The granular connection (Xenakis, Vaggione, Di Scipio...)

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Abstract. This paper examines: 1) the way Xenakis introduced the granular paradigm; 2) some elements for the history of the granular paradigm (especially the work of Horacio Vaggione and Agostino Di Scipio).

NB. The English version of this article has not been revised (except 2.2)

Many ways start from or go through Xenakis. One of these ways is the granular paradigm[1]. In this paper, I will start from Xenakis, suggesting that, in his aesthetic, this approach is a "theory" in the ancient meaning of the word, and searching for the constituent elements of this "vision". Then, I will try to incorporate the granular paradigm into a musical historicity, searching for his becoming inside other aesthetics, in particular with Horacio Vaggione's and Agostino Di Scipio's music.

1. XENAKIS AND THE GRANULAR PARADIGM AS A "THEORY"

1.1. A "theory"

Xenakis expounds the granular paradigm as a "basic hypothesis (lemma)" [Xenakis, 1960: 84][2] in the first part of the article "Elements of Stochastic Music", published in 1960 (finished in 1959), which became well known thanks to his integration into *Musiques formelles* (1963, chapter 2) and his English translation (*Formalized Music*, 1971, 1992)[3]. Here is this "lemma", quoted according to the original English version, along with, inside square

[1] In this paper, I will use alternately the terms "paradigm" and "approach", following the example of Vaggione, 2005: *passim*.

[2] Xenakis, 1963: 61: "Hypothèse de base (Lemme)"; in Xenakis, 1992: 43, it becomes: "basic temporary hypothesis (lemma)".

[3] Chapter 2 of *Musiques formelles* and *Formalized Music* is made up of four articles published in the *Gravesaner Blätter*: Xenakis, 1960, 1960b, 1961, 1961b. They are important differences, and parts of this chapter do not appear in these original publications. (One of the most striking missing parts in these original publications is the end of chapter 2: Xenakis, 1963: 108ss; Xenakis, 1992: p. 89ss. Probably Xenakis intended to publish this last part in the following issue of *Graveser Blätter*, but, instead of it, he published Xenakis, 1962, maybe because *Musiques formelles* was already planned). The original publications were also made in German (with the title "Grundlagen einer stochastischen Musik"), in the same four issues. Unfortunately, in the Archives Xenakis (Bibliothèque Nationale de France), the original unpublished French version, if there is one, seems to not exist, except the small "Prologue" in Xenakis, 1960: 84-86.

brackets, the most significant changes in *Musiques formelles* quoted according to their translation in *Formalized Music*, and also, in italics, the words of *Musiques formelles* when they diverge from *Formalized Music*[4]:

> "All sounds represent an integration of corpuscles [grains], of elementary acoustic particles, of sound quanta. Each of these elementary particles possesses a double nature: the frequency and the intensity (the life-time of each corpuscle being minimum and invariable) [Each of these elementary grains has a threefold nature: duration, frequency, and intensity]. Every sound, every even continuous variation of sound is to be understood as an assembly of a sufficient number [of a large number / *suffisamment nombreux*] of elementary particles [grains] being disposed adequately within the time level. Thus any sound complex can be analyzed into series of pure sinusoidal tones, even if the variations of these latter are infinitely close together, of short duration and complex. During the attack of a complex sound, its full chord [body] and its decay, thousands of pure tones appear within a very short interval Δt [in a more or less short interval of time, Δt / *dans un intervalle de temps Δt assez court*]. Hecatombs of pure sounds are necessary for the creation of a complex sound. This one should be imagined as to be a display of fireworks sparkling in all colours, each luminous point of which appearing and disappearing instantaneously on the background of the black sky. But there would be so many luminous spots in this firework and they would be organized in such a way that their rapid and swarming succession creates forms, slowly uncoiling volutes[5] or in the contrary short explosions inflaming the whole sky. A sufficient number of instantaneously appearing and disappearing spots would form a luminous line" [Xenakis, 1960: 86-87 / Into square brackets: Xenakis, 1992: 43-44 / Into square brackets with italics: Xenakis, 1963: 61].

In the end of the second sentence, there is an important footnote:

> "This description of the micro-structure of acoustic signals [of the elementary structure of the sonic symbols / *signaux*] is used as the starting-point of the musical realization and must be understood rather as to be an intuitive representation than of scientific consistence [and is consequently only a hypothesis, rather than an established scientific fact / *et n'est par conséquent qu'une image plutôt qu'un fait scientifiquement fondé*]. But it can be considered as to be a first approach [approximation / *approche*] towards the ideas introduced into the theory of information by Gabor […]" [Xenakis, 1960: 86 / Into square brackets: Xenakis, 1992: 373 / Into square brackets with italics: Xenakis, 1963: 61].

We will go back to Gabor later. For the moment, let's put the emphasis on the idea that, for Xenakis, at that time, the granular approach is "an intuitive representation" or, in *Musiques formelles*' terms, an "image" –it becomes an "hypothesis" only in 1971. An *intuitive representation*, an *image*: I think that what is at stake in this formulations explains why the "way" that represents the granular paradigm is, for Xenakis and probably for other composers, a very wide way. To limit myself, for the moment, to Xenakis: an "intuitive representation", an "image", in the terms of Xenakis' aesthetic, is not only "poetry" (inspiration), but it is more than experimentation. I don't mean that there is an opposition between intuition and practical (or abstract) rationality. On the contrary, this kind of "intuitive representation" includes both elements, encompassing also a lot of others, including science, music, philosophical ideas, human experiences. It is a kind of vision of the world. In other terms, it is a *theory* in the ancient meaning of the term: a θεωρια (from θεωρω, to "see", to "contemplate", to "think")[6].

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[4] There are other differences between "Elements of Stochastic Music" and *Fomalized Music*, but they affect only the language. It is due to the fact that, probably, the translator of this chapter of *Formalized Music* translated directly *Musiques formelles*. So, the chronology should be: a) perhaps French manuscript articles; b) English and German translations in Xenakis, 1960-1961b; c) use of the original French (if it exists) for *Musiques formelles*, but with some important changes; d) English translation in *Formalized Music* (directly from *Musiques formelles*), with some other changes.

[5] "forms and spirals, slowly unfolding" in *Formalized Music*: it's probably a bad translation of "des formes, des volutes à déroulement lent" in *Musiques formelles*.

[6] As regards "theory" in Xenakis, in relationship with his use of cellular automata, cf. Solomos, 2005.

In Xenakis' musical production, there is only one composition that can be absolutely labeled as granular, the mixed piece *Analogique A* (1958, instrumental, where nine strings produce short sounds: pizzicati, short arcos and col legno: cf. **figure 1**) *et B* (1959, electronic, based on sine tones), which is the subject of "Elements of Stochastic Music". It is probable that Xenakis thought it as an experimentation as, in *Musiques formelles*, chapter 2, he writes, about the *A* piece, that "the hypothesis […] cannot, therefore, be confirmed or invalidated under these conditions" [Xenakis, 1992: 103; Xenakis, 1963: 122)][7]. Perhaps because of this conclusion, he didn't repeat the experience[8]. The concrete music *Concret PH*, composed just before *Analogique A et B*, in 1958, probably started in 1957[9], which is based on burning wood-embers, is often also quoted. This very short piece is clearly connected to its architectural context (the famous Pavillon Philips of the Bruxelles' Expo of 1958, conceived by Xenakis)[10].

However, the fact that the granular approach, in Xenakis' aesthetic, is a theory and not only an experimentation, explains why we find granularity in a lot of his works, limited to precise sequences: his music has undoubtedly a granular "sensibility" (among other ones)[11]. It would be too long to quote all these works. Let's only say that granularity appears in one of the three important xenakian "sonorities", the one which is made up of masses of short

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7 This part of *Musiques formelles* was not published in the *Gravesaner Blätter*'s articles.

8 There is a big discussion about the "failure" of *Analogique A et B*. Di Scipio [2005: 96] writes: "I would […] like to say that *Analogique* can be reasonably regarded as a very problematic musical composition. Some would say it is one of the less successful works ever composed by Xenakis. That is usually explained with the strong emphasis he put on the mathematical and constructive details, summing up to an overload of theoretical and technical premises whose final musical results are poor. In short, some look at it as an unsatisfactory experiment. This is, in a way, simply true, evidence being that, indeed, Xenakis never took up the approach again in later works. But this tells us little. But I would rather say, instead, that the problems Xenakis raised in this work, and that certainly he left without clear-cut solutions, give this music a peculiar character that is very palpable in the experience of listening. If we regard all human cognition as based on problem-solving, like most of us do, then it should be clear that those problems left without solutions had to do precisely with aspects of composing that remained (and probably had to remain) non-formalized. Xenakis himself felt urged to introduce a number of manual, non-formalized adjustments. As a result, the final music, as we listen to it, is less an unsatisfactory work, and more a work expressive of a lively and intricate dialectics between formalization and intuition".

