Section II.2.2.2–Musical Object Generators (p.80). Described in Appendix IV.4.4.2 (p.163) and programmed before, it didn't rely on note values and metered notation but on time durations (in milliseconds). Each object was exported from OpenMusic individually as a MIDI file, to be subsequently imported into notation software. As MIDI files do not currently support quarter-tones, the pitches had to be very tightly proofread and manually changed, a time-consuming process. After assigning quarter-tones to the correct pitches, the objects could be compiled as shown in Figure II.3-11.

Inside OpenMusic, the objects existed in time-based notation (inside *MULTI-SEQ* objects). Rhythmic quantization — which converts the note events to note values on a metered score — involved approximations carried out by the quantization algorithm of the music notation software. It was configured to allow only a certain degree of notational complexity — for example by preventing the creation of certain types of complex tuplets — but the whole process is cumbersome and can introduce distortions (a compromise between notational accuracy and simplicity/clarity) to the original time-based notation.

Figure II.3-11 – Algorithm output of musical objects based on the pitch reservoirs shown at the top (OpenMusic accidental notation). Quarter-tones had to be added by hand. Notes featuring a rectangle are errors produced by OpenMusic quantization (many times easy to spot because they default to middle C). The instrumental ranges used were: cl., vln., vc., pno. (top to bottom).

After durations were doubled for better notational clarity, the outputs shown in Figure II.3-11 were implemented in bars 147-157 of *Dégradé*. The last three objects were not used and the orchestration of the algorithm output was changed to fl., vln., vc., pno., although the flute excluded the existing quarter-tones. The replacement of previous section's clarinet with flute, along with the fact that now quarter-tones are present, helped give this music a slightly different overall timbral quality, which developed the articulation of form. It created a subsection within a section. The harmonic rhythm was also subject to intervention as shown in Table II.3-3.

Table II.3-3 – Harmonic rhythm.

Chord	1	2	3	4	5	6
Beats	8	8	7	8	7	6

Reshaping and Character

After looking at the algorithm output shown in Figure II.2-36 (p.84) — produced while composing the piece *Dégradé* — and imagining the performance of it, it became clear that a doubling of its durations would be helpful: it would make the music easier to read and perform. The algorithm output was then distributed by available instruments, reshaped and integrated with other music material.

It was implemented in the score from bar 97 to 126. It's interesting to note how the raw output could reveal melodic figures. This was acknowledged and maintained to a great extent. For instance, the initial figure on the clarinet part in bar 97 uses the first four notes of (algorithm output's) voice 1. In bar 100, the clarinet plays again the figure contained in the end of the second bar of the first voice while the piano plays a heterophonic and sustained version.

Further reshaping occurs on the third beat of bar 101: the flute plays part of the figure contained in the raw material and extends the duration of pitch B so that it connects with the following A. Accordingly, in some passages, durations were augmented to create *legato* melodies inside a single instrument or to increase overlap between the instruments, making the harmony more present. In other passages, durations were left unchanged in order to express the rhythm of the local musical object.

The main principle guiding the composition was a desire to have subtlety in character.[65] Therefore, dynamic markings in the range of '*ppp*' to '*p*' abound, with occasional 'dynamic eruptions' that break the monotony.

Creative Reshaping: Stream Segregation

Manual intervention can change the algorithmic material so that it gives rise to two different perceptual streams. In a way, this type of manual intervention gives rise to a kind of musical complementation. In contrast with manual complementation (see Section II.3.2.3), this added stream of music is originated from the algorithmic material itself and not created entirely by hand.

Figure II.3-12- Passage from bars 28-32 of *Dégradé* showing the melodic segregation by means of transposition.

The transposition of segments of the algorithm output gives rise to auditory stream segregation.[66] When the transposition between the two elements becomes large enough, we start to hear two separate melodic streams arising from a single one. Figure II.3-12 shows the raw algorithm output plus its score implementation. The output was firstly transposed as a whole by 3 octaves plus a M2. After that, some pitches were progressively transposed up and sustained. In the first bar of Figure II.3-12, some free variation of the initial output was also carried out.

[65] See score's notes for execution: 'the music is soft, sensitive, "silky", even a little lyrical'.

[66] See page 89 for the definition.

Unwelcome Aspects

In spite of the control I exerted during algorithm design, and mostly due to indeterminism, algorithmic procedures sometimes produced results that had unwelcome aspects. It was all too easy to overlook them while I was inside OpenMusic, either because of a 'rushed' visual and/or playback assessment, or because of a somewhat slack aesthetic judgement, which could have been stricter. Also, the larger the algorithm outputs, the more time it takes to analyse and judge them properly.

As an example, also while composing *Dégradé*, I had to carry out local changes to the algorithm's output in order to correct pitch sequences that had unwelcome intervallic implications. As shown in Figure II.3-13, pitch F on the first semiquaver of the second beat of bar 45 was changed to E to prevent two adjacent octaves (F-F-F). The A♯ in the first semiquaver of the third beat was changed to B to prevent an octave. These unwelcome intervallic implications arise because the compositional technique, automated through algorithm design (see Section II.2.2.2–Juxtaposing Melodic Figurations), only controlled pitch ranges and not intervallic or harmonic aspects (except for trills, which could be either m2s or M2s).

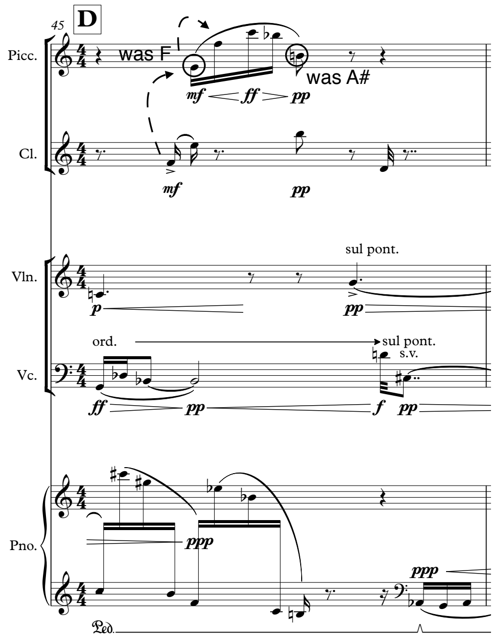

Figure II.3-13 – Annotated score excerpt from *Dégradé*.

As the research progressed, I learned to exercise more and more aesthetic control and judgement while producing algorithmic materials, particularly in terms of pitch and harmony. Somewhat simultaneously, I began to leave more space for manual composition so that I could take care of local implications *while* a musical material was growing in the score.

Cadences

Murail's statements quoted on page 33, are especially relevant in terms of cadential gestures, which are essential devices for controlling musical flow and form. When he says "I need objects that have a meaning: expectation, closure, opening, or whatever" (Murail 2009, p.11), we can instantly imagine how hard it would be to automate these aspects of music. There is something in them not comparable to easy-to-formulate technical procedures: they're formal functions related to musical rhetoric.

In bars 50-51 of the piece *Dégradé*, the manual intervention *ritardando* creates a cadential gesture, which makes the algorithm's output line stop (low G, at the start of the 7th bar of Figure II.2-33, p.81). The *ritardandi* that occur afterwards, instead of creating cadences, break some of the monotony that builds up due to the rhythmic activity of the main line.

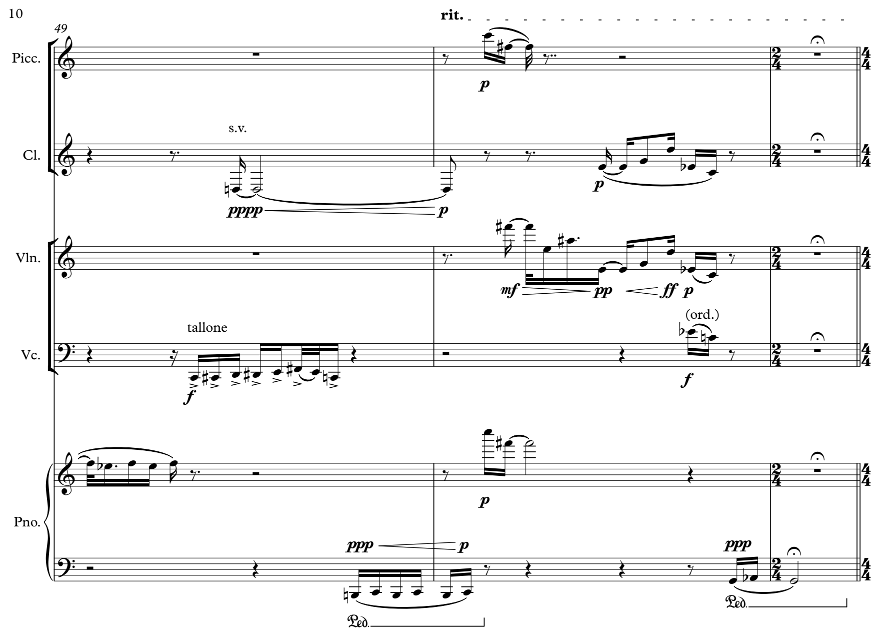

Figure II.3-14 – Score excerpt from *Dégradé* showing an intermediate cadence.

Microtonality and Instrumentation

Score implementation of the harmonic progressions discussed in Section II.2.1.4–Circular and Helicoidal Harmony, p.64, was initially automatic into a multi-staff, non-instrumental score, but relied on intense subsequent interventions due to the complex task of adapting the music to the available instrumentation. The ubiquitous presence of quarter-tones meant that great attention had to be given to playability. I always tried to allow time for quarter-tone preparation by the players and preferably chose lower fingerboard positions for the bowed strings so as to improve tuning accuracy. Often, this implied the use of artificial harmonics, which had a welcome acoustical consequence of creating a pale, rather thin initial textural sonority. In spite of these preventive measures, a reasonably accurate performance of the score would nevertheless be demanding — but by no means unattainable, I believe — in terms of tuning: an *n*-element string section would take considerable effort in tuning the same quarter-tone homogenously, but also in trying to tune it with an additional woodwind or brass instrument.

All the progressions exist mainly on the bowed string section with the exception of the one featured at the bottom of Figure II.2-21 (p.66) — implemented at bar 88 with anacrusis — which spread to the woodwind and brass sections, to create denser, homophonic orchestral textures. The progressions shown in Figure II.2-20 (p.66) were initially scored for strings only, but I eventually added some woodwinds to create a denser, more idiomatic orchestral texture. Importantly, one of those progressions exposed P5s quite dramatically and in an unprepared way. Instead of reprogramming the algorithm to get more harmonic continuity, I decided to accept this characteristic so as to give rise to a new parallel fifths line on the bassoons (bar 17 and after, a manual elaboration).

II.3.2.2 Manual Elaboration

Often, manual elaboration follows intervention. These procedures develop musical materials coming from algorithms, either because they're produced as incomplete in some way, or simply because developing them makes musical sense.

While composing the piece *Dégradé*, and after composing *Shapes*, I tried to achieve different and more satisfying balances between algorithmic and manual composition. Although many algorithm-generated materials were automatically implemented, a dominant concern was to have them serve as raw material for further manual elaboration.

Manual elaboration relied on important concepts such as spontaneity and intuition. These aspects create an important tension with the control coming from algorithm design and automatic implementation. The spontaneity/control tension is a core aspect of musical composition and, therefore, it is only natural that I'd stumble upon its significance.

A first example can be found in the first bars of *Dégradé*. The algorithm output shown in Figure II.2-31 (p.79) was used to build the piano part from bars 1 to 33 of the score, which constituted the basis for further manual intervention and elaboration. The prevailing idea was that the other instruments would be contaminated by the piano part (manual elaboration) but would also add fresh, new musical material (manual complementation).

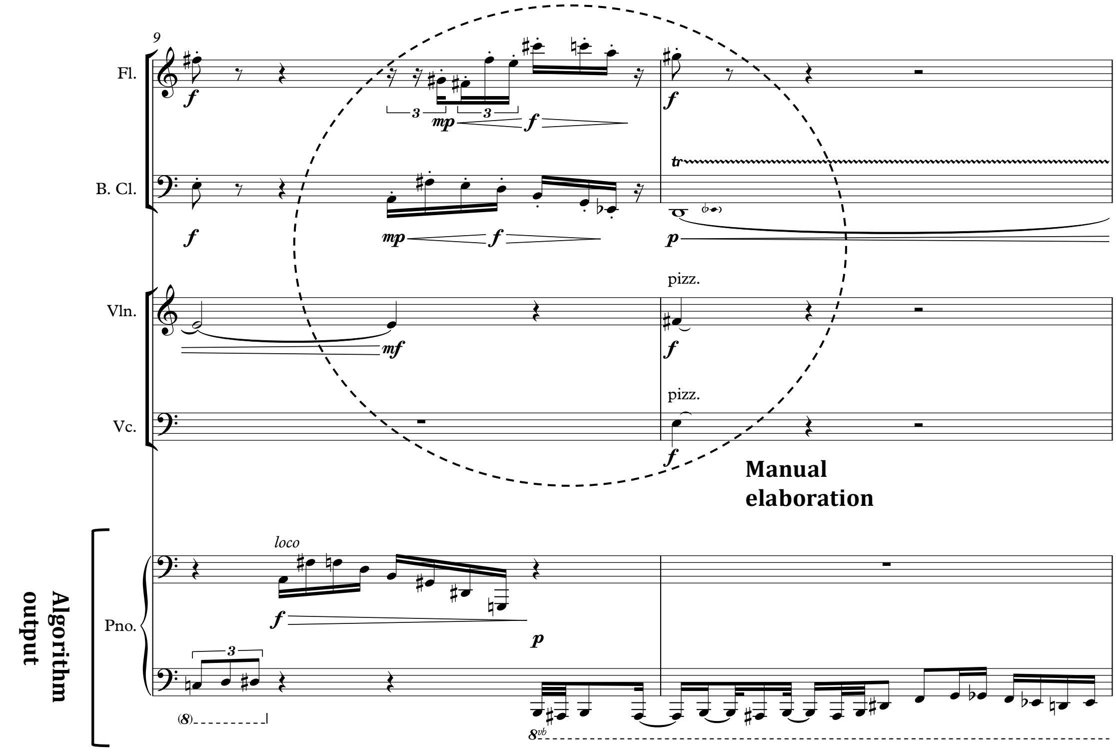

Figure II.3-15 – Annotated score excerpt from *Dégradé* showing manual elaboration.

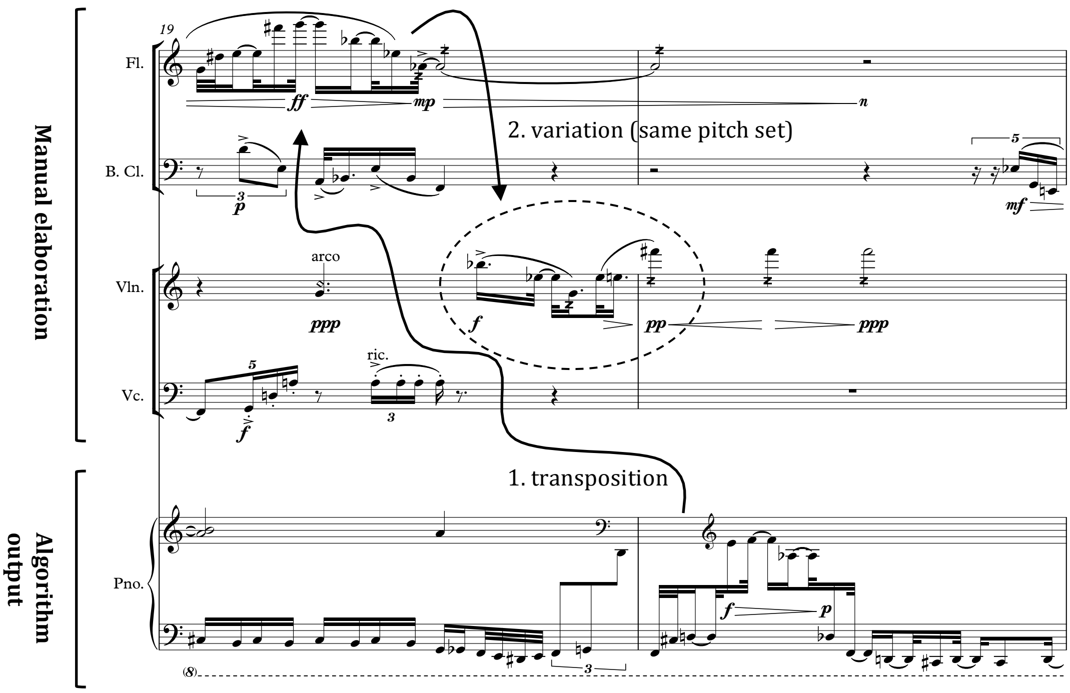

Figure II.3-16 – Annotated score excerpt from *Dégradé* showing more intricate manual elaboration.

In bars 5-11, a wave-like event is created with an overall shape that is different from the piano 'pitch-waves'. Nevertheless the intimate relation between the two can readily be seen in Figure II.3-15. Around bar 19, the contamination is also noticeable, but the elaboration is more intricate (Figure II.3-16). Further ahead, and building on the algorithm output shown in Figure II.2-33 (p. 81), the wave-like figure is harmonized with M2s (piano) and then with m2s and M2s (piccolo), exemplifying yet another kind of elaboration (Figure II.3-17).

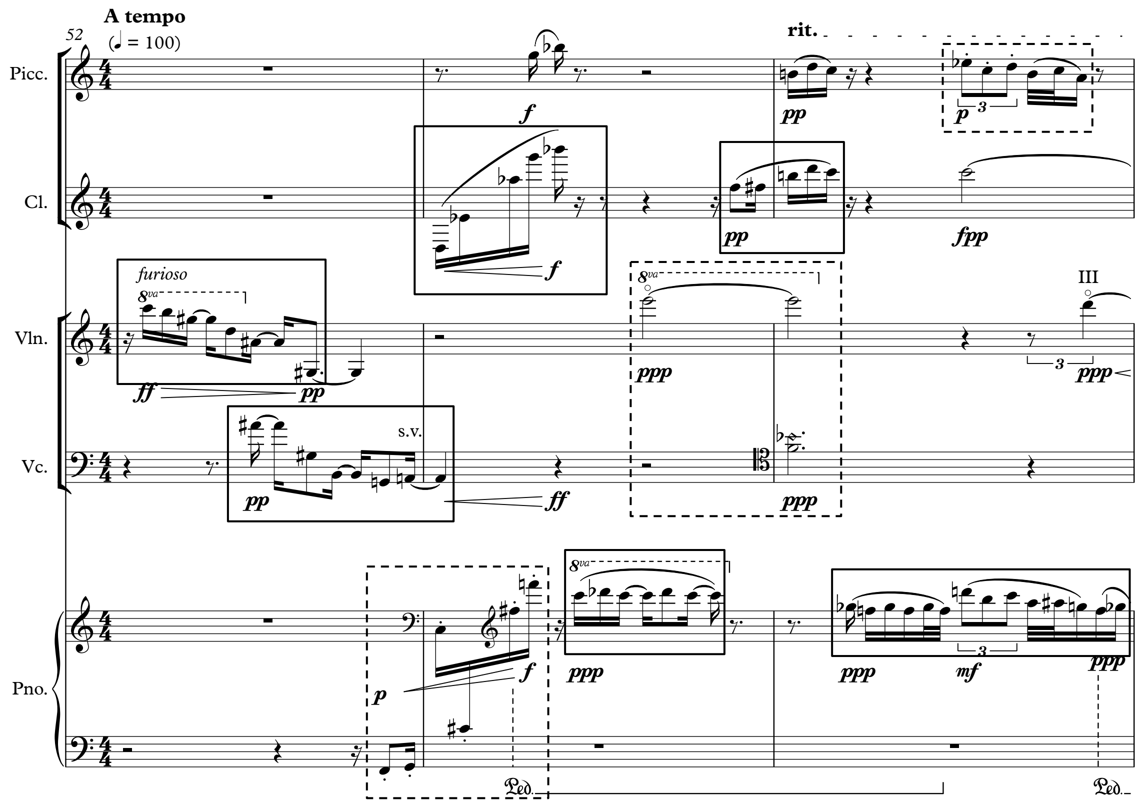

Figure II.3-17 – Annotated score excerpt from *Dégradé*. Solid boxes indicate algorithm output. Dashed boxes indicate manual elaboration procedures.

A different type of elaboration can be found in bar 128, where a flute melody is manually added to the texture made up of materials coming from the musical object generation algorithm. Although it clearly stands out in the music, there is fusion with the pre-existing texture, creating a typical ‘melody plus accompaniment’ texture. This is because of the harmonic relation and/or resonance between the two. If we collect all the pitches from the harmonic progression on which the algorithm output is based and transpose one octave up until they fit the flute's range, a mode is obtained:

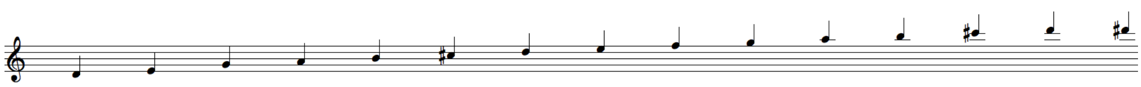

Figure II.3-18 – Mode arising from all the notes in the progression after transposing them up one octave.

This was the underlying mode for the flute's melody. Since all harmonic series' partials are reproduced at the octave above (any integer multiplied by two gives an integer also), there were strong resonance links between the two materials. In spite of this, moment-to-moment combinations of pitches were very important to consider, along with the use of notes not contained in the mode (F♯4 and B♭4, for instance) to chromatize/expand it.

Figure II.3-19 – Annotated score excerpt from *Dégradé* showing manual elaboration.

In the piece *Duet*, we can find manual elaboration procedures aiming at emphasizing features on which algorithm design was based on. The algorithm output shown in Figure II.2-43 (p.91) was implemented mainly in piano 2, starting at bar 176, sixth semiquaver.

An excerpt of the score implementation is shown in Figure II.3-20. To piano 1 the function of stressing the melodic segregation (that is the basis of the algorithm) was ascribed and carried out manually. As the piano 1 'picks up' materials from the algorithm output (contained in piano 2), it develops them to varying extents. In the upbeat of bar 179, a three-note figure[67] is picked up from piano 2 without alteration, but further on, in bar 180, left hand, a m3 above the picked-up low C♯ is added. In bar 181, right hand, a quaver triplet contrapuntal

[67] This figure is one of the chosen pitch sequences that the algorithm will transpose up by applying the interval vector, segregating it from the rest of the sequence.

continuation is added to the high figure and in the second beat of bar 182 the low B picked-up from the piano 2 is succeeded by more notes creating a short contrapuntal figure. Still in bar 182, right hand, a tuplet figure is again added but it is now of m3 crotchets. From bar 184, a syncopation of the high segregated figure is begun by stressing only the third note (C♯ on the right hand) with octave doubling (timbral).

Figure II.3-20 – Annotated score excerpt from *Duet*. Boxes indicate the algorithm output.

These manual developments of the algorithmic material continue the individualization that was already part of the automated technique. They instil freshness and depth into music that relied only on a mechanical process.

In the piece *The Life is Ours* , the implementation of the output shown in Figure II.3-21 (coming out of the melodic colouring algorithm discussed in Section II.2.1.2, p.49)[68] at bar 7, in the brass section, was automatic but underwent subsequent manual interventions and elaborations. In Figure II.3-22 one can see the respective excerpt from the final score. I carried out manual interventions such as duration doubling and discarding the first part of the algorithmic harmonization. Octave doubling of the lowest voice plus re-harmonization of the

[68] See also Appendix IV.4.8, p.172, for the algorithmic description of the closely related *spectral enrichment* algorithm used to generate the material shown in Figure II.3-21.

first part by hand were subsequent manual elaborations. The reason for reharmonizing was that I wanted a denser sonority to follow the timpani crescendo (see first page of the score in Figure II.3-27, p.137). This aesthetic decision draws attention to the importance of musical context in CAC.

Figure II.3-21 – Spectral enrichment (melodic colouring) of a melody. The initial melody is shown at the bottom staff. Allowed partials were the odd numbers 3, 5, 7, 9, 11, 13 and 15.

Figure II.3-22 – Score implementation of the algorithm output shown in the figure above.

Remote Manual Elaboration

Algorithmic materials and their manual elaborations can be placed far apart on a score. While composing the percussion piece *Stochafrica*, I considered that the vibraphone, being a *pitched* percussion instrument, needed a compositional strategy that wasn't ostinato-based. As the unpitched percussion section was already progressing compositionally, I based the vibraphone part on it. The important percussive ostinato, shown in Figure II.3-23 and generated algorithmically, was regarded as a contour in register insofar as the different instruments could be ordered from low to high:

Bass drum < timpano < toms < snare drum < cymbal < triangle

The transition from register contour to melodic contour was, thus, very straightforward.

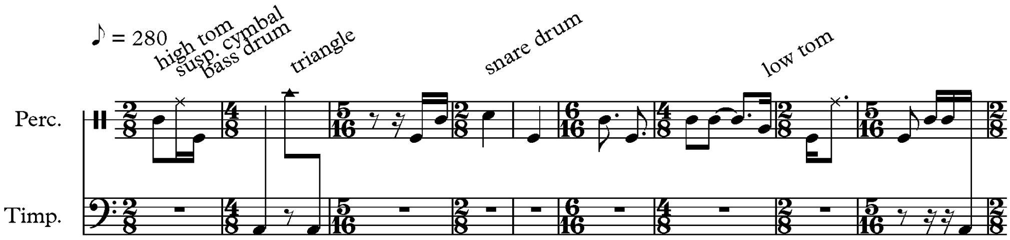

Figure II.3-23 – The 21-note ostinato implemented at bar 317 of *Stochafrica*.

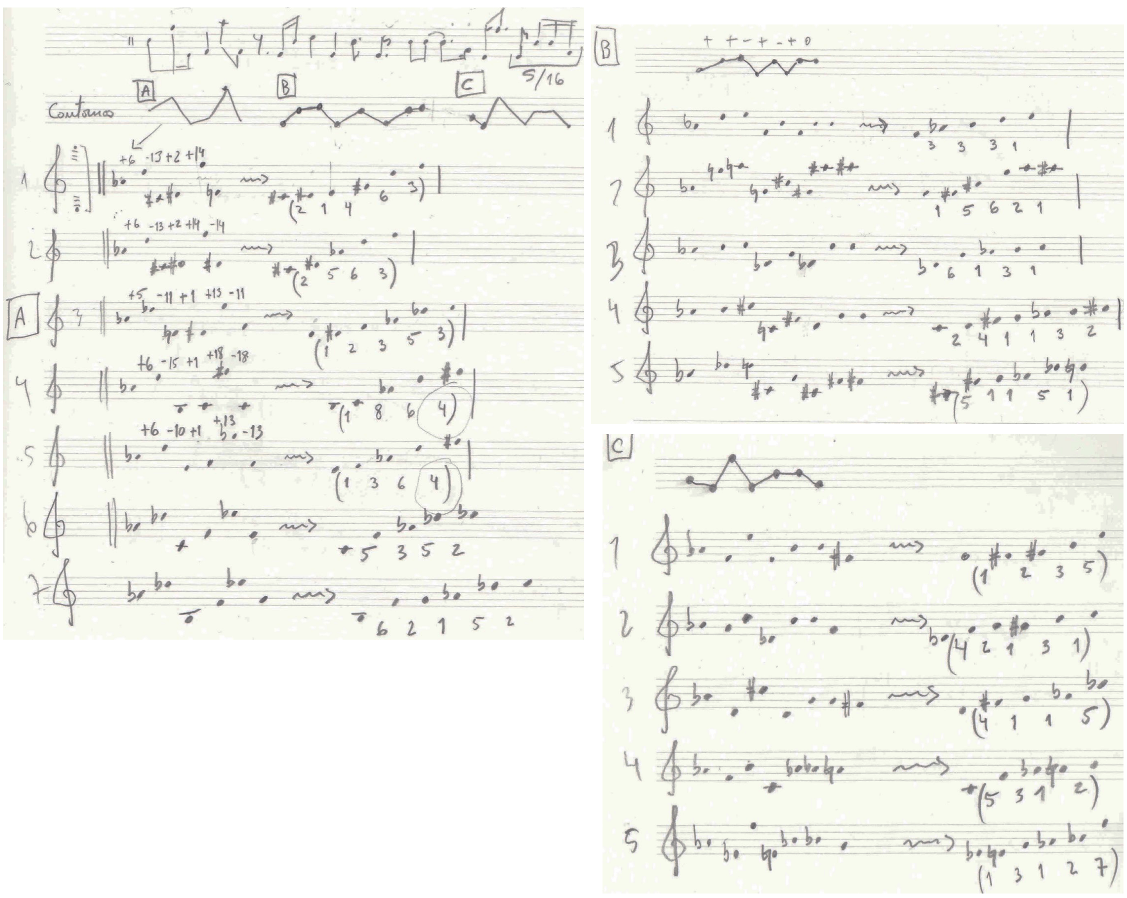

Figure II.3-24 – Sketches for the derivation of melodic figures from a rhythm. Numbers represent intervals in semitones.

At the top of the leftmost sketch featured in Figure II.3-24 the ostinato is shown, along with its segmentation into three parts: A, B and C. The melodic figures I created follow each contour segment and constitute an example of manual elaboration.[69] Instead of placing the developments at the same score location — thus enlarging the initial material — they are placed far apart, or remotely: the original ostinato is located at bar 317, while its manual elaboration in the vibraphone is located at bar 63.

An excerpt from a preliminary score is shown in Figure II.3-25, annotated to show the melodic figures. They were often used quite literally, sometimes varied, and were interspersed with different material of various functions: contrasting, cadential or simply connective. To produce the final score, phrasing and articulation were further clarified.

Figure II.3-25 – Preliminary score showing manual composition based on the melodic figures.

II.3.2.3 Manual Complementation

As defined in Section I.5.1, manual complementation means adding a material of a different conception to the score so that it coexists with algorithm-generated materials. Music complementation is a quite usual device in composition

[69] See page 40 for the definition.

but, in CAC, and carried out manually, it acquires more significance as it usually relates to the balance between manual and machine composition.

In bar 106 of the piece *Dégradé*, a descending arpeggio-like melody — based on the intervals of m2, M2, m7, M7, m9 and M9 — is added to the pre-existing texture. As the melodic figuration, implicit harmony, unequivocal directionality and defined timbre (piano) of this added element is so unique, it does not fuse with the pre-existing texture (it is stream-segregated). And so a different stream is created adding richness and depth to the music.

Figure II.3-26 – Excerpt from the score of *Dégradé* showing manual complementation.

More intricate configurations of manual and machine composition usually rely on a mixture of procedures, like those present at the beginning of *The Life is Ours*' score (Figure II.3-27).

Figure II.3-27 – Excerpt from the first page of the score of *The Life is Ours*. Solid boxes indicate automatic implementations of algorithm outputs. Dashed boxes indicate manual procedures.

Other situations can exist where manual complementation occupies a more significant part of a given score's passage, as in *Agnostos*' first movement. In the excerpt shown in Figure II.3-28, the algorithmic material (a fractal melody)[70] is heard as a continuous background, whereas manual complementation creates new sonic events. The creation of additional layers prevented the algorithmic materials from existing alone in the score — risking a monotonous or mechanical effect — and enabled a more flexible control of the musical discourse.

70 See Section II.2.1.5, p.67, for its algorithmic generation.

Figure II.3-28 – Score implementation of the algorithm-generated fractal (boxed) and manual complementation (unboxed) in *Agnostos.*

II.4 Manual Composition

The following two sections provide short analytical commentaries on two pieces of the portfolio composed using no automated methods. While *To the Muses* was composed quite early in the research period (see Figure II.1-1, p.43), providing contrasting compositional strategies which clarified aspects of both manual and machine composition, *Two Different Pieces*, composed before the last three pieces, built on an accumulation of knowledge and critical reflection. It went much further in clarifying the exclusive aspects of human creative thought.

II.4.1 To the Muses

II.4.1.1 The Composition Project

The word 'music' has its origins in Greek mythology denoting the "(art) of the Muses" (Oxford University Press 2013a). *To the Muses* is based on William Blake's (1757–1827) poem, which appealed to me because of its musical allusions.[71] The piece explored compositional processes realized manually and showed how different from algorithmic procedures a manual process could be in nature, but also gave me some hints regarding the characteristics an algorithm should have so that it could, hypothetically, imitate less systematic aspects of human creative thought. This reflection continued throughout the research period.

II.4.1.2 Manual Procedures

The manual procedures I chose to analyse deal with processes of melodic variation, particularly melodic contour contraction of the same kind found in Messiaen, a composer I much admire. In the third piece (*L'échange*) of *Vingt Regards sur l'Enfant Jésus* for piano (1944) Messiaen uses the term 'agrandissement asymétrique' to denote melodic contour enlargement.

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[71] As a poet, Blake seems to be aware that the muses "were originally the patron goddesses of poets (who in early times were also musicians, providing their own accompaniments)" (Encyclopedia Britannica Inc. 2015). Expressions such as "From ancient melody have ceas'd", "melodious winds", "The languid strings do scarcely move! / The sound is forc'd, the notes are few!" (Blake 2006) allude directly to music, but also metaphorically to inspirational issues. This is further emphasized by expressions such as "Fair Nine [muses], forsaking Poetry!" and "How have you left the ancient love" (*Ibid.*).