9 "En musique, j'essaie de terminer, en dépit de toutes les difficultés matérielles de ce sacré 'club' de Schaeffer, les quelques minutes que j'avais commencées l'année dernière" (letter from Xenakis to Scherchen, 10/7/1958, Archives Xenakis, dossier œuvre 3/4). See also this funny letter: "Nous savons que vous avez cherché un bruit comme le crépitement de charbon de bois qui se refroidit et nous avons entendu il y a quelques semaines un concert électronique à Eindhoven. Pour une des pièces la plupart du public suivait un texte imprimé sur quelques pages d'un papier mince mais assez dur. Le bruit fait par quelques centaines de pages tournées en même temps était très curieux et s'assimilait très bien à la musique. Peut-être vous pouvez en tirer quelque profit " (letter from Kalff to Xenakis, 30/11/1957, Archives Xenakis, dossiers architecture X(A) 4-1).

10 "Œuvre commandée par Philips pour son pavillon de l'Exposition Universelle 1958 de Bruxelles. *Concret P.H.* devait préparer psychologiquement le public au spectacle élaboré par Le Corbusier et accompagné d'une musique de Varèse. Les 400 haut-parleurs qui tapissaient l'intérieur de la coque devaient remplir l'espace de cette scintillation sonore et réaliser une émanation commune de l'architecture et de la musique, conçues comme un tout : en effet, la rugosité du béton et son coefficient de frottement interne trouvaient en quelque sorte un écho dans le timbre des scintillations. La continuité statistique des développements formels des sonorités granulaires et la stéréophonie cinématique devaient établir une homologie complète entre les sons et les formes plastiques du Pavillon dont j'avais également conçu l'architecture entièrement fondée sur les surfaces réglées gauches ou 'Paraboloïdes Hyperboliques (P.H.)'", writes Xenakis for *Concret PH*.

11 This expression granular "sensibility" is also borrowed from Vaggione (2005: 348, footnote 9) who is speaking about his own music.

sounds, of "cloud of sounds" (one of the most known Xenakis' expression)[12]. **Figure 2** and **3** show just two different achievements of granular sonorities, in *Herma* (1960-61) and *Eridanos* (1972). As regards the first granular sequences in his music, we find them already in *Pithoprakta* (1955-56), thus before *Concret PH* and *Analogique A et B*. Everybody knows bars 52-59 of *Pithoprakta*, where more that 1000 pizzicati-glissandi[13] of the string orchestra are produced for a duration lesser than 20 seconds. Xenakis calculated their values (pitch of the attack, duration and glissandi speed) with probabilities and made their distribution in time thanks to a graph[14] (**figure 4**).

1.2. Some constituent elements of the theory

After defining the granular paradigm in Xenakis' aesthetic as a theory –in a way, as a "vision"–, let's try to describe shortly its constituent elements. By "constituents", I mean elements that contribute to its birth, or that constitute its goals, or that form its philosophical (in the broad sense) background. Here are six such constituents:

1. The duality wave-corpuscle. Xenakis was aware of this debate in physics. And, as at that time, he wanted that music "catches up" with science, it is naturally that he thought to "transpose" the idea of corpuscle into music[15]. One of the first (or maybe the first) mention to this idea exists in the article "La crise de la musique sérielle", published in 1955: speaking about the series, he says:

> "Pourquoi la continuité du spectre des fréquences ? du spectre des timbres ? du spectre des intensités et des durées ? Mais laissons de côté la question de la continuité (elle sera d'ailleurs dans peu de temps, pour la recherche musicale, le pendant de l'état ondulatoire du corpuscule-onde de la matière) […]" [Xenakis, 1955: 3].

2. The notions of mass, cloud of sounds and probabilities are one of the most important constituents. The abovementioned granular sonority of *Pithoprakta* is a probabilistic mass of short and numerous sounds. The idea of granularity is indeed inscribed in the beginnings of Xenakis' use of probabilities, as the "parabole" [Xenakis, 1958-59] that allowed him to introduce probabilities in music was:

> "Let's identify short sounds, for example: pizz., with molecules; we obtain an homomorphic transformation from the physical field to the sound field. The individual movement of sounds no longer matters" [Xenakis, 1958-59: 19 (I translate)].

Xenakis describes *Concret PH* as a "nuage de poussières de sons" a "gaz sonore" [Xenakis *in* Delalande, 1997: 115], which is also the definition of the probabilistic masses of

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[12] As regards the notion of "sonority" in Xenakis' music and its three sonorities (sliding sounds, static sounds and masses of short sounds), cf. Solomos, 1993, 1996: chapter 5, 2001.

[13] 1142 according to the historical article published in the *Gravesaner Blätter* (Xenakis, 1956: 31). According to *Musiques formelles* (Xenakis, 1963: 30; 1992: 15), they are 1148. My analysis counted 1146.

[14] Xenakis drew two graphs for this part of *Pithoprakta* (cf. Gibson, 1994). The one reproduced here is the final version.

[15] It's strange that, when (in the late 1970s: cf. Xenakis, 1976: 192-196) Xenakis drew tables comparing the evolution of music and sciences, which show its own contributions, he didn't mention its work with the granular paradigm. But it is true that he limits himself to mathematics.

short sounds in his music. The questions raised by the probabilistic masses –density, order and disorder, continuity and discontinuity– belong also to the granular approach.

3. What is specific to the granular paradigm is the idea to go from one level to another. It is of course this idea, which will generate the granular synthesis as a specific future of the granular approach. In Xenakis, this idea is expressed with the following general formulations of "Elements of Stochastic Music":

- to create "sound complexes", "complex sounds" (cf. the first quotation);
- to create sonorities of higher order:

> "Supposing that every point of these clouds represents not only a pure frequency and its satellite intensity but already a structure of elementary particles [grains] being arranged a priori. We think that a sonority of second order and even third order etc. [second, third, or higher order] could be created in this way" [Xenakis, 1960: 90 / Into square brackets: Xenakis, 1992: 47 (the last change don't appear in Xenakis, 1963: 65)].

(It's worth mentioning that Xenakis thought also this idea as sound synthesis, even if he didn't use the term. It is shown for instance in the following quotation, which shows the utopia of sound synthesis as encompassing all possible sounds, a utopia characteristic of the sound synthesis' pioneers:

> "Within human limits and with the manipulations of all sort of these particle clouds [grain clusters], we can hope to produce not only the sounds of classical instruments, of elastic bodies and, generally spoken, of those ones utilized with predilection by the concrete music, but also acoustic emotions [sonic perturbations / *ébranlements sonores*[16]] with evolutions which have been unprecedented and unimaginable up to now" [Xenakis, 1960: 90 / Into square brackets: Xenakis, 1992: 47 / Into square brackets with italics: Xenakis, 1963: 65].)

It is probably in this theorizing that appears for the first time the distinction between micro- and macrostructure (and even micro- and macrosounds[17]), even if it is not so theorized as it will be in latter Xenakis' writings[18].

4. Specific also to Xenakis' theory is the idea that it is not only an hypothesis about the nature of sound, but also about hearing. The quotations I gave in 3 are taken from a paragraph heading "Psychophysiology", where Xenakis makes reference to two books dealing with psychoacoustics[19], and quotes the well-known Fletcher-Munsion graph (which correlates intensity and frequency to show the limits of human audition), among other questions.

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16 "perturbation" isn't a very good translation. The French word, "ébranlement" is near to the term used in the original version, "émotion" as the question is about "motion", but without its psychological impact.

17 We find the expression "microsound" *in* Xenakis, 1960: 93 (Xenakis, 1992: 50; 1963: 68).

18 For instance: "La musique a toutes sortes de formes, au niveau microscopique, au niveau macroscopique, au niveau de l'échantillon", writes Xenakis, 1985: 127.