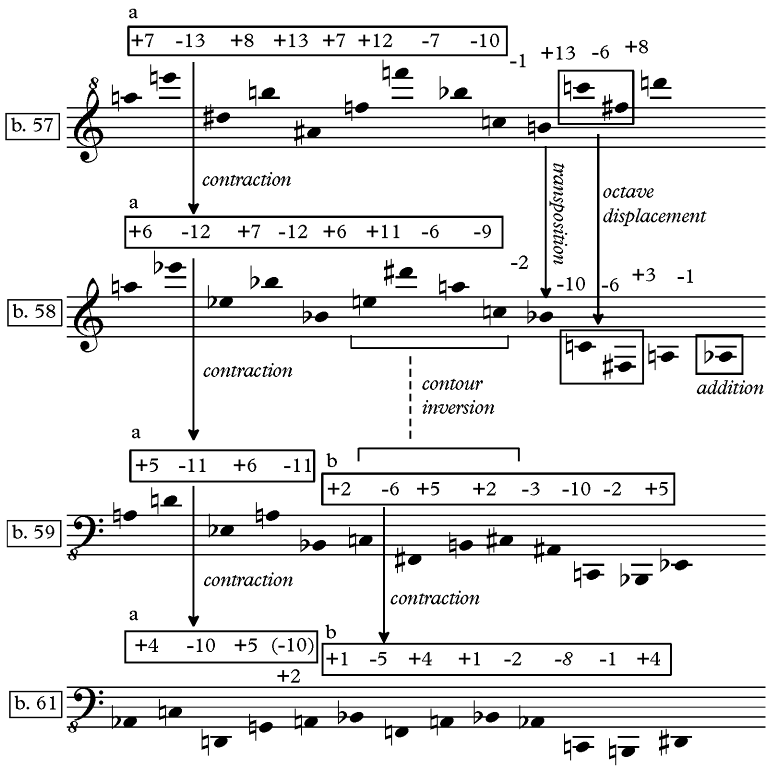

Figure II.4-1 - The melodic variation process in four main steps. Numbers indicate intervals in semitones, their sign indicating direction.

The starting material is found on the score from the second beat of bar 57 until the end of that bar. If we follow what happens to this 'melodic object' up to bar 62 we can outline four main steps as shown in Figure II.4-1. These steps involve contour contraction and inversion, transposition, octave displacement and addition.

The first step (bar 57 to 58) only contracts the first eight intervals mathematically, the remaining four pitches being subject to transposition, octave displacement and addition (pitch A♭ is added as a last note). Thus, this first step is not pure contraction but a mixture of processes. After the added A♭ is eliminated, the first four intervals are then progressively shortened by a semitone with the exception of the last with suffers an additional octave displacement in the last step. The remaining intervals — labelled *b* in the Figure — undergo a contour inversion — *sensu lato* and again not mathematically — before undergoing a two-semitone contraction (the interval of -10 semitones is contracted to -8, instead of -9).

II.4.1.3 Reflections

The analysed set of different internal procedures that constitute the melodic variation display the degree of flexibility and invention involved in manual composition. Implying a mixture of techniques and not strictly mathematical procedures, the whole process could only partly be related to algorithmic non-determinism (see page 31 for the definition) if hypothetically automated: it would have to be a non-determinism affecting the choice of internal processes to combine (programming subroutines?) and the extent to which they act (on one note? on three?). With all probability, if an automated algorithm had been built for melodic variation, it would have displayed a lot less diversification of internal processes. Furthermore, although the same result shown in Figure II.4-1 could be reproduced by designing an algorithm containing exactly the same set of procedures, that algorithm would lack the underlying unsystematic nature of human choice: it would only mimic *this instance* of *this* variation process.

Human manual composition (as opposed to automated composition) can, on the contrary, envisage new procedures 'on-the-fly' — either complex or very simple ones in a kind of improvisation — intuit their musical appropriateness, combine and vary them in a systematic or unsystematic way. The path to automating this kind of composition could only be considered through the most advanced knowledge of artificial intelligence linked to creativity.

II.4.2 Two Different Pieces

II.4.2.1 The Composition Project: Not Knowing

By the time I was about to start composing *Two Different Pieces*, aesthetic reflection about the purpose, adequacy, advantages and shortcomings of both manual and automated methods was intensifying. I was particularly interested in trying to find out more about the exclusively human aspects of thought that manifest in human creativity and how they could be more directly connected to the act of composing. This implied removing intermediates between thought and score, namely automation tools.

The discovery of the book *On Not Knowing: How Artists Think* (Fisher and Fortnum 2013) had a great impact. In the Preface, the authors write:

> Artists often begin something without knowing how it will turn out. In practice, this translates as thinking through doing.
> [...]
> Not knowing represents a lack or absence, inadequacy to be overcome. However, the essays, conversations and case studies gathered together here describe a kind of liminal space where *not knowing* is not only not overcome, but sought, explored and savoured; where failure, boredom, frustration and getting lost are constructively deployed alongside wonder, secrets and play (p.7).

Not knowing how the piece would turn out was exactly what I set out to begin with. This attitude is the very the opposite of trying to exert as much *control* as possible, an attitude that marked many (but not all) previous automation-based compositional projects: devise techniques, automate them, fine-tune them, assess materials, etc. I wanted not to go down that road again, and discover what is it that I could be missing: the unsystematic procedures, the spontaneous gestures, the manifestations of imagination and intuition, the complexity of human decision-making, the unprogrammable aspects of composing. Stockhausen said:

> Intuition transforms... every normal action into something special that one doesn't know oneself. So I am a craftsman, I can start working with sounds, with apparatuses and find all sorts of new combinations. But when I want to create something that amazes me and moves me, I need intuition. I don't mean an intellectual idea. I need a sound vision, or I need to become involved, to come into a state where I do something without knowing why I do it. Very often everything else is in order, but then I touch my well-constructed music or section of music, and I change something; and as a matter of fact, I change what I thought was very well constructed, because I feel I must do that. And then something happens every now and then which is amazing and which is also for me unknown (Stockhausen 1999).

II.4.2.2 Analytical Notes

The following analytical notes refer more to the experiential aspect than to classical analytical topics such as harmony, form, rhythm, and their processes of evolution. This is because the experience, and indeed the aesthetic implications of composing manually were at the core of this research project.

Both movements explored articulation to a fair amount, which, as noted before,[72] can't be automated using OpenMusic. It involves specific knowledge of the instrument's technical constraints and possibilities and it has a different nature from pitch and rhythm, in that it is not easily quantifiable.

Vortex

The first movement is based on 'whirling' sonorities, which gave it its name. I worked by imagining the instrumental sounds and their manipulations, approached as studio techniques. Creating sonic effects was, thus, the most prevalent idea behind the music: long trills and tremolos, along with *glissandi* and some patterned sequences, creating superimpositions and evolving through time. A sense of progression and direction was paramount and some passages did rely on momentary planning, mainly to control evolution in the register.

The piano was the main sound generator of 'whirls', with the violin being either contaminated by it (bars 7-20) or enhancing the effect (bar 52 and bars 65-68). At other times, the violin provided a sustained and melodically neutral line, building on the local harmony (bar 32) or creating an additional perceptual stream (bars 34-42).

Intermediate cadential gestures of various strengths were frequently created (bars 17, 25, 43, 51 and 53). These important musical functions punctuate musical discourse and time flow in this rather flowing and active movement. Since in manual composition the composer is more involved in the dynamic shaping of the music, these kinds of gestures arise much more naturally, not having to be imposed on top of machine-generated material.[73] Dynamics are an important musical element to create cadences but by no means the only one. In atonal music, gradual rarefaction is one of the processes most frequently employed.

It is important to point out that despite the fact that one can draw *a posteriori* the previous general analytical observations, no pre-compositional plan and/or system were developed for the composition of this movement. Composition progressed at each moment by drawing possible derivations, proliferations, elaborations, reiterations or other possible developments or

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72 See Section II.3.2.1, p.118.

73 See page 126 (Cadences) for an instance of this manual intervention performed on algorithmic material.

consequences of already written material, appropriateness constantly being judged together with the decision to opt for inserting new material (formal articulation moments). These processes — that one can generally designate by recurrence, variation and contrast — took place *while* composing the actual score. Decision-making was, therefore, very intimately connected to score writing and not to the development of systematic procedures (pre-compositional technique sketching) that would later be used to generate materials for the score. It was as if composition progressed by *improvisation* but with the chance to judge, so as to either keep or change.

This content-first, or bottom-up, approach is very clearly accounted for by Roads in his book *Microsound* (2001, p.13):

> [A] strict bottom-up approach conceives of form as the result of a process of internal development provoked by interactions on lower levels of musical structure. This approach was articulated by Edgard Varèse (1971), who said, "Form is a result—the result of a process."
> [...]
> A different bottom-up approach appears in the work of the conceptual and chance composers, following in the wake of John Cage. Cage (1973) often conceived of form as arising from a series of accidents—random or **improvised** events occurring on the sound object level. For Cage, form (and indeed sound) was a side-effect of a conceptual strategy.

Arch

The composition of this movement started by assigning a simple contour shape to the piano part: it would describe an arch on each bar, having the melodic movement 'up-up-down-down'. The actual pitches and intervals were chosen according to a free variation of their implications: sometimes a passage implied a mode, sometimes a chord, sometimes it implied a memory connection with something that has happened before. Register and range of the arch were also important elements I considered.

The violin part was composed after the piano part. It hosts most of the spontaneous composition, unfolding against the more continuous, less active piano part. One can surely find recurrences and variations of the same material, but the same compositional attitude described in the last paragraph of *Vortex*'s analytical notes applies.

II.4.2.3 Reflections

The composition of this piece provides a vivid example of practice-based research since, at the time, I wasn't satisfied just with the fact that important reflections and aesthetic changes were manifesting in my thought. I had to assess them practically so as to draw important experiential knowledge. This was behind the decision of using no automated methods, and thus constituted a second instance of the exclusive use of manual composition.[74] In this sense, this research resonates with Mawhinney's, a composer who also uses OpenMusic:

> *Hunshigo* (2005), a 40-minute work for violin and piano, was written without any computer techniques; indeed, in the work I made a concerted effort to write an extended piece which did not use any *conscious* techniques at all. Ideas were notated as they were conceived, with very little consideration given to global form (Mawhinney 2008).

Manual composition as a concept is manifestly insufficient to accurately describe this research project. The composing action was characterized by a desire to truly exist in the moment, letting the unknown course of events lead to discovery; indeed the discovery of the piece I was completing. To a certain extent, I think automatism[75] can be a useful concept as the procedures were very much bound to pure imagination and intuition. But it is important to note that this automatism does not correspond to using prescriptive and elaborate procedures for composition, but rather to the relatively unfiltered action of the subconscious. This amounted to a very unsystematic attitude, to contrast with a high degree of order present in computer-assisted composition projects.

Kurtág rightly notes that the results of this kind composing, if viewed *a posteriori*, "might prove [that the composer has] travelled along a much too well-trodden path" (Varga 2009, p.58). Hence, it is crucial to be aware of the difference between what happened during the *action of composing* and what after all resulted from it (the piece), analysable as any other product of human enterprise.

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[74] The first being *To the Muses*.

[75] See definition on p.27.

To conclude, this was a risk-taking artistic project. I can well recall the excitement that came from being in close contact with my creative intuition and indeed with the imponderable nature of the present moment, but a sense of insecurity pervaded the construction of the piece, only partly alleviated by the limited playback capabilities of notation software. Furthermore, this project could have been yet more risky, even dangerous, if the experimental aesthetic attitude did not fully ground itself on sound aesthetic reflection.

III A Concluding Reflection

Sometimes composers draw up elaborate and detailed pre-compositional plans. If they reduce composing merely to literally realising those plans in score, composing becomes a purely mechanical task — a tedious, even boring activity. After working for some years with a high degree of formalization and automation, my composing was beginning to feel a little rigid and predictable. I started to think about how I spend my time during composing and how creatively stimulating it could, or should be.

The piece *Two Different Pieces* was deliberately composed without algorithmic methods. By the time I started working on it, I was already well aware of the important tension between control and spontaneity. However, I wanted to dig deeper that time because I was getting sensitive to the fact that algorithmic composition could be considered, at its very limit, equivalent to artificial intelligence (AI). Human behaviour — including spontaneity — could hypothetically be automated:[76] a composer would program a computer up to a point where he/she would no longer have an active role after all the programming is complete and subsequently executed to generate a complete piece. This would mean that, apart from the programming phase, the artist would be totally withdrawn from the actual piece's construction process. The program would have to mimic composer's decision-making, a very complex thing to achieve.

High degrees of automatism[77] have, as we know, been used by some composers, notably after the Second World War,[78] but one should consider these experiments as being only halfway between manual composition and AI-based composition. This is because the algorithms involved did not attempt at accurately mimicking human behaviour. A more recent work, the previously mentioned algorithmic piece *Çoğluotobüsişletmesi* (1979) by Clarence Barlow, is also extremely automatic. But could we say its algorithms entirely reproduce human

[76] It is interesting to note that this reflection was to gain resonance from an article the scientist Stephen Hawking published at that time in *The Independent*. He warned humanity about the evermore imminent and dangerous consequences of AI (Hawking et al. 2014).

[77] See definition in the Introduction, page 27.

[78] Either from the so-called Integral Serialism current, headed by Boulez, Nono and Stockhausen, or from the Indeterminacy current headed by Cage.

creative thought? The connection remains: these forms of automatism imply a considerable degree of withdrawal, on the part of the composer, from decision-making. The reasons for this can be various. An important one was, historically, to eliminate personal *bias*, considered a hindrance for the development of new music because it contained traces of tradition; the same tradition that led to Nazism and the Second World War. I asked myself some questions:

1. What could I be missing by partially withdrawing myself from decision-making?
2. What is the difference between doing and automating to do?
3. What aspects of art making would we consider exclusive to humans, impossible or very hard to be recreated by a machine?

Partial answers were already found during the composition of *To the Muses*, but later I would arrive at more far-reaching conclusions. If we take the choice-based definition of authorship outlined by Meyer,[79] then we are forced to conclude that when the artist is withdrawn from decision-making — implying indeterminism[80] in the algorithm he's using — authorship can be said to lie at a more general level: the algorithm design, i.e. the rationale behind the mechanism of getting one out of a set of pre-defined possibilities. Hence, it does not lie at a particular choice but at a *set of choices* (or universe). In musical terms, this means that if, for instance, you program a computer to calculate a major chord containing the note G, *any* chord chosen from the set comprising C major, E♭ major and G major, would be a viable result, whereas if you would have to choose a particular G-containing major chord yourself — say E♭ major — you would be the author of that particular and definite choice. Consequently, the more active a role a composer has during composition, the better it displays his/her *personal involvement*. Of course, this aspect of authorship *per se* should not be taken as a value by itself as it can even be irrelevant in case the result is artistically weak. The important point is that, after having tried a high level of automation before, what worried me was indeed how involved was I, the author, in developing the music materials that actually ended up in the final score.

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79 See page 33.

80 Indeterminism, to be sure, is always present when an algorithm has to *choose* among different possibilities.

Manually working out a passage is a very different experience from automating it. It can take more time, or it can be quicker, depending on how much programming work is involved, or how much manual sketching and calculation is involved. The difference I want to emphasize lies in the fact that an algorithm outputs a musical result that does not feature composer intervention *during* its construction, but only during the algorithmic formulation and design that generated it. This is a very important conclusion to arrive at. When I build a particular music passage manually, a time frame is opened allowing its shaping to dynamically depart (or not) from the initial planning. This implies flexibility and plasticity that is in contrast with the rigidity of an algorithmic calculation (and the more elaborate an algorithm is, the more complete are the musical results it can output). Therefore we find a kind of paradox: although algorithms can *speed up* music material construction, they can *slow down* the composition process, either because of the time required to program the machine, or because of post-processing: an additional stage which can either be carried out manually or through algorithm redesign and/or refinement. On a recent video interview, Saariaho gives her view on the aspect of speed in computer-assisted composition:

> I never like when somebody says: "I'm using the computer because it makes things go quicker". I don't like the idea. I don't think it should go quicker. I think if for something we must really take much time it's making art [*sic*] (Saariaho 2012).

During the time it takes to shape a music material, all the special potentialities of human thought can be called for and engaged. Here are the hard-to-automate, composition-relevant, aspects I found important:

- Context adaptation – this means a shift of strategy as context changes. It can be related to the idea of *situatedness* in artificial intelligence (Frankish and Ramsey 2014, p.129).
- Unsystematic procedure – understood here as a procedure “not done or acting according to a fixed plan or system; unmethodical” (Oxford University Press 2013a).
- Personal bias – what, in what we do, derives from our past experiences (including training), and what artistic goal are we after.

- Imagination – "the faculty or action of forming new ideas, or images or concepts of external objects not present to the senses" (Oxford University Press 2013a). This would imply an algorithm that would formulate by itself new algorithms. About composing, Boulez states that:

> A great part is played by the imagination, which is the most irrational of all our faculties. Why should our imagination carry us at some given moment in one direction rather than another? This is a complex problem and difficult to explain: all that one can say is that the unconscious plays an incalculable role (Boulez 1990, p.126).

- Judgement – "the ability to make considered decisions or come to sensible conclusions" (Oxford University Press 2013a). A composer needs time to actively judge the adequacy of the materials he/she is manipulating. For instance, if he/she is working out a harmonic progression at the piano, it is likely that every chord is scrutinized, whereas if an algorithm outputs a stream of chords, it is less likely that the composer spends enough time judging each chord. This can be of prime importance and a real concern to have when using algorithms.
- Interdependence – this is probably one of the main reasons why human behaviour would be so hard to automate. Some human cognitive faculties seem to condition each other in various, complex ways, and not exist entirely independently. A very famous, and striking, interdependence is to be found, surprisingly, between reason and emotion. In his book *Descartes' Error: Emotion, Reason and the Human Brain*, the neuroscientist Damasio writes:

> I advanced the hypothesis (known as the somatic marker hypothesis) that emotion was in the loop of reason, and that emotion could assist the reasoning process rather than necessarily disturb it, as was commonly assumed. […] When emotion is entirely left out of the reasoning picture, as happens in certain neurological conditions, reason turns out to be even more flawed than when emotion plays bad tricks on our decisions (Damasio 2008, sec.Preface).

Based on what they learned during education, composers often fear unsystematic procedures because they can imply a loss of security and control. On the other hand, a search for the word 'unsystematic' on the *Oxford Thesaurus of English* reveals its artistic potential:

> unmethodical, uncoordinated, undirected, disorganized, unarranged, unplanned, unpremeditated, indiscriminate; random, inconsistent, desultory, patchy, fragmentary, sketchy, sporadic, spasmodic, fitful, inconstant, intermittent, irregular, erratic, stray, spot, casual, occasional, haphazard; chaotic, non-linear, entropic, fractal (Oxford University Press 2013b).

Of course, not all artistic projects resonate with these ideas. But there is something that all these words have in common: their incompatibility with how machines fundamentally work. A machine could imitate these 'behaviours' but only by feeding it with strict — and indeed systematic — programming instructions. Can the same be said of human behaviour? Can we perform something unmethodically but at the same time consistently? The composer György Kurtág, when asked if he keeps "any particular system, an organizing principle", answers:

> There is no system. Not only do my compositions have none — I have to invent them anew each time. Even if in the end, one might prove to have travelled along a much too well-trodden path (Varga 2009, p.58).

At least experientially, composers can engage with the unsystematic (even if their brains are to be found working systematically). They can lower the amount of conscious control so as to, perhaps, raise the chances of discovering something new. Furthermore, to *know* exactly how we do what we do is very different from the experience of *doing* it. This was what *Two Different Pieces* was about: practice as opposed to theory. I was searching for true and exclusive potential residing in human nature. I wished truly to inhabit and exist in the composing moment, while being in focus with the way human creative thought unfolds. This meant not knowing beforehand the precise flow of events during composing, making one prone to envisage unforeseen possibilities. I would subsequently carry this mental framework to the composition of *Agnostos*.

Famous philosophical reflections concerning knowledge point out the same attitude.[81] The state of 'not-knowing' is a necessary condition for the process of

[81] See Plato's quote on page 115.

acquiring knowledge, the process of discovering, to unfold. Creatively, this is the most productive state. I ask: if composers knew how a piece was going to be before writing it, would they still write it? Probably it depends, but I doubt that many cases exist where an *absolutely exact* plan precedes actual composition. Although I acknowledge its importance, I don't think that pre-compositional planning is a necessary condition to start writing a piece.

Manually composed pieces of the portfolio provided valuable contrast with other computer-assisted works, thus adding necessary aesthetic reflection. CAC projects, on the other hand, enabled a gradual exploration of the adequacy and implications of using algorithms. The most aesthetically comfortable use I gave them was as a musical laboratory, where techniques could to be developed, tested, refined and assessed. The playback functionalities were found to be an important aspect of the software: microtonal playback was easily attained, along with the playback of complex textures, impossible to play at a piano. Nevertheless, playback suffered from the limitations of MIDI: unexpressive, mechanical and not accurately simulating human instrument playing in all its dimensions.

Looking back at the algorithmic explorations carried out, I can conclude that too much determinism meant absolute technical control, but many times implied too mechanical results to be obtained. This mechanicalness had to be counteracted through subsequent manual procedures. By contrast, indeterminism often aided discovery and was a source of novelty, with the drawback that, if used in high levels, it could mean too little control of the moment-to-moment note combinations, many times leading to arbitrary results. It follows that a balance had to be achieved — exemplified by the *Canti Firmi* and *Agnostos* projects — or discarded on the basis of sound aesthetic reasoning — *Stochafrica* project.

The path of improving the algorithms one uses is, perhaps, never-ending. The ultimate objective — the complete replacement of the human by the machine during the composition of a piece — would have, after all, far-reaching aesthetic and ontological consequences. It's either a compromised situation where the machine would perform all programmable routines — with the drawback of the inability to explore hard-to-program human characteristics — or a perhaps utopian situation where the machine is an exact copy of the composer as a human being.

Underlying all this reflection is the idea that one's experiences in the past have made what one is. Here we find a strong link between art and life. Art-making is affected by one's life but also codifies it. As Magnus Lindberg put it:

> While our life clearly shows through in our works in some way, I still believe that music is a sufficiently sophisticated medium to be able to filter these experiences; we cannot attribute such and such a piece to a moment of euphoria or depression (Lindberg 1993, p.7).

IV Appendix

IV.1 Vectorial Harmony

This is an idea I derived from a morphological conception of musical harmony. Its formulation as been the subject of an article I published during the research period (Gato 2013). This type of harmony is obtained by choosing an initial chord and an ordered set of intervals to be applied to each note. This ordered set is called an *interval vector* and is composed of numbers representing the intervals along with a sign: '+' or '-', meaning movement up or down. The word vector is used to denote directionality of that movement. It represents a defined shape for voice leading and we can say that, in vectorial harmony, the vector is the very element that contains a defined morphology: it is the element that controls the transformation of the initial chord. Vectorial harmony produces chord progressions from superimposition of voices moving according to an interval vector. I use it mainly because — as will be made clear in the Analytical Commentaries — it provides a very ordered and regular chord progression that one can extend, and direct up or down (depending on the sum of the intervals contained in the vector). The recurrence contained in this regularity stimulates auditory memory and, it that sense, reveals awareness of the listener's musical cognition.

In Figure IV.1-1 an example taken from one of the folio pieces (*Shapes*) is shown. In this particular case, the interval vectors are obtained by rotating the intervals of an initial vector so as to create what I call *rotational* vectorial harmony.[82] It can be regarded as a superimposition of canonic lines although each chord is usually taken individually as a pitch reservoir. On the other hand, if the musical realization is homorhythmic, the top and bottom voices will stand out in canon. Furthermore, if the internal voices have a sufficiently distinct timbre, the

[82] Rotational vectorial harmony is similar (but not equivalent) to the so-called rotational arrays used by Stravinsky in serial works such as *The Flood* (1962) (see Straus 2003, p.169). Stravinsky's technique is pitch-class-based and assumes octave equivalence (much like Boulez's rotation technique used in *Dérive I*), two features that contrast with my technique. Given an initial chord, it produces a sequence of fixed-register pitch reservoirs.

canonic aspect could be more noticeable among them as well: it all depends on the musical context.

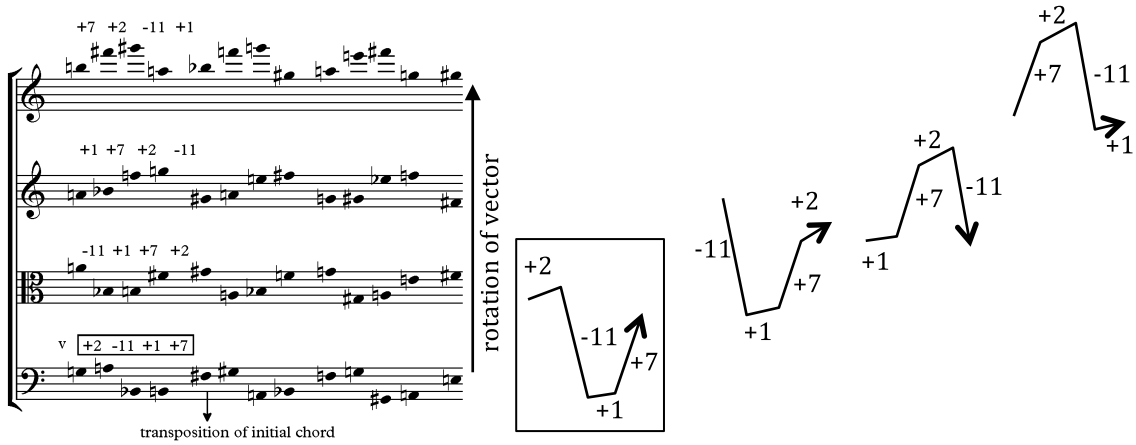

Figure IV.1-1 – Rotational vectorial harmony used in the first bars of *Shapes* along with the morphology of the interval vectors. See page 47 for a deeper discussion.

Other types of vectorial harmony can be formulated, such as *retrogradational* vectorial harmony (where vectors alternate between prime and retrograde). The interaction between the two defining materials — initial chord and vector — is still under research. For instance, if the vector contains an interval that is present on the initial chord, we can create a common note between two chords.

IV.2 Modular Harmony

This is an idea I derived, again, from a morphological conception of musical harmony. This kind of harmony is obtained by fixing a particular kind of pitch 'module'[83] inside a chord (a subset of the chord's pitches), and adding new pitches according to a defined rule, thus producing the following chord. The prefix *modular* means a treatment of harmony as a progression of structured modules, as if chords were mere superimpositions and progressions were made by altering their configurations — much in the same way as what happens with some kinds of physical objects (like pieces of furniture).

Modular harmony grew out of my desire to maintain intervallic consistency and create a good amount of harmonic linkage between the chords. This linkage is

[83] Module: 'each of a set of standardized parts or independent units that can be used to construct a more complex structure, such as an item of furniture or a building'. (Oxford Dictionaries 2010a)

assured by the module — there is always one common set of pitches maintained in unison[84] between any two chords, which means varying levels of chord-to-chord connectedness — which, in itself, also contributes to intervallic consistency. This is why, in contrast to vectorial harmony, no special attention is given to voice leading. The rules that define how new notes are added are what determines the degrees of novelty in the chord sonorities.

Figure IV.2-1 – Modular harmony example. Notation from the software OpenMusic: only sharps are used and they apply only to the chord on which they appear. Top staff and bottom staff sound two octaves higher and lower, respectively. Some sharps appear superimposed (fourth and seventh chord, top pitches).

An example of modular harmony is shown in Figure IV.2-1. The second chord maintains the two highest notes of the first — the module — and adds notes below. Starting from the B pitch and going down: a m9, a M2, and a P4, all intervals contained in the initial chord. The third chord maintains the lowest four pitches of the second and adds a M2 above them. The fifth chord maintains only the C♯-D♯ module and adds pitches above and below, and so forth.

IV.3 Circular and Helicoidal Harmony

As a composer, I tend to keep notes of ideas that interest me at a particular time. Sometimes a common subject groups them. One of those groups is called 'Harmonic Morphology' where I theorize about what shapes musical harmony can take, and what in harmony is compatible with a shape conception. With particular relevance to *Agnostos*' first movement, I asked myself what could *circular harmony* mean. I decided that it would mean a sequence of chords that describes a circular path in terms of development: it starts on a chord, progresses to another, and then comes back to the first in retrograde form.

For a 4-chord set the sequence would look like Figure IV.3-1.

[84] Either through enharmony or through prolongation/reiteration of the pitches.

1 2 3 4 3 2   1 2 3 4 3 2   1 ...

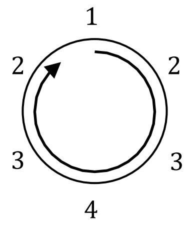

Figure IV.3-1 – Chord sequence and graphical depiction of circular harmony.

This corresponds to a particular kind of harmonic ostinato (much like a *chaconne*).

Helicoidal harmony, I theorized further, could be considered to be what results from subjecting circular harmony to some variation principle. Hence:

1 2 3 4 3’ 2’   1’ 2’’ 3’’ 4’ 3’’’ 2’’’   1’’ 2’’’’ 3’’’’...

which can be depicted as shown in Figure IV.3-2, the axis representing the variation principle.

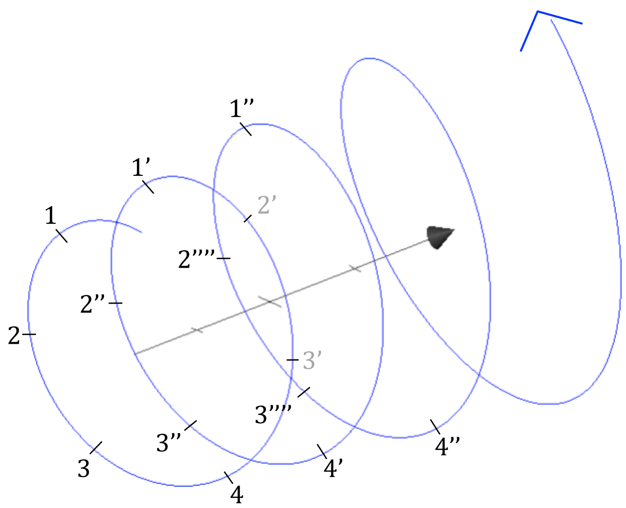

Figure IV.3-2 – A depiction of helicoidal harmony in space.

IV.4 Algorithm descriptions

IV.4.1 Pulse Unfocusing

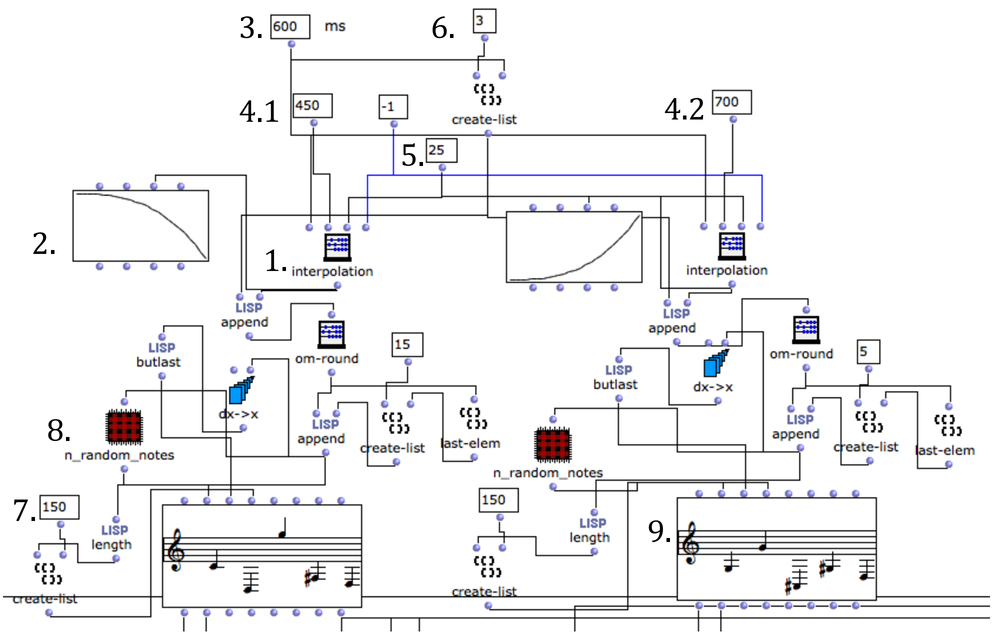

Figure IV.4-1 - Excerpt of the OpenMusic patch used for creating pulse unfocusing. Only two voices are shown for clarity.

The algorithm is based on an interpolation between initial and final values for the distance between attacks (Δonsets) for a given voice. This is seen as an interpolation function on the patch (labelled 1 on the Figure), the output of which is graphically represented as a *BPF* (labelled 2). At top left, we have the initial distance between note onsets: 600 ms. This is the interpolation start value (labelled 3). Labels 4.1 and 4.2 on the Figure indicate end values for the interpolation. The value 25 — as indicated by label 5 in the Figure — is the number of samples for the interpolation, and so it means that we'll get 25 numbers between start and end values. Just before this list of numbers we add 3 times the initial value for Δonsets (label 6). This corresponds to the initial part of the texture, meaning regular and equal pulses on the voices. Now that the pulses onsets lists are created, we define all durations to be 150 ms (label 7). To finish up, we add a process of generating random pitches for the pulses. This corresponds to label 8 on the Figure. The result of this process for each voice is fed into a *CHORD-SEQ* object for visualisation (label 9). From here onwards we just have to deal with the quantization[85] of onsets and durations — calculated in units of time — in order to convert them to musical notation. This is carried out with *OMQUANTIFY* (not shown), an object that accepts a list of durations of notes and rests and outputs a so-called 'rhythm tree'. It is this rhythm tree that enables OpenMusic to configure a *VOICE* object, an end result notated with pitched note values on a staff.