19 Stevens and Davies, *Hearing*, Willey and Son, New York, 1948; Winckel, 1960. Cf. Xenakis, 1960: 90 and Xenakis, 1963: 65; in Xenakis, 1992: 47, the references appear as numbers (bibliographical references), but there is no bibliography in the end of the book! In the Carnet 19 (Archives Xenakis), used from 1957 to 1959, we find some notes on the first book. In the second book, which is in fact a book on acoustics and which is pioneering as regards the definition of "timbre", we find the following ideas that certainly interested Xenakis (cf. *infra*): "L'ensemble des constatations que nous avons faites dans les pages qui précèdent nous montre que dans son architecture d'ensemble, la musique est un mouvement ; bien plus, que le matériau isolé, le son, est exclusivement un élément mouvant " (Winckel, 1960:119); "On peut donc affirmer à coup sûr que les sons stationnaires, tels que les représente la notation musicale habituelle, n'existent pas dans la réalité sonore : la musique ne vit que grâce aux régimes transitoires pendant lesquels les sons possèdent un timbre continuellement variable et différent du timbre neutre en régime stationnaire " (Winckel, 1960:129).

5. In Xenakis' formulation of the granular approach, hearing and vision are interrelated. Let's remind the "basic hypothesis (lemma)":

> "Hecatombs of pure sounds are necessary for the creation of a complex sound. This one should be imagined as to be a display of fireworks sparkling in all colours, each luminous point of which appearing and disappearing instantaneously on the background of the black sky. But there would be so many luminous spots in this firework and they would be organized in such a way that their rapid and swarming succession creates forms, slowly uncoiling volutes or in the contrary short explosions inflaming the whole sky. A sufficient number of instantaneously appearing and disappearing spots would form a luminous line".

In the article "Elements of Stochastic Music" there is an introduction that doesn't appear in *Musiques formelles* / *Formalized Music*. Xenakis writes that his book[20]

> "may be read by everybody, but especially by a new category of searchers: the 'experimental composers', they may be musicians, film-producers, painters, sculptors etc. provided that they dispose of a certain mathematical luggage and particularly of a spirit of adventure. For I am convinced that the mathematics, physics and psychology, a sort of new Trivium, must be taught by the conservatoires within one generation if not the Scientific Research will run the risk of founding a new department: 'the Audio-visual Research" which would absorb the studies about composition brought about by the actual conservatoires" [Xenakis, 1960: 85-86].

Xenakis have never explained the title *Analogique*. One hypothesis is that this title would refer to the analogy of hearing and seeing. As explains Matossian [1981: 158], Gabor's corpuscular hypothesis "exerce une puissante influence, en tant qu'image, sur la conception qu'a Xenakis de l'œuvre, car ses notes comportent des photographies de grains ou de cellules répartis autour de noyaux d'une densité plus concentrée, groupés ensemble de façon distincte. […] Comment une image visuelle peut-elle se transformer en procédé de composition ? "[21].

6. In the Preface of the second edition of *Formalized Music*, written in 1991, Xenakis says:

> "An important task of the research program at CEMAMu is to develop synthesis through quantified sounds but with up-to-date tools capable of involving autosimilitudes, symmetries or deterministic chaos, or stochastics within a dynamic evolution of amplitude frequency frames where each pixel corresponds to a sound quantum of 'phonon', as already imagined by Einstein in the 1910s. This research, which I started in 1958 and wrongly attributed to Gabor, can now be pursued with much more powerful and modern means. Some surprises can be expected!" [Xenakis, 1992: XIII].

We see that Xenakis doesn't attribute his theory to Gabor, but to Einstein. In "Elements of Stochastic Music", there is the footnote that I already quoted, but with cutting the end. Here it is again, without this cutting:

> "But it can be considered as to be a first approach towards the ideas introduced into the theory of information by Gabor (see Meyer-Eppler, p. 21)".

That means that he hadn't read at that time Gabor's historical articles [Gabor, 1946, 1947] as he quotes his researches through Werner Meyer-Eppler's book. An asterisk gives the reference to this book (*Grunglagen und Anwendungen der Informations-theorie*, 1959). And yet Xenakis begins his experiments –to limit us to *Analogique A et B*– at least on 1958, and this book was published in 1959. (Of course, he could have attended at previous lectures of

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[20] It is probable that, in the end of the 1950s, Xenakis had planed to make a book thanks to Hermann Scherchen. This book would probably have been a version of *Musiques formelles*, with the title *Mécanisme d'une musique*, as argues Kanach, 2001: 203.

[21] In Xenakis Archives (dossiers œuvres 5/10) there are two such photographs.

Meyer-Eppler dealing with that question[22], or heard about Gabor from Abraham Moles[23] or from others.) The misinterpretation, if there is a misinterpretation, begins probably with the fact that the reference to Meyer-Eppler disappeared totally in *Formalized Music* (the version from where Xenakis' researches became most known) due to an error of the publisher[24]. In some interviews, Xenakis repeats that he made his hypothesis without knowing Gabor, and with Einstein as a reference[25] [26].

In one of these interviews, he says:

> "In the 1950s I proposed a theory about sound synthesis based on the quanta sound. The acoustic quanta goes back to a theory by Einstein around 1917 to do with phonons. It's all connected with the observation that the transmission of heat and of sound through molecules of atoms is by *energy* jumps, just as in the case of photons. They controlled by the same equation, the Planck equation. I'd developed my theory purely by intuition and realized only later that it had already been proposed in physics" [Xenakis *in* Varga, 1996: 1997 (the emphasis is mine)].

Energy: the word is also used in a "Carnet", in some notes from November 1958 probably related to the granular researches:

> "Une musique est un ensemble de transformations énergétiques.
> I. Transformations ordonnées ou simplement dénombrables ou quelconques atomiques (sons pures, sinusoïdaux)
> de fréquence continues (vitesse), discrètes (log).
> de dynamique.
> C'est-à-dire deux ~~paramètres~~ variables indépendantes fréquence cycle/sec ou rapport de fréquences = intervalles et niveau sonores dB attribué à chaque valeur de a). Les transformations peuvent être indépendantes ou liées entre ces deux variables et contrôlées par des représentations canoniques ou par des protocoles (matrices). Déterminées ou pas. Ces transformations me définissent la collection et sa structure interne.
> II. Sur un plan plus général.

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[22] "In his later lecture *Metamorphose des Klangelemente*, presented in 1955 at among other places, Gravesano, Switzerland at the studio of Hermann Scherchen, Meyer-Eppler described the Gabor matrix as a kind of score that could be composed with a 'Mosaiktechnik'" (Roads, 2001: 62). Xenakis could have attended at this lecture.

[23] This hypothesis is made by Di Scipio (1998: 70). After verification, I tend to confirm it. Xenakis, 1962: 182, writes: "[The] atomic hypothesis is corroborated by the theory of the elementary acoustic signal introduced into information theory by Gabor […] Also, A. Moles has been emphasizing the quantum nature of auditory perception for years (A. Moles: 'Théorie de l'information et Perception Esthétique', Flammarion, Paris). These two facts have made me express the quantum theory of musical composition". *Théorie de l'information…* was published in 1958. In another version of Xenakis, 1962, we read: "Cette hypothèse atomique est corroborée par la théorie du signal acoustique élémentaire introduite par Gabor dans la théorie de l'information. […] Par ailleurs, A. Moles a *depuis de longues années* mis en relief la quantification de la perception" (Xenakis, 1961c: 313, the emphasis is mine). Curiously, in another version of these two articles, 1961d: 139, Xenakis don't mention at all Moles… Xenakis knew quite well Abraham Moles, probably since the second part of the 1950s. In the Archives Xenakis, there is a copy of Moles' article "Some Basic Aspects of an Information Theory of Music", *Journal of the Audio Engineering Society* vol. 6 n°3,July 1958, p. 184-186, with a dedication to Xenakis. In 1960, they created the informal group "MYAM", labeled after the initials of its 4 members, Abraham *M*oles, *Y*annis Xenakis, *A*lain de Chambure, *M*ichel Philippot.

[24] As I already have said, the bibliographical references disappeared in *Formalized Music* –it is not the case of *Musiques formelles*.

[25] Cf. Restagno, 1988: 30; Albèra, 1989: 80; Varga, 1996: 197. In his interview, Robindoré, 1996: 11) writes: "In the late 1940s, Iannis Xenakis read an article entitled 'Acoustical Quanta and the Theory of Hearing' in the British scientific journal *Nature*. This article, by the Nobel-prize winning physicist Dennis Gabor, presented a theory on the particle nature of acoustical phenomena. Not content with mathematical theory, Dennis Gabor constructed his own sound granulator, which could compress and expand the time scale of recorder sounds […]. Xenakis pondered the compositional applications of this discovery"; but she doesn't give the chance to Xenakis to contradict or confirm this affirmation!