IV.4.2 Rhythmic Complex

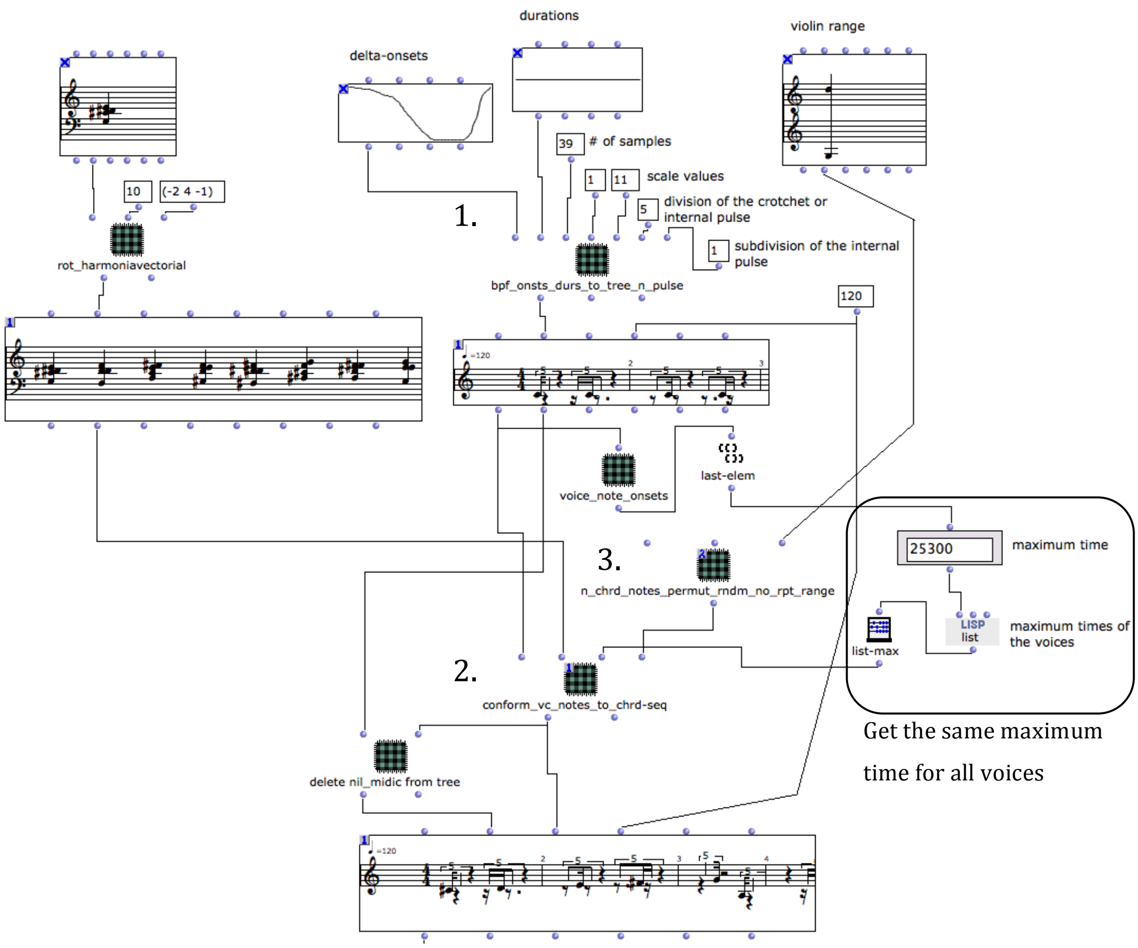

Figure IV.4-2 – OpenMusic patch for the construction of one voice of the rhythmic complex.

The algorithm is fed with the following initial materials:

- The initial chord for vectorial harmony, the vector and number of cycles.
- The contours for the Δonsets[86] and durations.
- The number of samples to take out of the BPFs. This equals the number of attacks.

[85] A means of translating numeric sequences to musical rhythm.

[86] Δonset is the distance between the attacks of two adjacent notes. Onset is the attack location.

- The scale values for the Δonsets contour. This equals the minimum and maximum distance between note onsets.
- The subdivision of the crotchet. This equals the internal pulse[87] for the voice.
- The subdivision of the internal pulse.
- The instrument's range.
- Tempo/bpm.

The abstraction labelled 1 builds the rhythm for the voice and the abstraction labelled 2 incorporates pitches from the harmonic progression according to the method defined in abstraction labelled 3: using random permutations of chord notes that fit the instrument's range.

IV.4.3 Melodic Figuration Juxtaposition

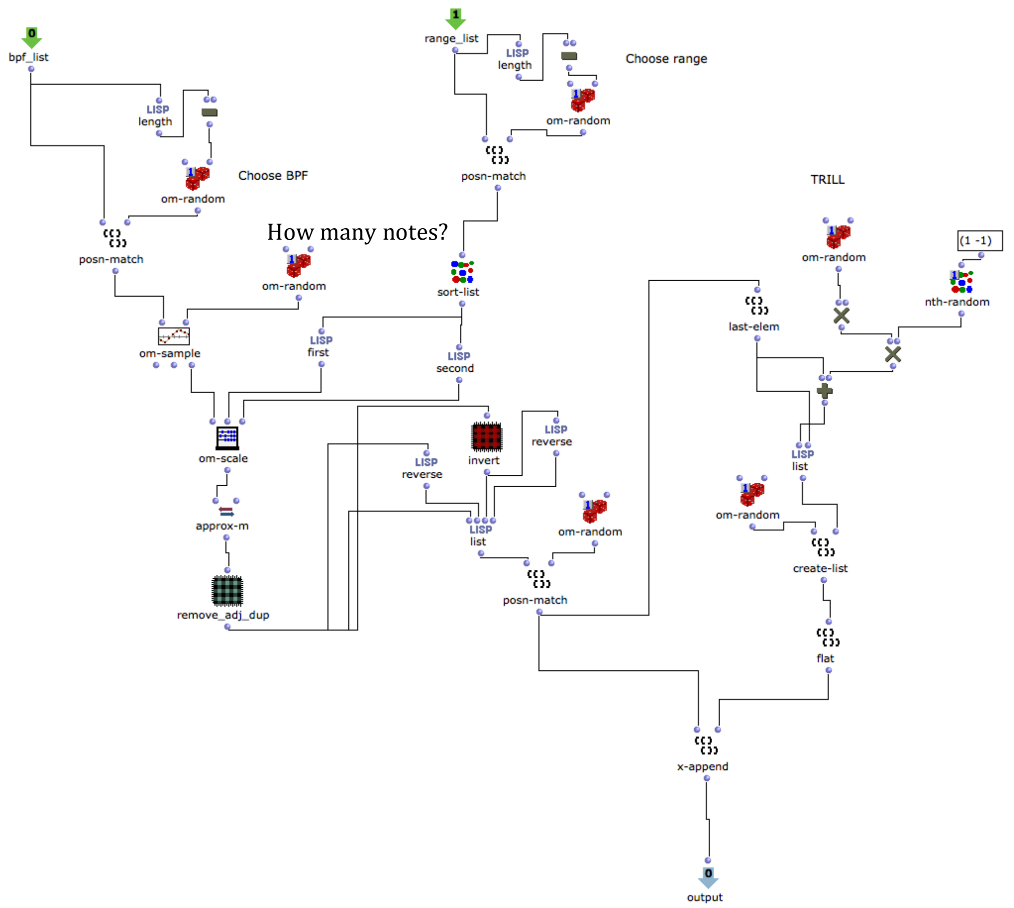

Figure IV.4-3 – OpenMusic patch excerpt.

[87] Pulse in this context means the smallest duration figure used as a grid for the onsets of notes. It can be defined mathematically as the Lowest Common Denominator (LCD) for all durations.

This patch is part of a bigger patch used to automate the procedure. This excerpt shows how the program picks a melodic contour contained in a *BPF* object list ('bpf_list' input object, top left of figure) and a chromatic range ('range_list' input object), chooses one of the possible simple serial-like operations — retrograde, invert, and retrograde and invert — and generates a pitch sequence corresponding to the melodic figuration, appending a trill in the end. To extend the final melodic output one would evaluate this patch several times and collect the resulting juxtaposition. This is done by using an OpenMusic function named *REPEAT-N* (not shown).

IV.4.4 Musical Object Generators

IV.4.4.1 Algorithm 1: Note Value Rhythmic Notation

The OpenMusic visual programming is shown in Figure IV.4-4. Starting with the top-left part (label 1), the universe of beat subdivisions is defined. In label 2 the parameters for the whole texture are entered: number of notes for each voice, total duration and tempo. In label 3, the harmonic progression that underlies the whole passage is fed. Important abstractions were built to complete the process:

- ***create_rnd_tree_ratio_universe*** (label 4) - this abstraction takes in a total duration, tempo, number of notes to output and a list of divisions of the beat (currently a quarter-note). It then outputs a rhythm tree (effectively the rhythm we want to produce with it), which one can feed in to a *VOICE* object. By defining the allowed divisions of the beat and having them strictly defined in the process prevents possible quantization errors that may arise by using the function *OMQUANTIFY*.
- ***conform_vc_notes_to_chrd-seq*** - this abstraction takes in a *VOICE* object, a harmonic progression, the total time, and a process (a patch in a so-called lambda (λ) state) of choosing chord notes (*n_chrd_notes_permut_rndm_no_rpt_range*).

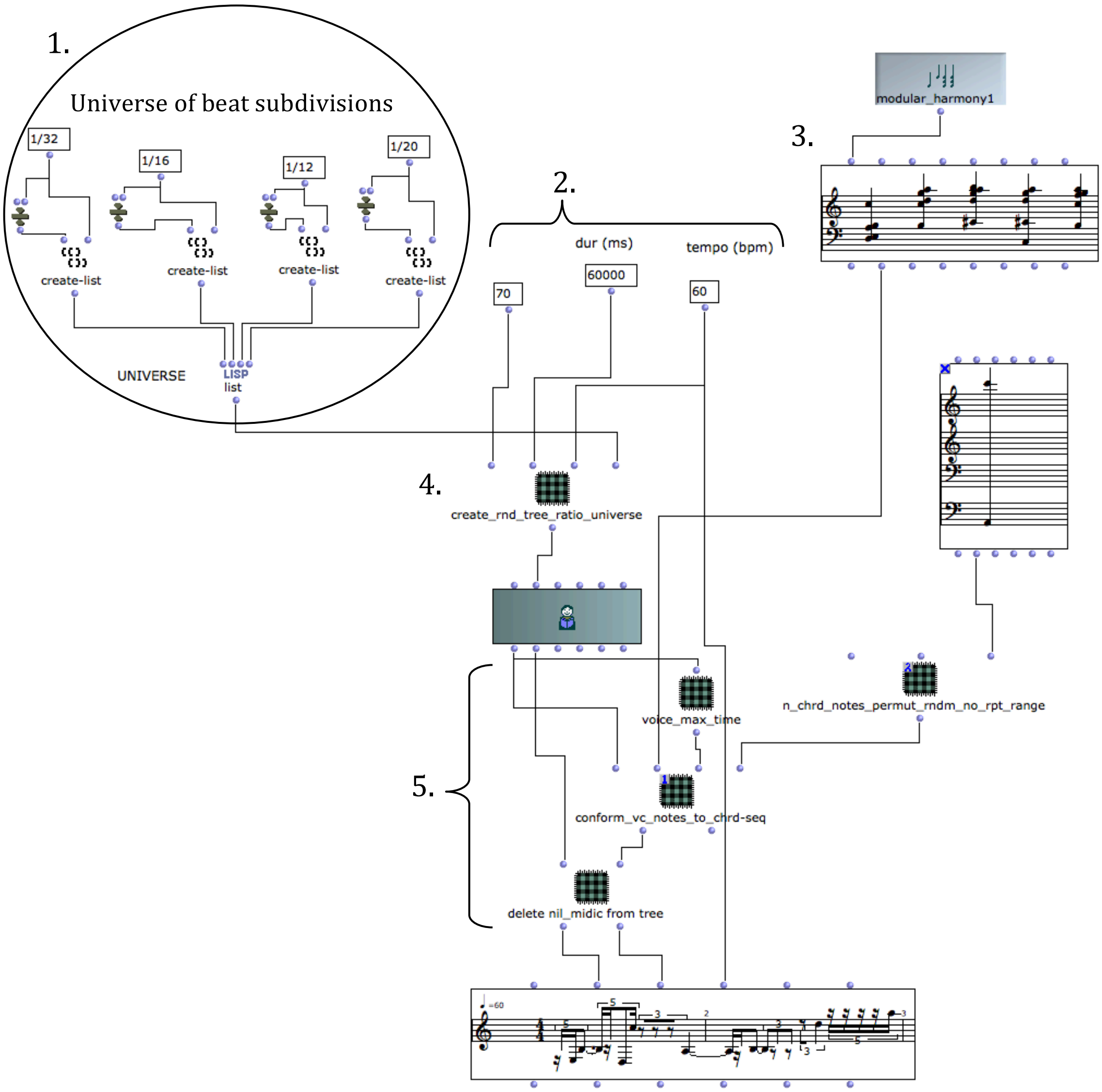

Figure IV.4-4 – Excerpt of the patch used to create the complete texture. Only the construction of a single voice (bottom) is shown.

IV.4.4.2 Algorithm 2: Time-based Rhythmic Notation and Quantization

The programming strategy for the second musical object generator algorithm was a bit different in terms of harmony and rhythm. Each individual object was created separately with a given harmonic colour inside a time window.

The first step was to build the chord progressions. I wanted a harmony based on the harmonic series but with a 'flavour' of M2 and so the solution was to base the harmony on two harmonic series a M2 apart. Joining the two harmonic series on the same set would create a M2 interval on top of every partial of the lowest fundamental. After some experimentation, it became clear that both semitone and quarter-tone approximations produced interesting chords. Furthermore, both approximations could be used; the one used last working as a variation of the first.

The procedure was to get all the partials between 3 and 13 inclusive for the two fundamentals. Then, all pitches were joined into one set and sorted from lowest to highest. Finally, chords were built by making groups of four pitches every two pitches (for example [1 2 3 4], [3 4 5 6], etc.). The algorithm is shown in Figure IV.4-5.

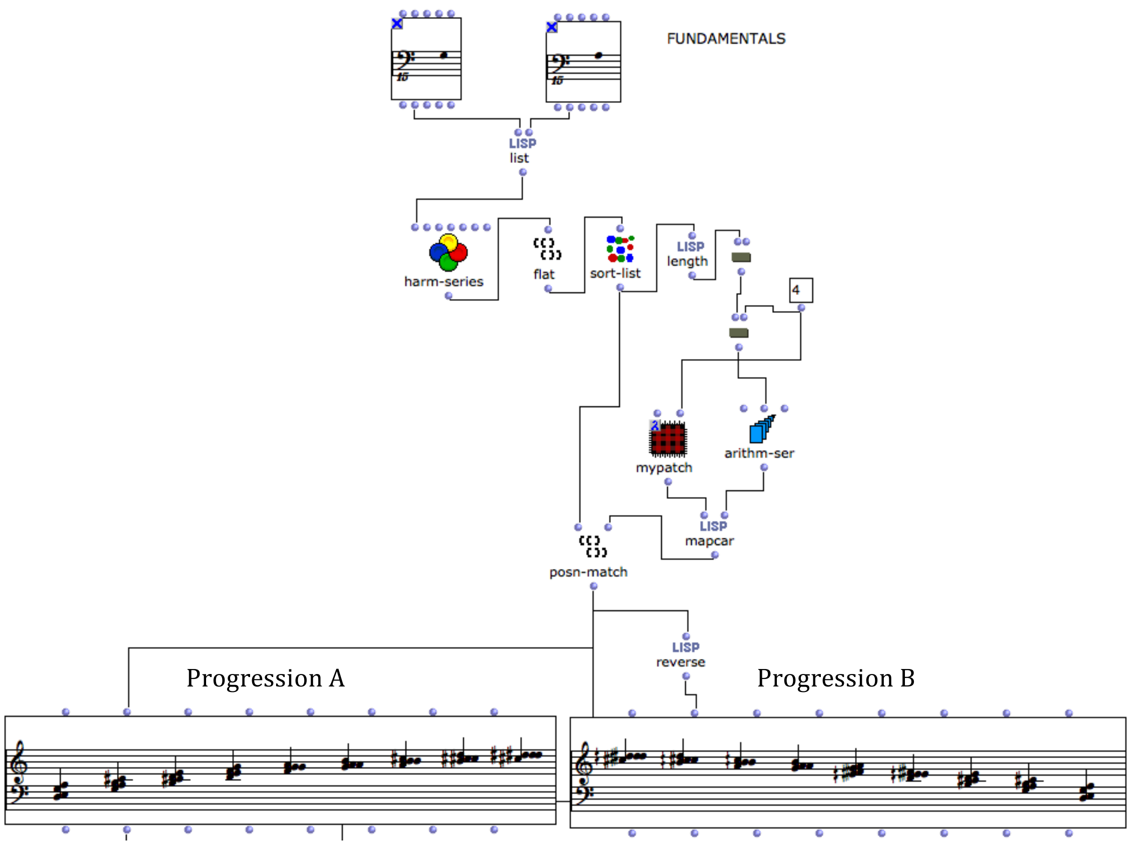

Figure IV.4-5 – OpenMusic patch for the generation of chords based on the harmonic series of G and A. At the bottom, to the left, the approximation of pitches is to the nearest semitone; to the right, the approximation is to the nearest quarter-tone.

The progressions differ only in their pitch approximation: to the semitone and to the quarter-tone, respectively. Each chord was fed into another patch, where the process of musical object generation took place.

The principle was to rely on an 'onsets-grid' for notes to be snapped to, the pitches being derived from a single chord (pitch reservoir). In Figure IV.4-6 below, one can see the total time (3000 ms), the distance between grid points (70 ms), and a process of varying each grid point so as to distort the grid and make it less regular (the abstraction named 'delta' to the right). The number of notes per voice could be chosen, along with the amount of variation (0.5 meaning 50%) so that different voices could have a different number of notes in the musical object.

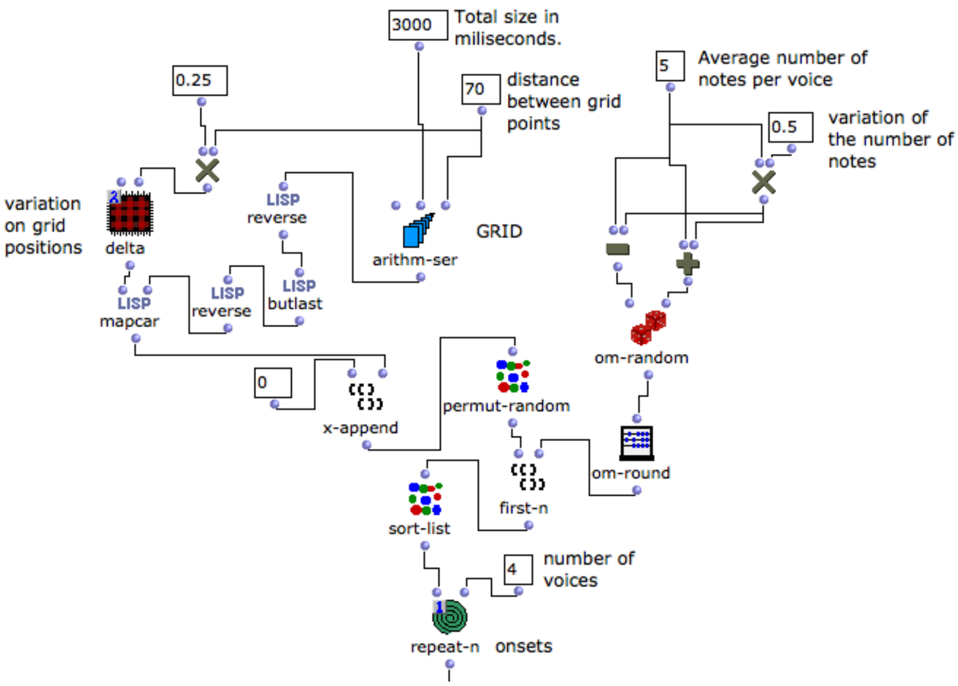

Figure IV.4-6 - First excerpt of the OpenMusic patch used to generate musical objects.

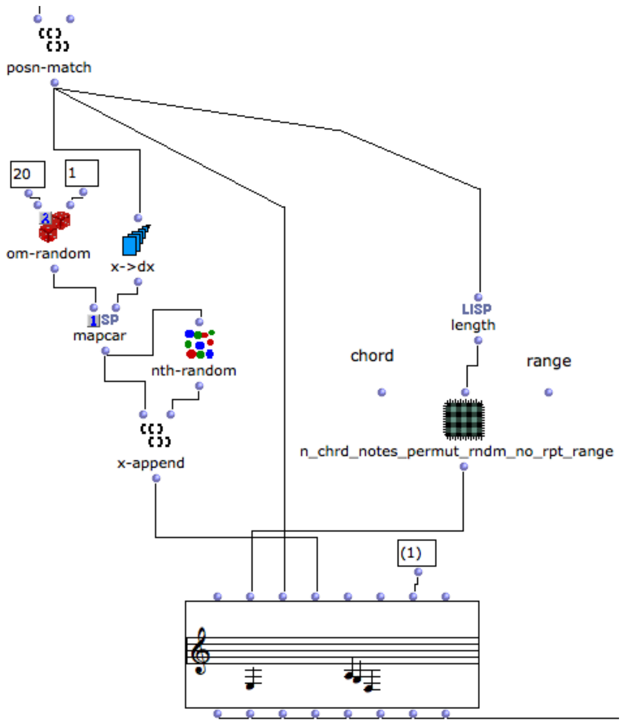

Figure IV.4-7 - Creation of the melodic sequence for one voice. Second excerpt of the OpenMusic patch used to generate musical objects.

In Figure IV.4-7, the creation of one voice is shown. At top-left, the selection of onsets from the grid is carried out (*POSN-MATCH*) and output directly to the bottommost object. The left part of the figure shows the creation of note durations indeterministically (using a random number generator). On the right, a given chord's notes (not shown) are selected/filtered according to an instrument's range.

After combining the voices, the procedure was to make musical objects for each chord and export them out of OpenMusic as MIDI files. After importing into the music notation software using its internal quantization process, each musical object was checked against its original version inside OpenMusic. In particular, quarter-tones had to be manually corrected because MIDI does not support them.

IV.4.5 Rhythmic Nesting

The idea behind rhythmic nesting is that one rhythm could grow inside another and gradually take over. Regarding the programming strategy, we start with two rhythms quantitatively defined by their sequence of durations. Then two simultaneous processes occur:

1. One of the rhythms gradually loses some of its durations. It shrinks by elimination (not by *diminution* of its durations).
2. The other rhythm begins with a small amount of its durations and gradually adds more. It grows by addition (and not by *augmentation* of its durations).

The rhythms are then alternated in time: the second rhythm is nested within or between the various restatements of the first. The following sequence of characters can illustrate this process:

aaaaa b aaaa bb [*aabbba*] *aa bbbb a bbbbb*

B inside a restatement of A

where *a* is a duration of rhythm A, and *b* of rhythm B. A quantitative example[88] would be:

A - (3 5 6 2 -2 9)   B - *(1 2 1 2 1 2)*

Nesting - (3 5 6 2 -2 9) *(1)* (3 5 6 *(1 2)* 2 -2) (3 5 6 2) *(1 2 1 2)* (3 5) *(1 2 1 2 1 2)*

where the *italic* font style is applied to rhythm B's durations.

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[88] I.e. durations are represented by factors of unit duration. Negative numbers are rests.

By creating reiterated statements of an enlarging or shrinking rhythm, this process stimulates listener's auditory memory and enables discourse coherence relations to be created. Given the recurrence of the two rhythms' fragments, a comparison is possible from moment to moment. If the composer then decides to give contrasting characteristics to the two rhythms — by ascribing to them different timbres, dynamics, implied harmonies or registers — he/she can further segregate them from one another.

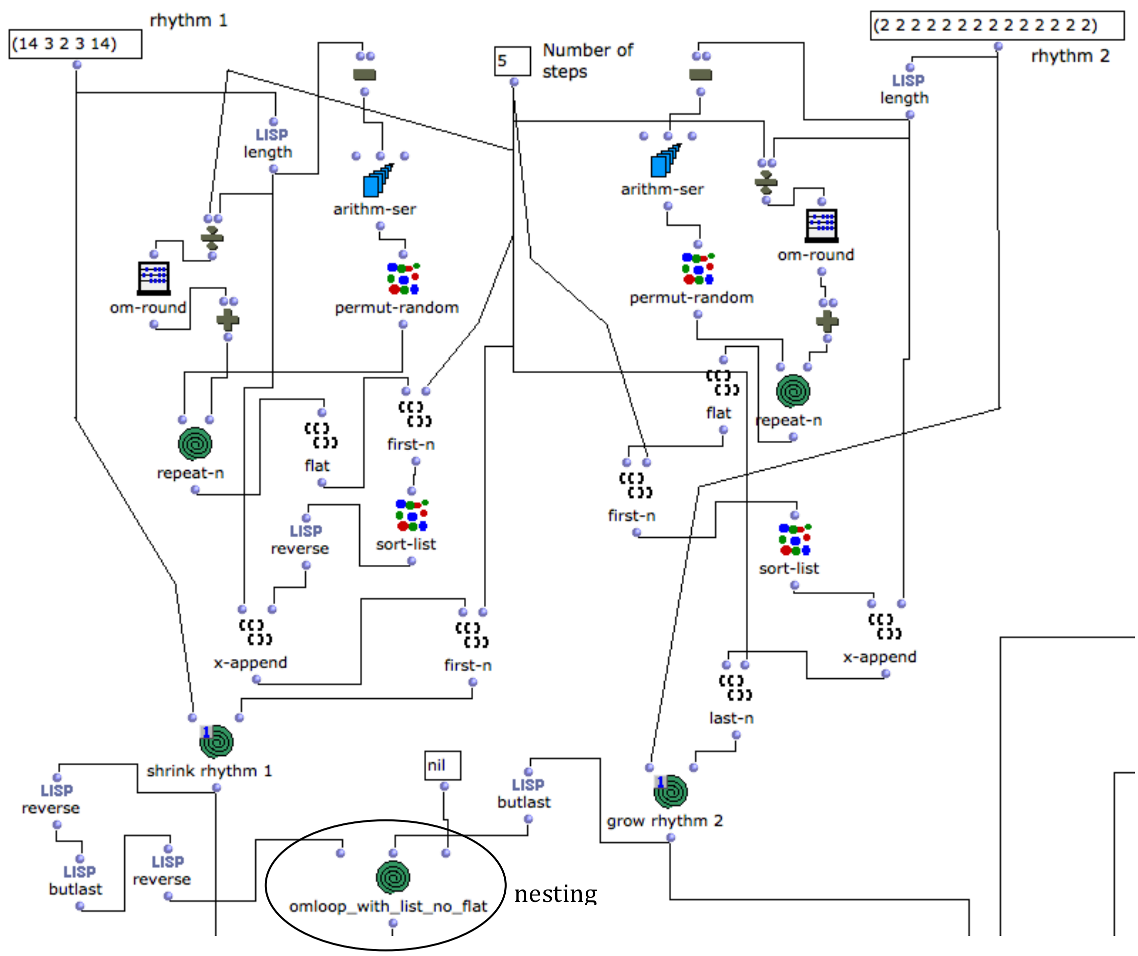

Figure IV.4-8 – OpenMusic patch excerpt showing the main part of the rhythmic nesting algorithm.

The algorithm for automating rhythmic nesting is shown in Figure IV.4-8. Each rhythm is represented by the numeric lists on top. After that they go through the process of shrinking and enlargement. In this process, indeterminism is introduced in the calculation of the lengths-sequence for the fragments (*PERMUT-RANDOM* object), although they are constrained to decrease (for the shrinking rhythm 1) and increase (for the growing rhythm 2). Further indeterminism is introduced in defining the places where the rhythm 2 fragments would nest: either on a precise location inside rhythm 1 or after it. This is accomplished by the *OMLOOP* labelled 'nesting' in the figure. After the numeric nesting list is created, it is distributed among two voices and directed to OpenMusic score objects (not shown).

IV.4.6 Folk Cross-Resynthesis

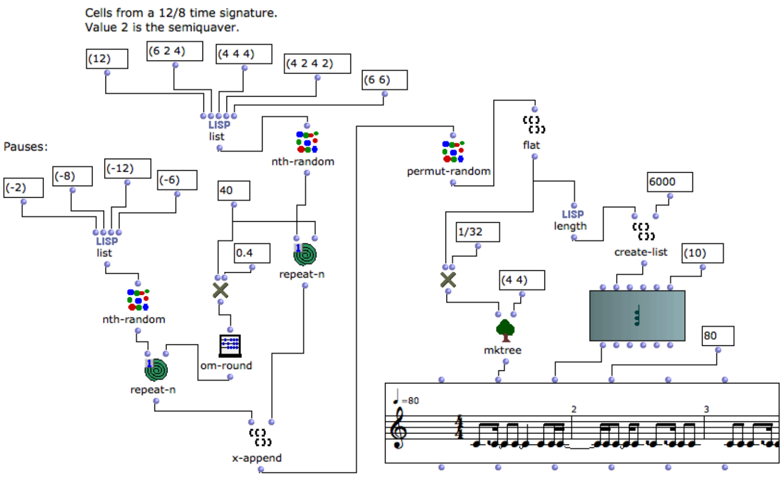

Figure IV.4-9 – Rhythmic polymerization from cells and pauses.

Rhythmic polymerization is shown in Figure IV.4-9. Rhythmic cells are fed at the top as numeric lists (relative durations). They are subsequently picked at random a number of times into a list (*REPEAT-N*). At the leftmost part of the algorithm, under 'Pauses:', the same process occurs for a predefined set of rests (negative values). The two lists are united and shuffled at random to create a final list (*PERMUT-RANDOM*). Subsequent steps, shown at the right, process the values into a score object (*VOICE*, bottom right).

To create a new pitch sequence based on a given melody, the patch shown in Figure IV.4-10 is used. A pitch range is initially fed, along with the interval set (in absolute values) and the desired number of pitches. The first pitch is calculated randomly inside the range (leftmost window). All values are fed into the *OMLOOP*, which is shown in the middle window. It accumulates a pitch with each iteration according to the process shown in the rightmost window: an interval from the set is picked at random and used either upward or downward on top of the previous pitch. If the resulting pitch is outside the range, then the interval is inverted (*OMIF*).

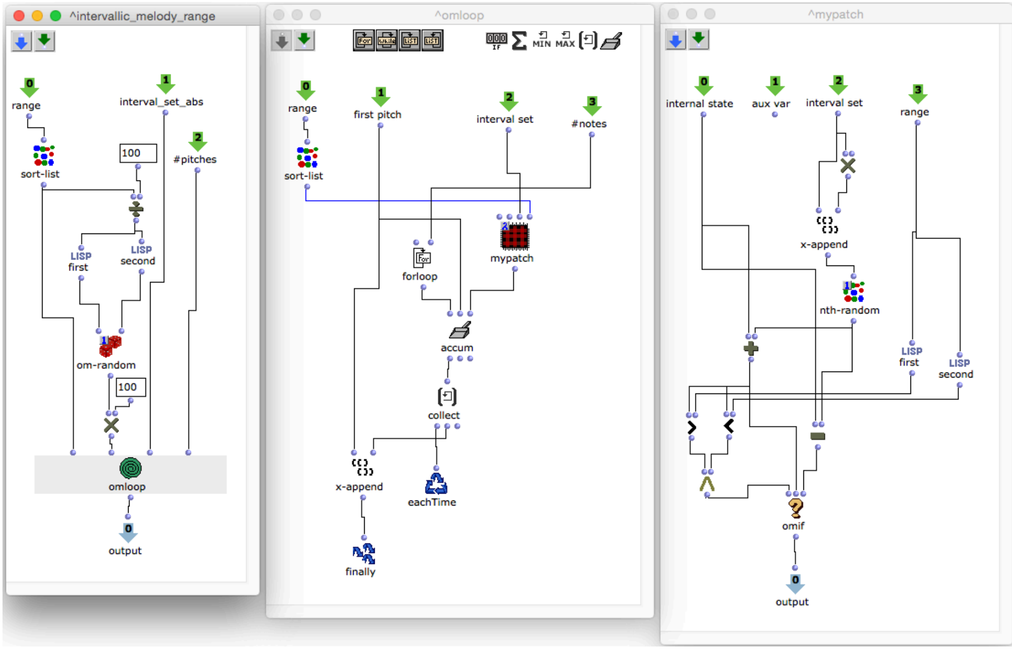

Figure IV.4-10 – Algorithm for the creation of a pitch sequence based on an interval set.

The combination of rhythm and pitch sequence is shown in Figure IV.4-11. The rhythmic polymer comes from one folk source and the pitches come from another.

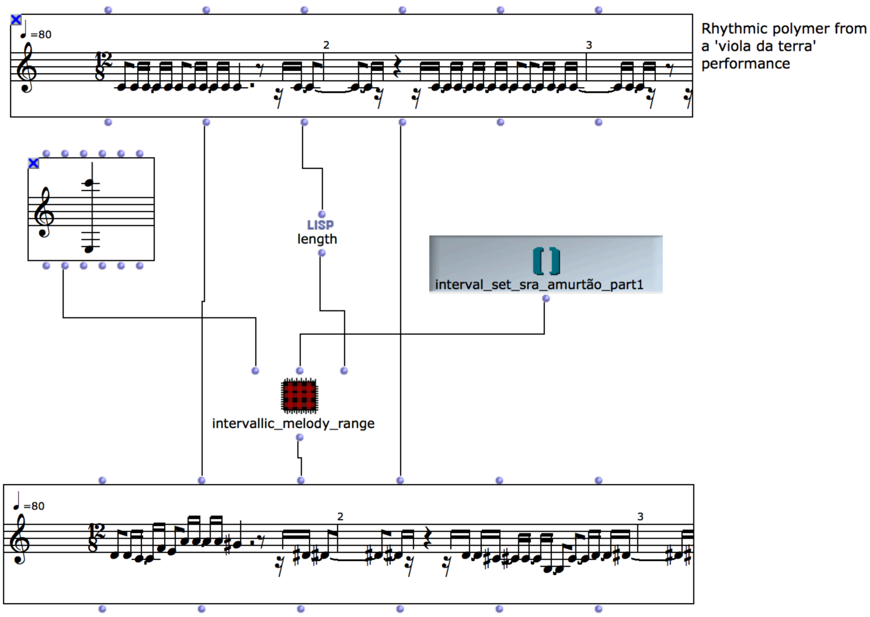

Figure IV.4-11 – Folk *cross-resynthesis*. Rhythmic material from a folk source is combined with intervallic material from another. The resulting melody was subsequently transposed two octaves down and its durations doubled.

IV.4.7 Rhythm-focusing Heterophony

The rhythmic process is depicted in Figure IV.4-12 and the algorithm I used is shown in Figure IV.4-13.