[26] As regards the reference to Einstein, I didn't found (for the moment) in the Archives what could have been Xenakis' sources.

Transformations entre groupes de transformations type TI.
Sur ce plan on rencontre les timbres car on introduit la simultanéité"[27].

As we know, "energy" is in the center of Xenakis' aesthetic –one of his late articles "Sur le temps" [Xenakis, 1988; English translation: Xenakis, 1992: chapter 10], is very clear on this point. His interest for the granular paradigm is probably related to that question. In a way, the granular theory coincides with his whole theory (vision) about music as energy phenomenon[28].

2. SOME ELEMENTS FOR A HISTORY OF THE GRANULAR APPROACH

2.1. The historicity of the granular paradigm

We will not go further into Xenakis' theory[29]. The next step for this article is to try to incorporate the granular approach into a musical historicity, before and after Xenakis, so as to confirm that this approach is a theory (in the given definition of this term), and not only experimentation or a technology. Note also that this historicity cannot be presented as a "line", and it is why I speak about a granular "connection".

If the scientific history of the granular paradigm is long –Curtis Roads [2001: 52] goes back to Isaac Beekman (1588-1637)–, the musical one seems short. It is very difficult to find granular sonorities before Xenakis. We could mention Debussy's "liquefaction" of the musical entities –in a way, there is a history of the dissolution of musical material: in Debussy the model of the water plays an important role, and Xenakis "goes further" as for him the liquid evaporates and becomes gas!–, which leads sometimes his music to construct smooth surfaces with small motives (cf. **figure 5**). But it is of course very difficult to do so. The webernian pointillism would be a better example, even if it were also questionable, as it would be also the case of some pizzicati textures in Bartók music. In Varèse's music, some

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[27] Carnet 23, Archives Xenakis.

[28] The idea of music as "energy", "movement", "motion", has a long tradition. We find it already in Plato's *Timaeus* –quoted by Xenakis in *Musiques formelles*: "The movements of sounds that cause movements in us in agreement with them 'procure a common pleasure for those who do not know how to reason; and for those who do know, a reasoned joy through the imitation of the divine harmony which they realize in perishable movements'" (Xenakis, 1963: 212; 1992: 179). As regards Xenakis, this may explain his admiration for Brahms. Brahms was a friend of Eduard Hanslick, who wrote the famous book *Vom Musikalish-Schönen* (1854) where he developed this idea. Hanslick was labeled as "formalist" because, as Brahms, he was against program music (Liszt). With xenakian eyes, we can read him today as the defender of an energy aesthetic as opposed to a "expressive", linguistic aesthetic. Indeed, Xenakis' conception of music as energy explains perhaps why he is against the idea of music as language.
cf. Solomos, 2004]

[29] For more details on Xenakis, cf.:
- the articles of Di Scipio: 1995, 1997, 1998, 2001, 2003, 2005, dealing with various aspects of this approach, with *Concret PH* and *Analogique A et B*, and with detailed analysis of the later;
- Roads 2001: p. 64-68 and *passim*, for an introduction to Xenakis' granular technics;
- Orcalli, 1993: chapter 4, and Bokesoy, 2004, for *Analogique*;
- Bridoux-Michel, 2005, Meric, 2005, and Harley, 2002 for some insights into *Concret PH* and *Analogique*.

sonorities have to do with granularity, as for instance *Ionisation*'s third sonority[30] (cf. **figure 6**)[31].

As regards composers contemporaneous with Xenakis, the serialism pointillism of the 1950s and its microstructural building is sometimes really evocative of granular sonorities, especially in Stockhausen's music. *Gruppen* (1955-57) is a good example. **Figure 7** shows one bar where, thanks to the "formant" structuration of the rhythms (theorized in Stockhausen, 1957), the density is enough so as to have, in theory, a synthesis for the ear: 28 notes could be placed inside a half note (cf. **figure 8**). In the 1950s and 1960s, Xenakis, when using rhythmical superimpositions, limits in general the divisions to 2, 3 and 5, thus having only 10 possible divisions of a unit (cf. **figure 1**). Of course, in Xenakis, the granular intention is there, would it be only as a sonority or as in *Analogique*, while in Stockhausen it is not the case. To continue with Stockhausen, the electronic part of *Kontakte* (1959-60) is probably his nearest piece to the granular approach as "nearly all the electronic sounds were produced with an impulse generator (the speed of the impulses could be varied continuously between 16 and 1/16 impulses per second, the duration of these impulses being variable between 1/10000 and 9/10 seconds)" [Stockhausen, 1996: 174]. But, even there, the idea of granularity is not present as such. As for the 1960s, some Ligeti's "clockwork" movements could have the appearance of granularity.

After Xenakis, there are first some isolated achievements, like these of Horacio Vaggione who, for instance, in *Modelos de Universo* (1971) and *Movimiento continuo* (1972), used a digital sound synthesis program called "Papova", running on a large IBM 7090 mainframe computer, to generate up to 20 sounds per second in each of four voices [cf. Vaggione, 1983]; or like this of Bernard Parmegiani in "Matières induites" (movement of *De natura sonorum*, 1975). The granular paradigm becomes granular synthesis since the end of the 1970s with Curtis Roads [1978], and then with Barry Truax [1988]. It is since the 1980s that the granular connection seems to work, with composers like Roads [cf. Roads, 2001: 302-311], Truax or Vaggione. And this is a "connection", and not a "line" (which would be drawn from Xenakis) as their aesthetics are totally different: Vaggione defines a multi-scale approach to time (cf. *infra*); Roads seems more interested in microsounds; with his soundscape compositions, Truax looks for going "inside a sound" and creating reverberation "in the listener's memory"[32]. Since the 1990s, granular approach is more and more

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[30] For an analysis of *Ionisation*' three "sonorities", cf. Solomos, 1995. These sonorities are first exposed and then serve the whole development of the work.

[31] Roads (2001: 54), after discussing Einstein's acoustical quanta (or phonon), writes: "In his own way, the visionary composer Edgar Varèse recognized the significance of this discovery: 'Every tone is a complex entity made up of elements ordered in various ways […] In other words, every tone is a molecule of music, and as such can be dissociated into component *sonal atoms* [… These] may be shown to be but waves of the all-pervading sonal *energy* radiating throughout the universe, like the recently discovered cosmic rays which Dr. Milliken calls, interestingly enough, the birth cries of the simple elements: helium, oxygen, silicon, and iron' (Varèse 1940)". If we put the emphasis on the word "energy", we find here one of the many links that bring together Varèse and Xenakis (cf. Solomos, 2006).

[32] "The technique I have found the most striking in the way it facilitates moving inside a sound is real-time granulation of sampled sounds. […] A dramatic shift of the sound called 'time-stretching' is made possible with this technique. […] This effect is used not merely to create drones, but to allow the innertimbral character of the sound to emerge and be observed, as if under microscope. […] In terms of the soundscape composition, the

widespread with composers like Agostino Di Scipio (cf. *infra*), Ludger Brümmer, Manuel Rocha [cf. Rocha, 1999], Ramon Gonzalez-Arroyo [cf. Gonzalez-Arroyo, 2005], Eduardo R. Miranda [cf. Miranda, 2002], Damian Keller, Mara Helmuth [cf. Helmuth, Davis, 2004], and many others. Musicians from the *electronica* scene are also more and more interested in the granular paradigm.

I would like to give an insight into the approaches of two composers of this connection, Horacio Vaggione (born in 1943) and Agostino Di Scipio (born in 1962). I choose them because they illustrate the aesthetic variety of this connection, because they belong to two different generations, and of course also because their "theory" (vision) is related to music of high quality.

2.2. Horacio Vaggione and the multi-scale approach to time[33]

As we have seen, Horacio Vaggione elaborated his granular approach already in the 1970s (and we could also make the relationship between this approach and the post-webernian pointillism of his music in the 1960s: cf. Laliberté: 352). Since the 1980s, with works like *Thema* (1985, for bass saxophone and computer-generated tape), *Tar* (1987, for bass clarinet and computer-generated tape), *Ash* (1989-90, electroacoustic music), *Kitab* (for bass clarinet, piano, double bass and computer set-up), *Schall* (1994, electroacoustic music), *Myr-S* (1996, for cello and electroacoustic set-up), *Préludes Suspendus II* (2000, electroacoustic music), *Atem* (2002, for horn, bass, clarinet, piano, double bass and electroacoustic set-up) or *Taléas* (2002-2004, for recorders and electroacoustics)[34], he is considered as to be a master of the granular paradigm. In his approach of this paradigm, the important question is *time*.