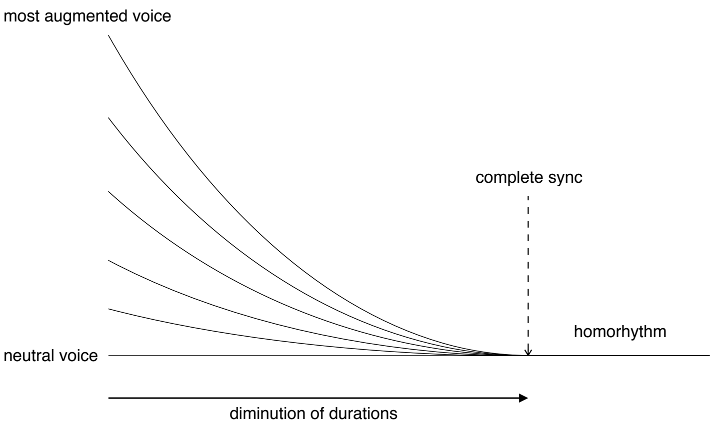

Figure IV.4-12 – Rhythm-focusing process by diminution.

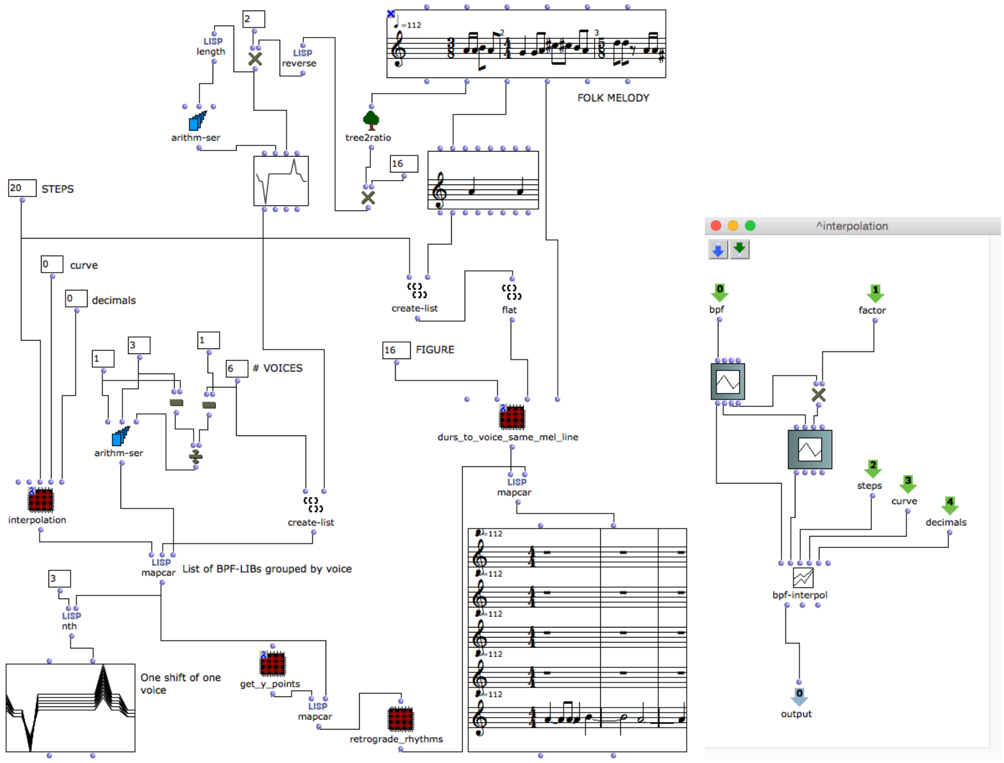

Figure IV.4-13 – Algorithm for rhythm-focusing. The BPFs show the durational contours of melodies. The graph on the lower left corner shows the progressive augmentation for the durations of a given voice. The patch window on the right is the *interpolation* abstraction.

A folk melody called *Chamarrita Preta* (*Grupo Folclórico da Casa do Povo de Bandeiras - 'Chamarrita Preta'* 2012) is initially submitted, and its sequence of relative durations calculated (using *TREE2RATIO*). It is then multiplied by 16 because 1/16, or semiquaver, is the smallest duration present in the melody. This makes all durations integers, the minimum duration becoming the value 1. The sequence of durations is reversed, doubled, and fed into an iterative augmentation process of different magnitudes: the leftmost *MAPCAR* function calls the *interpolation* lambda function which interpolates the initial sequence with five increasingly magnified versions. The focusing process is thus calculated in retrograde form: the initial sequence of durations, perfectly superimposed on the different voices at the beginning, is subject to augmentations of different magnitudes, gradually bringing the rhythms out of sync (as if reading Figure IV.4-12 backwards). Once these augmentations are calculated, the voices are retrograded again (*retrogade_rhythms* abstraction) so that the result becomes a gradual diminution of the durations, culminating in absolute homorhythm of the original melody (unison doubling). The end result of the algorithm is the *POLY* object shown at bottom right. Note that only one enlarged voice (the bottommost voice of the *POLY*, corresponding to the most augmented voice) has visible notes because the remaining voices were subject to smaller augmentation magnitudes and so start later in the score.

The decision to double the durations was taken in order to allow the minimum duration to be subdivided into an integer. As the augmentation process uses only integers, it eliminates the possibility of tuplets (which would create quantization and playability issues).[89]

[89] The decision to use only integers is both *operational* — to prevent quantization problems — and *aesthetic* — not allowing tuplets.

IV.4.8 Melodic Colouring

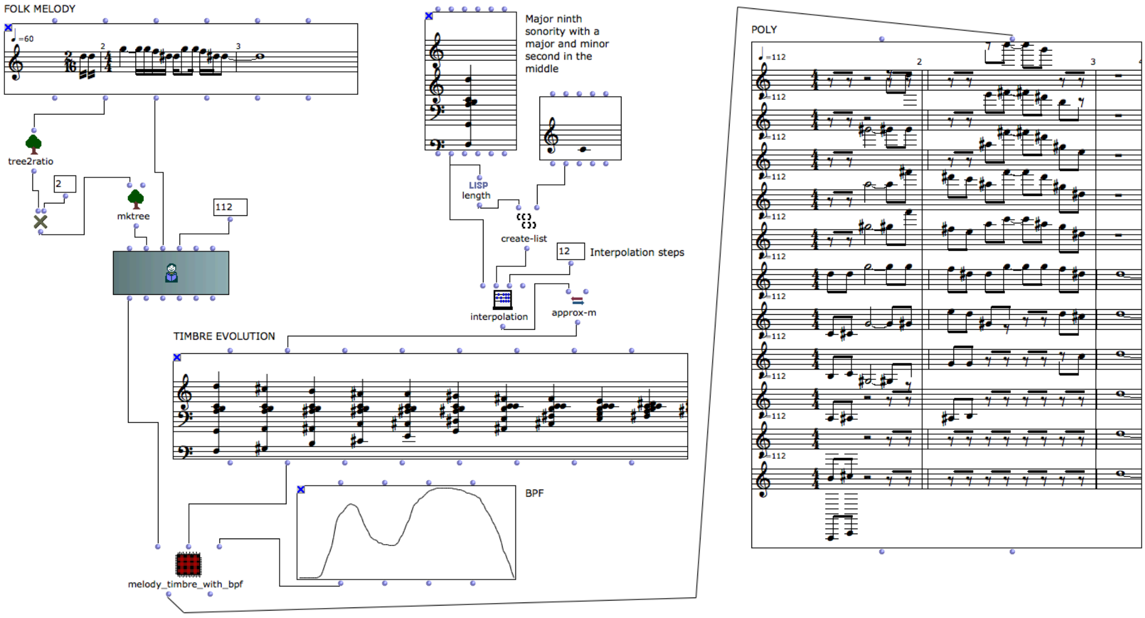

Figure IV.4-14 – Algorithm for melodic colouring. The timbre evolution is shown here as an interpolation of a chord to a unison in 12 steps.

As shown in Figure IV.4-14, a folk melody is fed, its durations doubled and its tempo changed. A harmonic progression ('TIMBRE EVOLUTION') is created by means of an interpolation from a given sonority to a unison (middle-top). The obtained timbre evolution is fed into an abstraction named 'melody_timbre_with_bpf' (shown in Figure IV.4-15) which also accepts a graphical function (*BPF*) to control the position of the folk melody's pitches inside each chord of the timbre evolution. If the values are high, the added pitches are added above the melody's pitches, if low they are added below. The result is output into a *POLY* object (right).

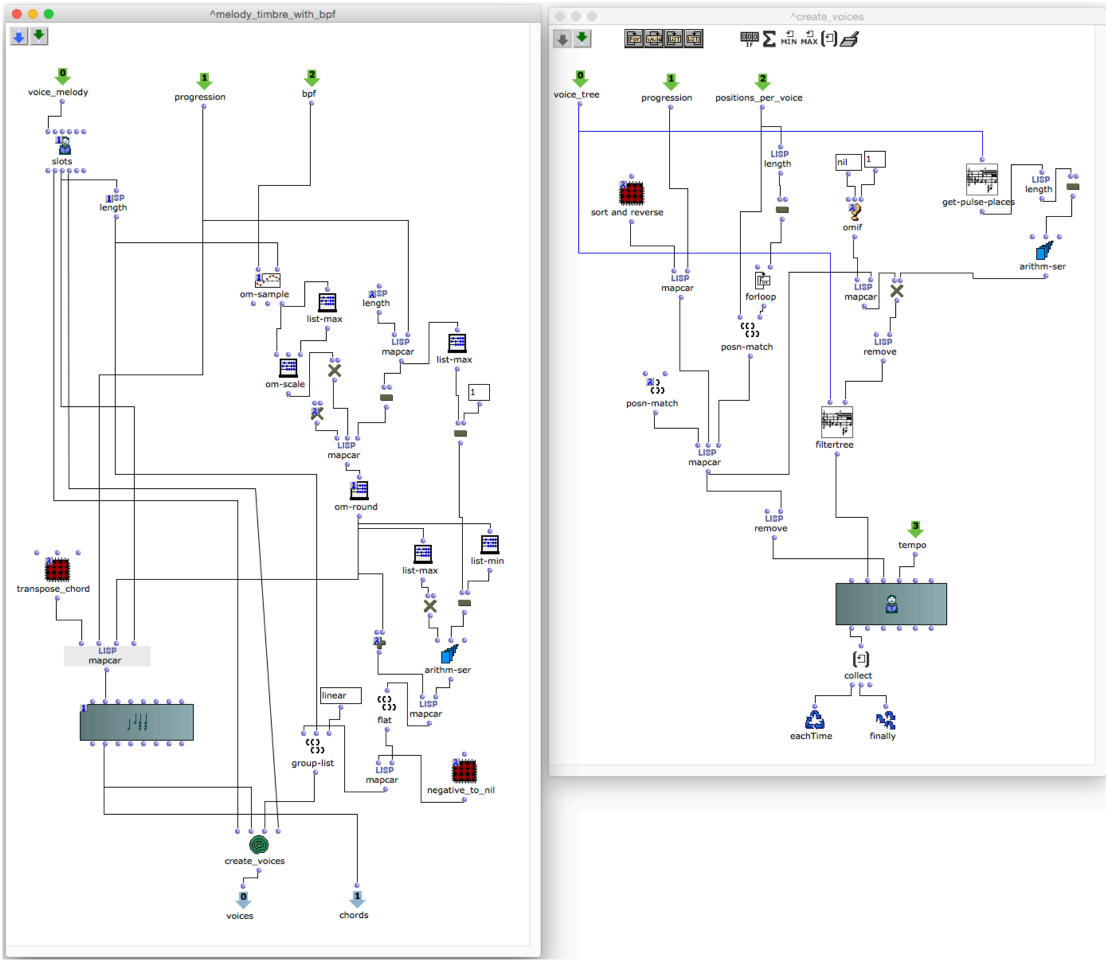

Figure IV.4-15 – The abstraction 'melody_timbre_with_bpf' (left) and its internal loop (right).

A similar algorithm used timbres that are subsets of the harmonic series. I've used this kind of procedure in the past,[90] calling it *spectral enrichment*. A process of calculating harmonic partials was used and connected to the same 'melody_timbre_with_bpf' patch used before. This *modularity* aspect of algorithmic composition is well documented and very appealing to me as it means that the composer can easily create variations on processes by merely patching together different combinations of a limited set of subroutines. The resulting algorithm is shown in Figure IV.4-16. As it is readily apparent, and in terms of programming, only the timbre evolution subroutine is different from the algorithm previously described. The partials of each pitch are generated from the allowed set in a number controlled by the density graph (top right, linearly increasing).

[90] In the piece *Vectorial-modular* (2011) for instance, an analysis of which can be found at the EarReader website (Gato 2013).

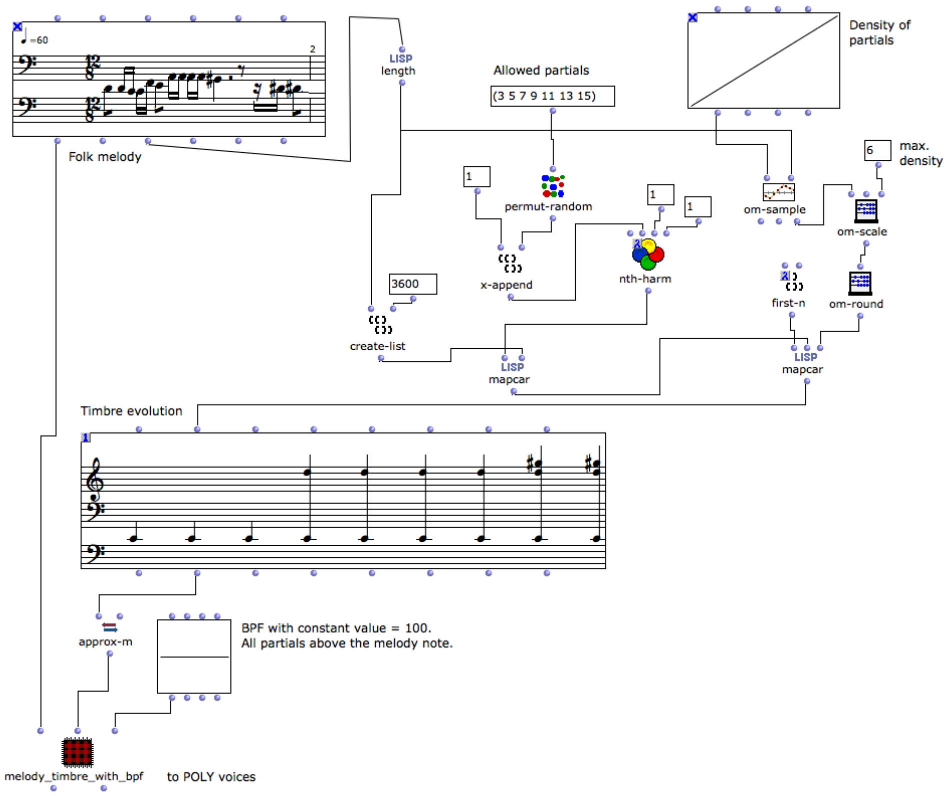

Figure IV.4-16 – Algorithm used for spectral enrichment.

IV.4.9 Helicoidal Harmony and Virtual Fundamentals

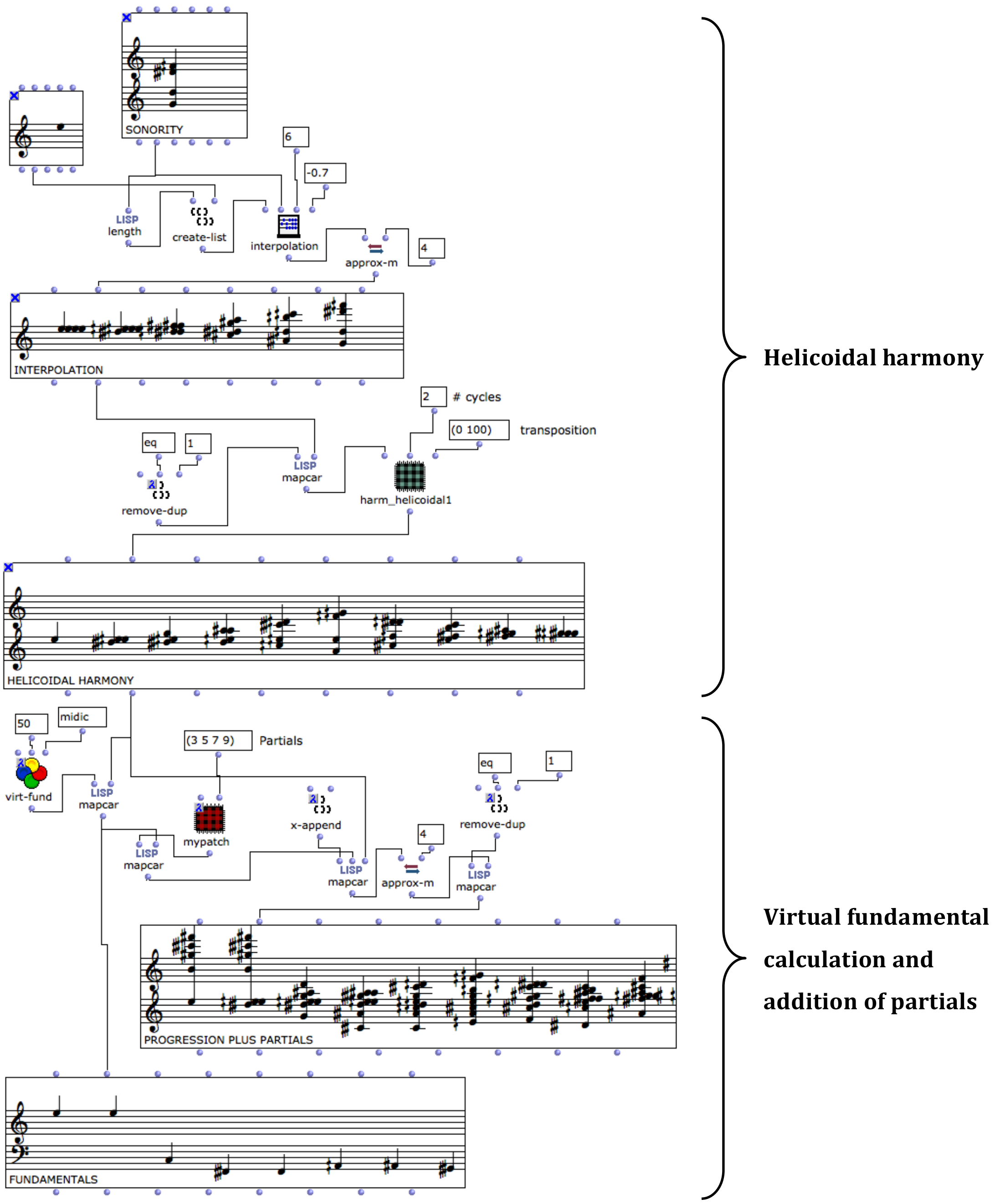

Figure IV.4-17 – Helicoidal harmony plus virtual fundamental algorithm.