A group of questions dealing with time are brought up by Vaggione. Among the most important, we begin by noticing that Vaggione, after composers like Xenakis and in parallel with the spectral composers, integrates the "modern" idea of time, considering it as irreversible. In this context, sound is no longer conceived in terms of periodicity or repetition, as defined by the "classical" acoustic model of Helmholtz, but as a dynamic, energetic phenomenon. One of his important references, in this domain, is the work by physicist Ilya Prigogine, the inventor of the "theory of dissipative structures". This is the theory to which Vaggione is referring when he describes "dissipative structures of sound energy" [cf. Vaggione, 2003a: 102].

Second, Vaggione is interested in delving into the infinitesimal, into what has often been presented as the "inner life" of sound, a crucial question for a long line of composers starting no doubt with Varèse and continuing through Stockhausen to the current vogue of "immersive" music. However, with relation to that issue, Vaggione differs in at least three ways. To begin with, he does not subscribe to the concept of "inner life" and its corollaries

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added duration […] allows the sound to reverberate in the listener's memory, providing time for long-term memories and associations to surface" (Truax, 1988: 96).

[33] This chapter is developed in Solomos, 2005b.

[34] For the electronic parts of the pieces, I quote Vaggione's terminoly given in Solomos (ed.), 2005: 413-418.

("immersion", "auscultation" or even "delving into the infinitesimal"), which tend to be associated with space. For him, it is a question of *time*, and this is why he prefers to speak about a "descent" into *micro-time*. Further, beyond his fascination for phenomena occurring at this particular temporal scale, for him, the crucial question is that of *articulation*, of how to *compose* these phenomena. The title of an article from 1996 sums up these two aspects: "Articulating Micro-Time" [Vaggione, 1996]. In addition, whereas in the problematic of the "inner life" fascination is frequently shown for a supposedly original matrix, a Unity –giving rise to the mystical leanings of composers like Scelsi, Stockhausen, Harvey, or even Grisey–, Vaggione sees this, on the contrary, as an opportunity to discover *pluralism*:

> "Descending into micro-time is for a musician, the means of discovering phenomena he is unaware of when he satisfies himself with the agitation of sound surfaces without taking into account their substrates. […] As Bachelard said: 'our intuition of time is still quite poor, limited to our intuitions of absolute beginning and continuous duration'. We have to therefore 'find the pluralism beneath identity', and 'to break down the identity far beyond an immediate experience summarised too soon as an aspect of the whole'" [Vaggione, 1998].

This explains Vaggione's interest for granular synthesis: it really is about finding "pluralism" (grains) beneath "identity" (the resulting sound). In addition, Vaggione stresses that a corpuscular description, unlike the oscillatory type, refers to irreversible time. The granular approach "enables us to work with complex morphologies in a space-time where irreversibility reigns: 'dissipative' structures that emerge within a directional space-time, rather than in symmetrical, smooth continuities" [Vaggione, 2005: 341]. This is why, in Vaggione's music, the granular approach is much more than a technique of synthesis. Not only does it permit him to articulate micro-time (synthesis), but he also applies it to macro-time (instrumental music). Moreover, he likes using the general concept of "granulation" and enjoys tracing it back to Lavoisier [cf. Vaggione, 1996: 34].

Third, some of Vaggione's texts, from the second part of the 1980s until the close of the 1990s, elaborate the idea of a *multi-scale* approach to time. The idea is not new in itself –e.g., Xenakis (cf. *supra*) and Grisey (who distinguish between three temporalities: cf. Baillet, 2001: 25) had already raised it–, but its developments are. Vaggione begins with the pragmatic observation that there exists, as much within both musical tradition and human perception, a threshold from which we can delimit two orders of scales, corresponding to the domains of micro- and macro-time. In musical tradition, it is the "note" that instrumental music considers as the elementary unit: macro-time "encompasses all possible scales" above, and micro-time, all those below [Vaggione, 1998b: 172]. The repercussions of this apparently innocuous formulation are enormous: they allow the break between instrumental and electroacoustic music to be reformulated and, in doing so, tempered. In fact, seen from this angle, the gap between the two does not dwell in a difference of "nature" (e.g., of material): it lies in a change of (temporal) scale. This way of thinking was made possible by the arrival of digital electronics, which permit micro-time to be composed. We can then view either side of the threshold, micro- and macro-time, as falling beneath the common emblem of the composable, of what can be articulated –without *abolishing* the threshold as there is a change of scale. In terms of human perception, the threshold is situated, as we know, between 50 and 100 milliseconds. Defined with the help of the granular model, this threshold signifies that, with less than ten to twenty sounds per second, the ear perceives grains as entities; when there are more, it perceives them as belonging to a global texture. By applying this model, as much

to synthesis as to the instrumental they can therefore be unified, without however abolishing the difference between them. In the case of synthesis, we perceive the granular nature of the resulting sound, but it is indeed "a" sound. With the instrumental, on the contrary, even when the threshold of micro-time is close to being attained –as is often the case in Vaggione's scores, where musicians are asked sometimes to play up to quintuplet of thirty-second notes to a quarter note of 100 MM (cf. **figure 9**)–, we remain within the framework of a segregative flux. This is why granulation must not be taken literally when it is applied to instruments: Vaggione is not looking for an "instrumental granular synthesis" [cf. Vaggione, 2005: 341ss].

I insist on the fact that the Vaggionian approach, which establishes the difference between the microscopic and the macroscopic in terms of time scales, does not set out to abolish the threshold that holds them together. This means that, even if these two levels can be unified, their disparities are however maintained. We cannot move from one level to another only by transposition. In Vaggionian terminology, a *nonlinearity* exists between time levels, an irreducibility from one to another. This is perhaps where the originality of his theorisation lies, because many musicians who also addressed this question, prior or parallel to him, were rather inclined to follow the principle of transposition. This is the case of Xenakis writing pieces conceived for the GENDYN programme, where everything is automatically deduced from a wave form; and equally applies to Grisey who was able to use the same waveform outline in several time scales (*Vortex temporum*). We could also refer to certain uses of fractals in music[35]. For Vaggione, nonlinearities between time scales not only exist, but can also be productive to musicians:

> "To recognise the reality of [the] mismatches [between the different time levels] does not drive us to paralysis; on the contrary, it gives us the possibility to explore the passages between different dimensions, allowing us to articulate them inside a syntactic network covering the whole spectrum of composable relationships" [Vaggione *in* Budón, 2000: 15].

2.3. Agostino Di Scipio and the question of emergence[36]

In a recent article, Vaggione writes:

> "Ainsi, par exemple, on peut penser que la véritable raison de l'incorporation réussie de l'approche granulaire à la composition musicale pourrait bien se décrire comme étant un transfert catégoriel du niveau du signal vers le niveau symbolique. Car les grains qu'on manipule en composition musicale n'"expliquent" rien, quant à la nature du sonore élémentaire : dans notre cas, ces grains *sont* – déjà – des morphologies musicales, situées au niveau du micro-temps, mais néanmoins composées. L'intérêt de l'approche granulaire, pour la composition musicale, consiste donc *dans le traitement symbolique d'éléments présents à l'échelle du micro-temps*. Les grains, pris dans ce sens, constituent des éléments ductiles avec lesquels on peut travailler des entités morphologiques, en les agglutinant et en les

[35] It would seem that this was not always the case for Vaggione. No doubt, he initially went through a stage where autosimilarity interested him (cf. Vaggione, 1989). "My last works like *Tahil* (1992), *Kitab* (1993) or like S*chall* (1994) and *Rechant* (1995) explore the dynamics of interaction, convolution, aliasing, and movement between laminar and turbulent sonic states, *out of which are born figures which do not function in the same way in different time scales*", he remarks in a revised version of the article from 1989. While reading my article (Solomos, 2005b), Vaggione said to me that he had already been interested in nonlinearities in the mid 1980's, with works like *Thema* (1985), *Ash* (1989-90) or *Till* (1991). We could hypothesise that it was in becoming aware of the non-linear effects of the transposition of timbres that he arrived at this point of view (cf. Vaggione, 2003: 106). From this moment on, nonlinearity, as a generator of singularities, became a central concern.

[36] This chapter is developed in Solomos, 2005c.

> projetant partout dans le composable, à toutes les échelles possibles. En partant d'une approche du sonore marqué par la discontinuité et la fragmentation, nous créons pour ainsi dire directement des objets musicaux, des objets composés" [Vaggione, 2006].

This quotation could be a good introduction (in the form of a critical discussion) to Agostino Di Scipio's granular approach, which focuses on the idea of *emergence* as it is developed in cognitive sciences [cf. Varela, 1996].

Let's start from Di Scipio's articles on Xenakis (cf. *supra*). Analyzing Xenakis' hypothesis of an (auto-)creation of higher order sonorities in *Analogique A et B*, Di Scipio makes a small shift in the conceptual issue: "Today cognitive scientists and epistemologists would probably describe the hypothesis of 2nd-order sonorities as a question of *emergent properties* of sound structure" [Di Scipio, 2001: 72]. The question of emergence can thus be formulated: "In this case [concerning *Analogique B*], the distinction can hardly be made between a model of musical articulation and a model of sound design, insofar as the composer's action is meant to let the musical (macro-level) structure emerge from sound itself and its internal organization (micro-level)" [Di Scipio, 1997: 165]. As regards the "failure" of *Analogique* –which, for Di Scipio, is not the failure of the grain's fusion as it was probably for Xenakis, but the failure of this emergence–, he explains that it due to Xenakis' mathematical tools: "One may ask whether the stochastic does really provide as good a means for higher-order sonorities to emerge from a ground-level pattern of minimal sonic units" [Di Scipio, 2001 : 73/79]. It is why, for his own music, he decided to use complex dynamic systems: "Chaos and the dynamics of complex systems, as accessible with iterated numerical processes, represented for me a way to compose small sonic units such that a higher-level sonority would manifest itself in the process" [Di Scipio *in* Anderson, 2005]. These systems enable him "[to] exploit [… a large] palette of grain arrangements, ranging from random to more patterned textures, across a variety of other behaviors" [Di Scipio, *in* Anderson, 2005]. Thus, Di Scipio, unlike Xenakis or Vaggione, tends to get rid of everything, which would be directly composed as a macroform design. For instance, in his music, there are no dramatic gestures, no dramatic intentions, etc. In one of his first articles [Di Scipio, 1994], he elaborated a "Theory of sonological emergence", where form (macroform) is viewed as "a process of timbre formation" [Di Scipio, 1994: 205].

According to this theory, the emergence is possible thanks to the fact that the composer develops *systems* (in the sense of cybernetics) close to living systems, which are characterized by the capacity of *auto-organization*: "The passage of a system or process from a given structural organization to a new state of order which is recognized as a function of the qualitative properties of the former, is what we call here a phenomenon of emergence […]. Similar phenomena can be described with rules of *morphostasis* (conservation of coherence, identity) and *morphogenesis* (dynamical behavior, change), which together capture the main peculiarity of social and living systems: self-organization" [Di Scipio, 1994: 206]. To make sure that the system is auto-organized, Di Scipio uses a "circular causality" [Di Scipio *in* Anderson, 2005], which extends the idea of feedback. For instance, in *Due di Uno* (2003, for violin, piccolo recorder and adaptive dsp), the instrumental sounds, which are electronically transformed, are also used as input for controlling these transformations [cf. Di Scipio, 2005b].

Thanks to this circular causality, Di Scipio redefines the usual notion, in live electronics, of "interaction" [cf. Di Scipio, 2003b]. In this usual notion, interaction operates as an information flow: a sound source is transformed. So, in reality, the system is not very interactive. For Di Scipio, composition itself could be the action of *composing* interactions. Thus,

> "a principal aim would be to create a *dynamical system* exhibiting an adaptive behavior to the surrounding external conditions, and capable to interfere with the external conditions themselves. […] A kind of *self-organization* is thus achieved […]. Here, 'interaction' is a structural element for something like a 'system' to emerge […]. System interactions, then would be only *indirectly* implemented, the by-products of carefully planned-out interdependencies among system components […]. This is a substantial move from interactive music composing to composing musical interactions, and perhaps more precisely it should be described as *a shift from creating wanted sounds via interactive means, towards creating wanted interactions having audible traces*" [Di Scipio, 2003b: 271].

We could say that, for Di Scipio, the notion of *process* is decisive: the process is more important than the result –and also than the origin.

Another important element in Di Scipio's approach is the idea of "ecosystem": interaction happens also with the acoustic environment. In the set of pieces *Audible Ecosystemics* (2002-2005, live electronics solos), which offers musical achievements of composed interactions (cf. **figure 10**), the ecosystem is a triangular interaction between the musician, the dsp computer and the sonic ambience [cf. Di Scipio, 2003b: 272-275]. This idea leads to an important role played by noise. To simplify, I would say that, in Di Scipio's music, noise is not disturbance (like in traditional music) neither sonic material (like in modern music). It is one of the agents of the interaction, as it is produced by the concrete place where happens the interaction: it is part of the system. In *Audible Ecosystemics*, "the role of *noise* is crucial […]. Noise is the medium itself where a sound-generating system is situated, strictly speaking, its *ambience*. In addition, noise is the energy supply by which a self-organizing system can maintain itself and develop" [Di Scipio, 2003b: 271].

A last important element of Di Scipio's approach is the elaboration of a *sub-symbolic* musical strategy. In the "Theory of sonological emergence", the emergence of a high level should happen through grains, samples, which are not symbols as they are located in a low level [cf. Di Scipio, 1994: 207]. With composed interactions, Di Scipio puts the interaction directly into the signal level: all the information exchanges have a sonic nature [cf. Di Scipio, 2003b: 272]. We can draw a parallel between this strategy and the model of emergence in cognitive sciences. To the question: "What is cognition?", the computationalist model answers : "A data processing: the manipulation of symbols from laws" [Varela, 1996: 42], while the emergence model answers: "The emergence of global states in a network of simple components" [Varela, 1996: 77]. As regards music, what is at stake here is the following idea: if we want that the higher level (the macrofrom) appears as an emergence and not as an independent construction, we have to work only in the lower level, abandoning the intermediate level, which is the level of symbols.

Processes and composed interactions, ecosystems, sub-symbolic strategy: all these elements converge. What is music?, asks Di Scipio. Is it a sonic result? No, as we have to compose the process itself and not the result. Is it a voluntary gesture (from one or more humans, the composer, the performer or the listener)? Not only, as the environment is part of

it. Is it a language (where the mediation of the symbol creates a dichotomy between matter and meaning)? No… For Di Scipio :

> "la musique est quelque chose qui n'a pas d'existence préalable, mais qui finalement se produit, quelque chose qui est toujours à réaliser, à renouveler chaque fois ; elle n'est jamais quelque chose qui est là, déjà existante et délimitée dans une forme idéale ou virtuelle, qui se prête à être re-présentée, ré-incarnée. En bref, je ne compose pas la musique elle-même, mais les conditions favorables qui pourront donner naissance à de la musique (*ma* musique). La responsabilité des actions à commettre (pour composer, pour jouer, pour écouter) a autant d'importance que les objets à faire (à composer, à jouer, à écouter)". [Di Scipio, 2006].