A harmonic progression is initially created by an interpolation from a unison to a given sonority. After removing any duplicate quarter-tones from each chord, the abstraction named 'harm_helicoidal1' will first concatenate the progression with its retrograde version *n* times and then apply an interval transposition vector (0 100, in semitones). This vector acts cumulatively so that the entire progression is gradually shifted according to its intervals. The *CHORD-SEQ* object labelled HELLICOIDAL HARMONY is created.

Each chord is then subject to a virtual fundamental estimation (*VIRT-FUND* object), the output of which is shown in the bottom score object labelled FUNDAMENTALS. Partials 3, 5, 7 and 9 from each fundamental are added to each corresponding chord and duplicate quarter-tones eliminated to obtain the final progression (labelled PROGRESSION PLUS PARTIALS).

IV.4.10 Sonority and Modalism – Cyclic Harmonic Process

The environment shown in Figure IV.4-18 shows each step of one cycle of the Cyclic Harmonic Process. Pure and distorted versions of an initial sonority undergo parallel transformations: from the middle to the right, the distorted branch is shown. Each intermediate material is output into a score object whose contents are not always visible. Some score objects enable the slow playback of others connected to them. Around the centre of the figure, confluence of materials is collected into a *POLY* object whose contents are labelled for reference (sonority, mode, filtered mode, subsets, virtual spectra, union of spectra, union no quarter-tones). All the relevant materials from each branch are collected into the *CLONE* object and stored in OM-INSTANCES of lists (the bottommost objects whose icon features two parentheses).

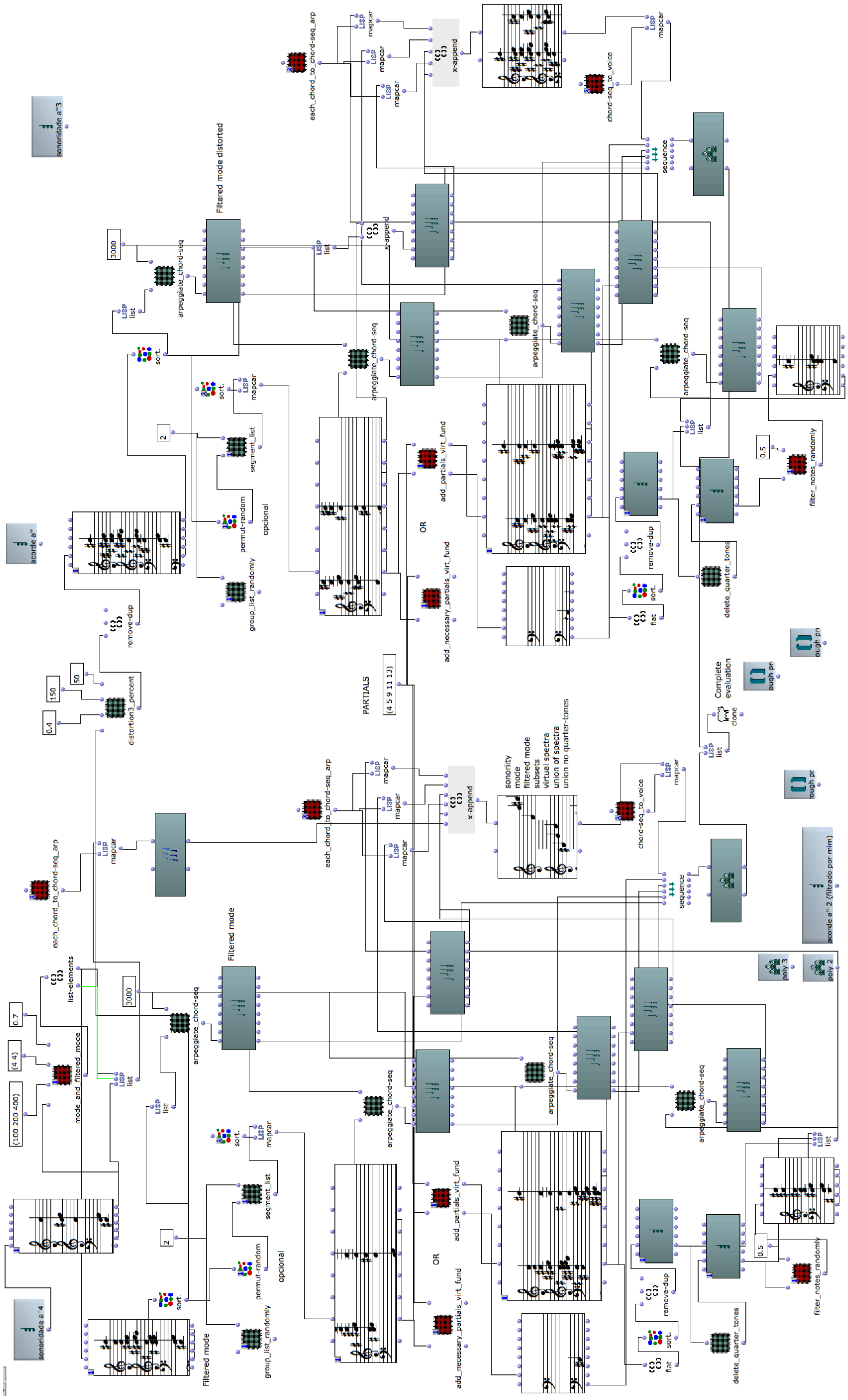

Figure IV.4-18 – Algorithmic environment for the automation and assessment of the Cyclic Harmonic Process.

IV.5 Rhythmic Morphology

The terminology used for the concepts related to rhythmic morphology was developed in my Master's Thesis (Gato 2010).

Musical rhythm can be viewed simply as a juxtaposition of durations (whether their are notes or rests). However, these durations can be grouped into a rhythmic *figure*. Figures, when juxtaposed, can be grouped into *zones* and, finally, zones can be juxtaposed and grouped in a ***rhythmic compound***. When rhythmic entities such as figures or zones are superimposed on one another, they are grouped into a ***rhythmic complex***. The rhythmic complex, thus, has a more loose definition. It can denote any (vertical) superimposition combination. To sum up, musical rhythm can be hierarchically grouped on the horizontal (time) or on the vertical (part or voice) dimension.

These hierarchical groupings of musical rhythm and associated terminologies reflect the morphological conception of rhythm as a shape that can be found on the various scales: rhythmic compounds are bigger than zones, which, in turn, are bigger than figures, and so forth. These subdivisions are necessary in order to describe the various processes of transformation that the composer can envisage.

IV.6 Polyrhythmic Textures

This appendix compiles an important ongoing research to classify the different kinds of polyrhythmic textures.

IV.6.1 Regarding Metre

Unimetric Texture

- In-phase – onset of common metres between two or more voices is temporally coincident, simultaneous.
- Out-of-phase – the onsets of common metres is not coincident; they are phased out.

NOTE: Using John F. Link’s nomenclature (Link 1994).

Polymetric Texture

It is a superimposition of different metres. Each voice exhibits a defined metre, but that metre is different amongst voices.

Ametric Texture

Individually, each voice does not possess a defined metre. The texture is a superimposition of irregular metres.

There are two types of ametry:

- Juxtaposition of different metres – irregular meter.
- Total absence of metre – when a voice does not show characteristics of metered music.

Partially Ametric Texture

- Simultaneous with polymetric: some voices have irregular metre, while others have a different but defined metre.
- Simultaneous with unimetric: some voices are metrically regular, while others form a unimetric texture.

In general, meter is **trivial** if it is of the same size as the pulse.

IV.6.2 Regarding Pulse

Unipulsional Texture

- In-phase – pulses of different voices are temporally coincident.
- Out-of-phase – pulses of different voices are of the same size but they are not temporally coincident.

Polypulsional Texture

Each voice has a defined pulse (a crochet or a quintuplet, for instance) but the texture is a superimposition of different pulses.

Apulsional Texture

A defined pulsation does not exist throughout each voice's individual rhythm.

Partially Apulsional

Some of the voices do not have a defined pulse.

IV.7 Gestalt Grouping Principles

These principles were historical findings of Cognitive Psychology. Theorized by the so-called Gestalt psychologists of the Berlin school at the turn of the twentieth century, they were primarily developed for visual perception and rely on the Helmholtz's concept of *unconscious inference*.[91] The source used, which links these concepts to auditory phenomena, is Roger Shepard's chapter *Cognitive Psychology and Music* on the book *Music, Cognition and Computerized Sound* (1999a):

- *Proximity*. Things that are located close together are likely to be grouped as being part of the same object.
- *Similarity*. When objects are equally spaced, the ones that appear similar tend to be grouped as being related.
- *Symmetry*. Because random unrelated objects in the world are not expected to exhibit symmetry, it would be most improbable for unrelated objects to exhibit symmetric relationships.
- *Good Continuation*. If objects are collinear, or arranged in such a way that it appears likely they continue each other, they tend to be grouped perceptually.
- *Common Fate*. Objects that move together are likely to be connected. A striking example is the fact that partials of a complex tone - playing a melody, for instance - are perceived as a single entity: timbre. It involves common onset time, common amplitude modulation, and common frequency modulation.

[91] The cognitive (unconscious) process by which the brain tries to obtain (*infers*) information that is missing in external stimuli based on available cues.

IV.8 A Reflection on Consonance

Consonance can be defined, in general terms, as "a combination of notes which are in harmony with each other due to the relationship between their frequencies" (Oxford University Press 2013a). I would, perhaps, add the word agreeable before harmony, and add that the relationship between the frequencies be a simple one in terms of integer-ratios (1/1 being the unison, 2/1 the octave, 3/2 the perfect fifth, 4/3 the perfect fourth, and so forth according to the generally agreed ordering of intervals in terms of consonance). Today, it is hard to consider the opposite term — dissonance — as something absolute. We are left only with degrees of consonance, the ordering/grading of which can be hard to control compositionally. A major chord is intrinsically more consonant than a 3-note cluster, but, as one explores the immense world of sonorities, the factors involved make comparisons and orderings harder. This is because human cognitive processes mediate the perception of sound, making it much more involved than just the physical reality describing its structure. Therefore, harmonic perception is a complex phenomenon, of which consonance is just one among various perceptual attributes:

- Register (e.g. a major triad sounds more dissonant on lower registers).
- Timbre of the pitches. If the pitches are not pure sine waves, then each of them contains partials. The relationships among the partials affect our perception of a given chord.
- Range or *ambitus.*
- Internal spacing. Spacing affects a chord's resonance because common pitched-instrument timbres usually follow the harmonic series spacing. This spacing prevents beats from arising out of the interference between lower partials, causing roughness in the sound.
- Presence of perfect intervals. Perfect intervals have a very particular, homogeneous sound. Some chords can be heard as a mixture of sonorities, particularly if they are exposed on the bottom or the top, and if spacing separates them in the register.
- Presence of imperfect consonances (historically so-called). These intervals don't sound as hollow as perfect consonances, tend to sound 'sweeter' and their presence can many times be perceived, especially if exposed.

- Overall intervallic content. One could easily distinguish a cluster from a stack of thirds, for instance.
- Resonance in the bass/lower region.
- Presence of beats. Some theories of consonance propose that beats between the partials of a sound are the prime sources dissonance. Beats are certainly an element we can aurally individualize on some chords, particularly (but not exclusively) if they contain quarter-tones.
- Fusibility of pitches, or homogeneity. This is an overall characteristic. A good, and very simple example comes from noting that the notes of a major chord in closed position (or in a position that fits the lower partials of the harmonic series) *fuse* much better than when the pitches are very separated in the register. Things get more complicated when each note is, in fact, an instrument timbre: consider again a major chord, but this time compare its presence on an homogeneous section of the orchestra (say three flutes, or violins plus violas) versus an heterogeneous orchestration (harp plus trumpet plus bassoon, for instance).

All these attributes make the task of establishing a consonance hierarchy very hard to achieve because they all affect our impression of a sound. This is not to say that a composer can never establish a working consonance scale for a particular composition. There is, however, much more to be explored in harmony as the human ear is sensitive to various additional characteristics.

IV.9 Fractal Numerical Analysis

Table IV.9-1 – Analysis of the fractal pitch sequence's intervals to show the canons. The top numbers in bold designate the internal pitch sequences: *x,y* meaning every *x* pitches starting on the y^{th} pitch (*y*=0 meaning the first pitch). Intervals are given in cents.

6,3 - (300	-100 100 200 0 -100 100 0 -200 400 -400 400 -600 500 -400 500 -700 700 -400 200 -700 1100 -400 0)			
6,2 - (300 -300		-100 -200 300 0 0 100 -300 500 -500 200 -400 400 -300 300 -500 400 -100 400 -900 400 300 200)		
6,1 - (200 200		100 200 -300 0 0 -100 300 -500 500 -200 400 -400 300 -300 500 -400 100 -400 900 -400 -300 -200)		
6,0 - (0 200			0 -200 0 -200 100 -200 300 -500 700 -400 400 -400 300 -300 400 -300 300 -600 400 100 300 -800 400)	
4,3 - (100 0 100 200 -100 200				-200 200 -100 -100 300 -100 0 300 -100 -200 0 200 0 -200 100 0 -100 200 100 -400 300 -200 200 -200 500 -800 700 -600 400 -200)
4,2 - (0 0 0 200 -200 -300 300				-200 200 -100 -100 300 -100 0 300 -100 -200 0 200 0 -200 100 0 -100 200 100 -400 300 -200 200 -200 500 -800 700 -600 400 -200)
4,1 - (300 100 0 -200 200 300 -300				200 -200 100 100 -300 100 0 -300 100 200 0 -200 0 200 -100 0 100 -200 -100 400 -300 200 -200 200 -500 800 -700 600 -400 200)
4,0 - (-200 500 -100 -100 -200 100 -200				200 -200 100 100 -300 100 0 -300 100 200 0 -200 0 200 -100 0 100 -200 -100 400 -300 200 -200 200 -500 800 -700 600 -400 200)
3,2 - (		100 200 -300 0 0 -100 300 -500 500 -200 400 -400 300 -300 500 -400 100 -400 900 -400 -300 -200 600 -400 0 -400 800 -400 100 -400 700 -400 0 -500 800 -400 100 -200 800 -400 0 -900 800 -400 100 200 600 -400 0)		
3,1 - (			0 200 0 200 -100 200 -300 500 -700 400 -400 400 -300 300 -400 300 -300 600 -400 -100 -300 800 -400 200 -600 1000 -400 0 -500 800 -400 100 -600 1100 -400 0 -700 800 -400 0 -200 1100 -400 0 -1100 800 -400 200 -200)	
3,0 - (	-100 100 200 0 -100 100 0 -200 400 -400 400 -600 500 -400 500 -700 700 -400 200 -700 1100 -400 0 -400 800 -400 -200 -200 700 -400 0 -300 800 -400 -300 0 700 -400 0 -600 800 -400 -300 400 700 -400 0 -800 800 -400)			
2,1 - (100 200 -100 200				-200 200 -100 -100 300 -100 0 300 -100 -200 0 200 0 -200 100 0 -100 200 100 -400 300 -200 200 -200 500 -800 700 -600 400 -200 200 -200 400 -600 600 -600 400 -200 300 -400 400 -400 300 -200 400 -600 700 -800 400 0 300 -600 400 -200 400 -600 400 -200 700 -1200 400 400 300 -1000 400 200 200 -600 400 -200)
2,0 - (0 -200 200 300 -300				200 -200 100 100 -300 100 0 -300 100 200 0 -200 0 200 -100 0 100 -200 -100 400 -300 200 -200 200 -500 800 -700 600 -400 200 -200 200 -400 600 -600 600 -400 200 -300 400 -400 400 -300 200 -400 600 -700 800 -400 0 -300 600 -400 200 -400 600 -400 200 -700 1200 -400 -400 -300 1000 -400 -200 -200 600 -400 200)

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