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FIGURES

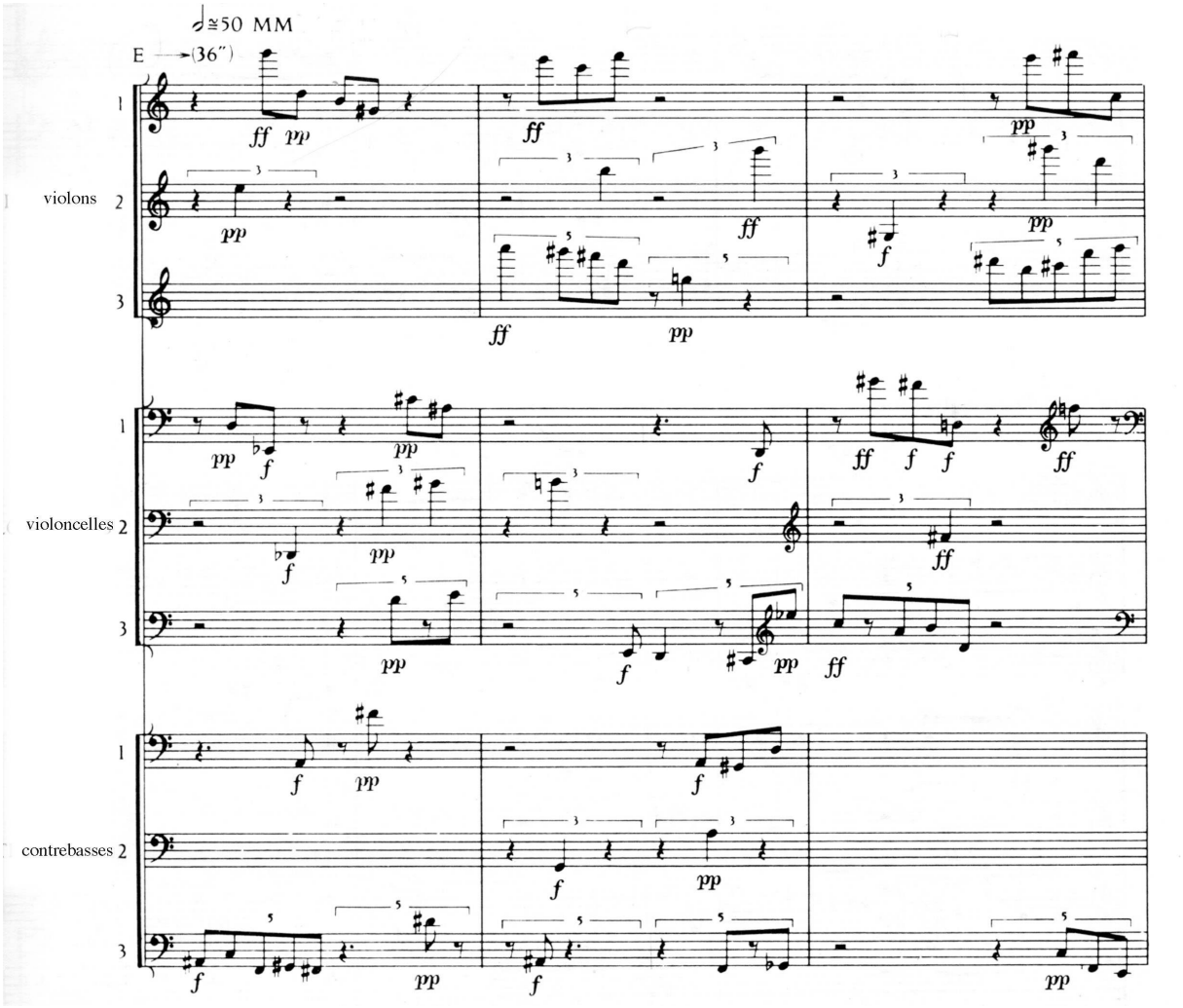


Figure 1. ***Analogique A*** **(1958, 9 strings): bars 0-2. © Éditions Salabert.**

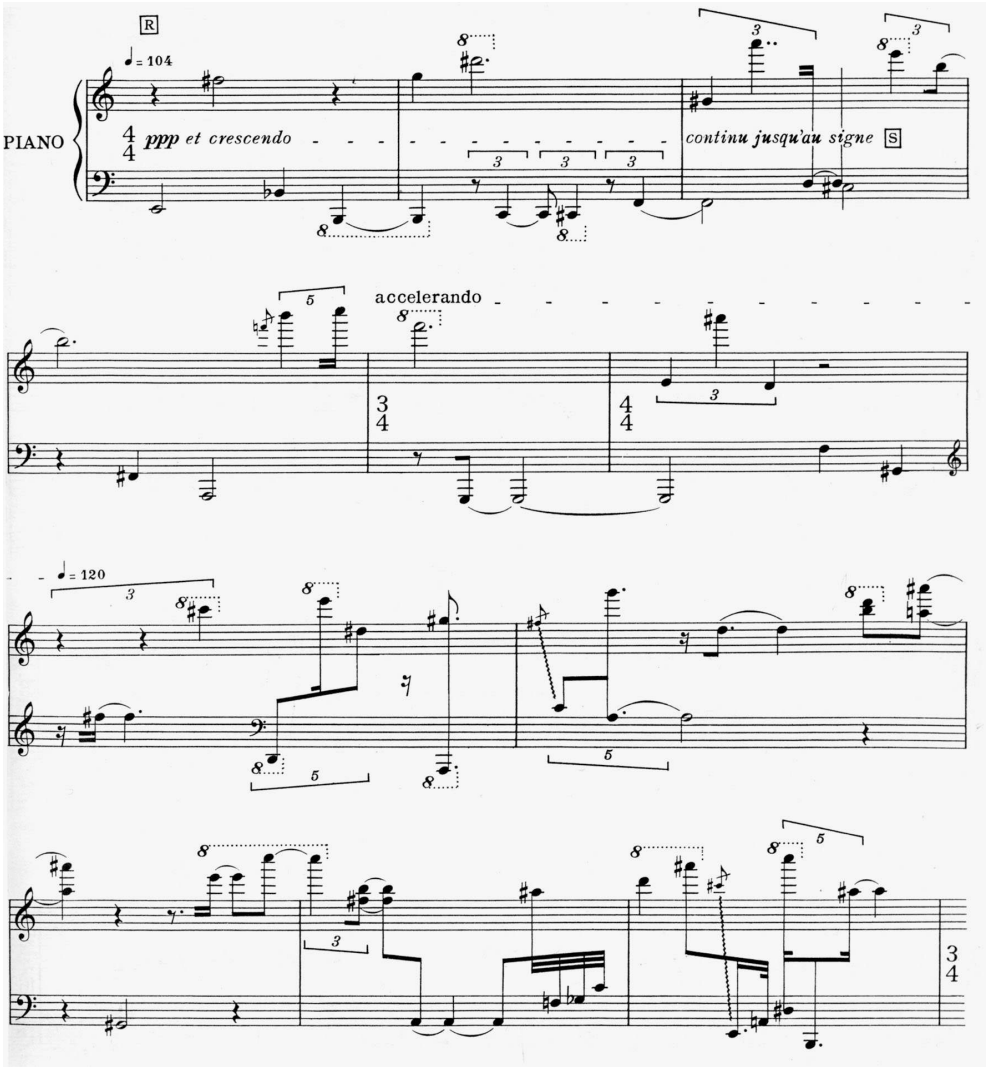


Figure 2. ***Herma*** **(1960-61, piano): page 1. © Boosey and Hawkes.**

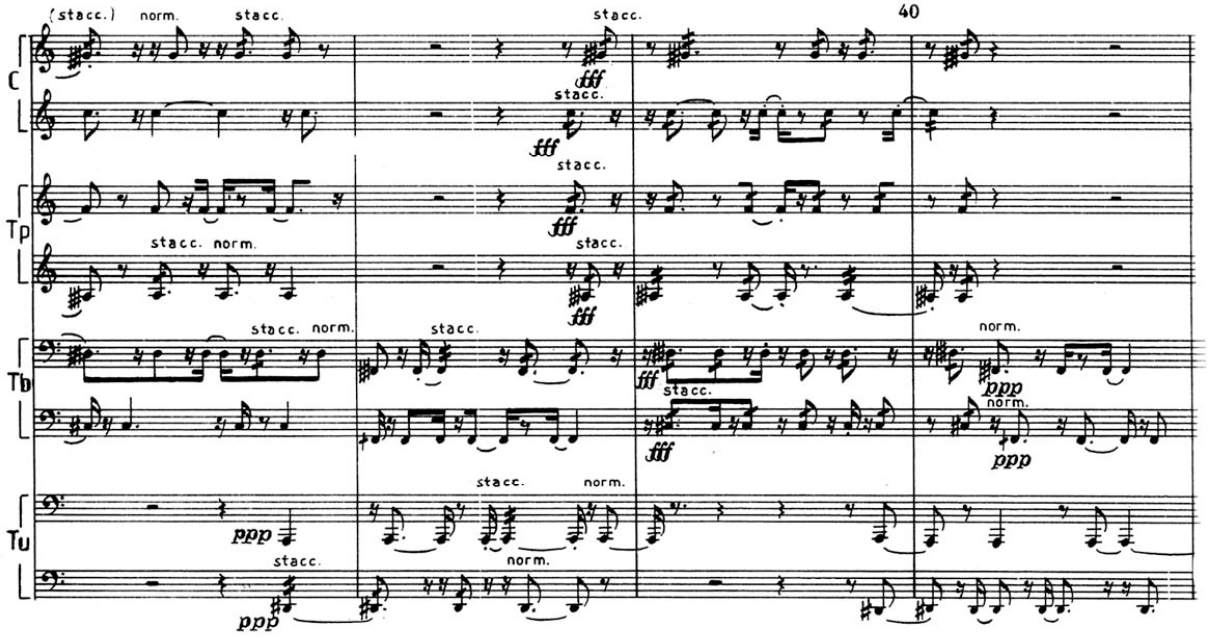


Figure 3. ***Eridanos*** **(1972, orchestra): bars 37-40 (brasses). © Éditions Salabert.**

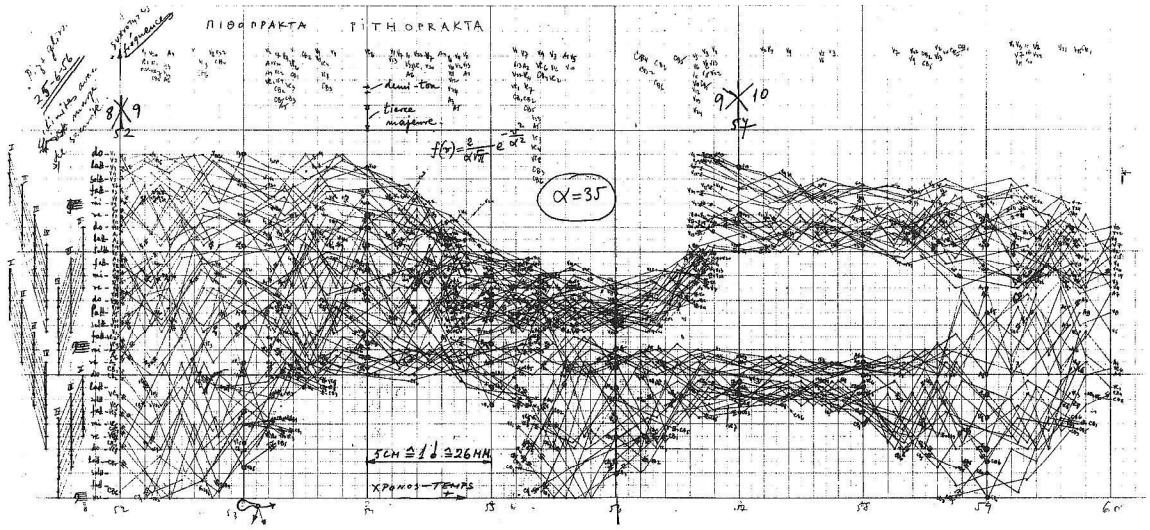


Figure 4. ***Pithoprakta*** **(1955-56, string orchestra, two trombones, percussion): bars 52-59: Xenakis' graph for the distribution in time of the string orchestra's pizzicati-glissandi. Archives Xenakis, Bibliothèque Nationale de France.**

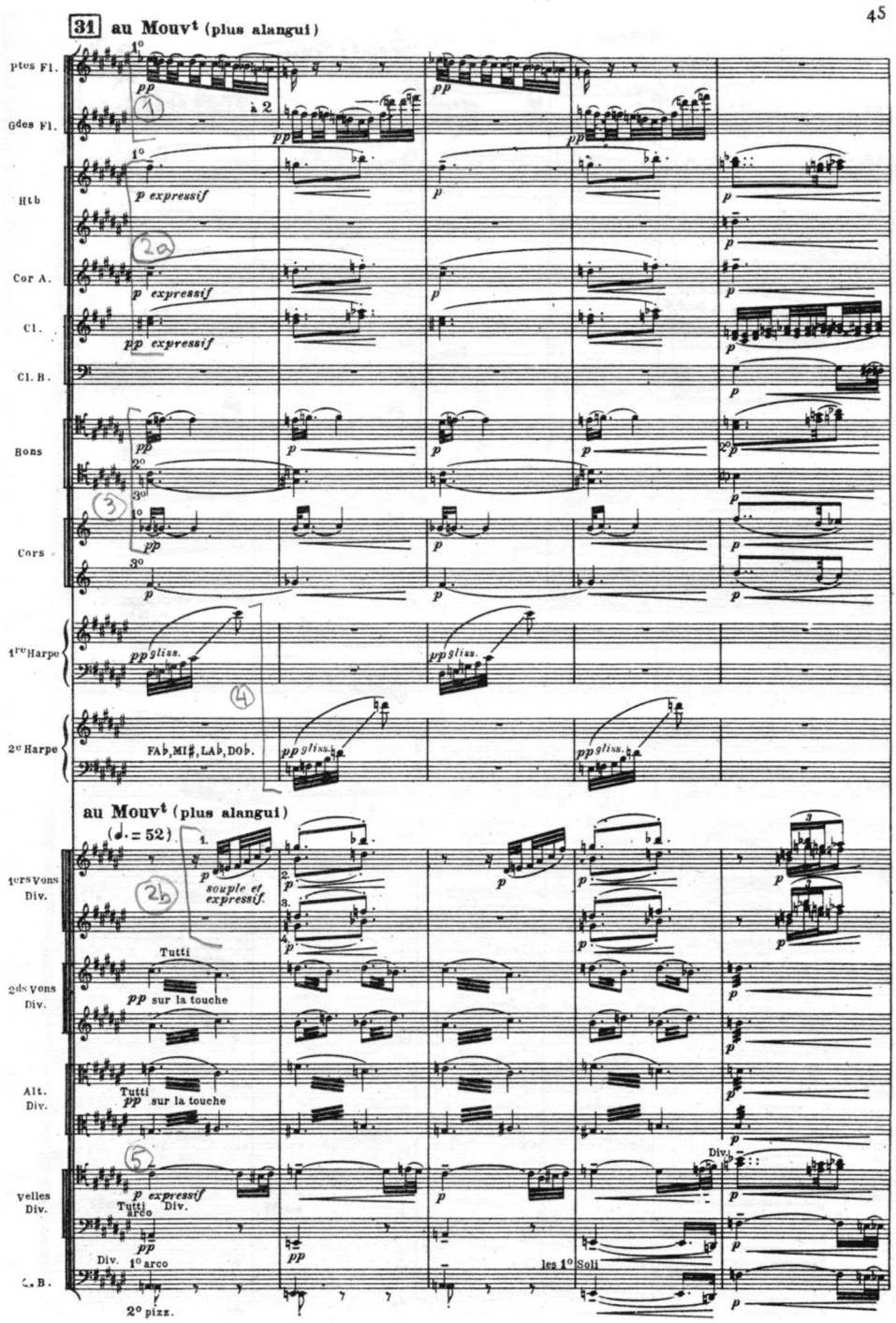


Figure 5. Debussy, *Jeux* (1913, orchestra): beginning of number 31. A smooth surface constructed with 5 small motives. © Éditions Durand.

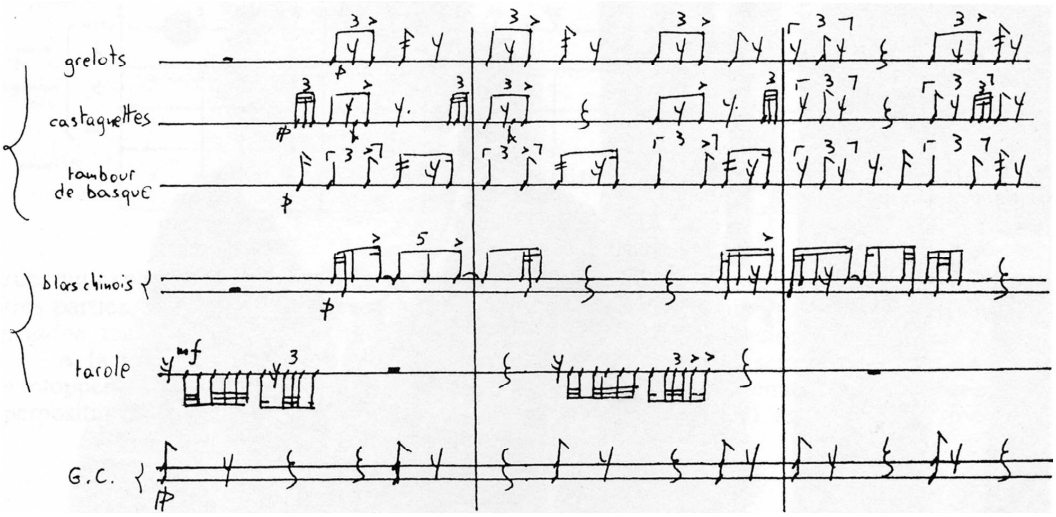


Figure 6. Varèse, *Ionisation* (1929-31, percussions): exposition of the third sonority (bars 18-20). Reduction.

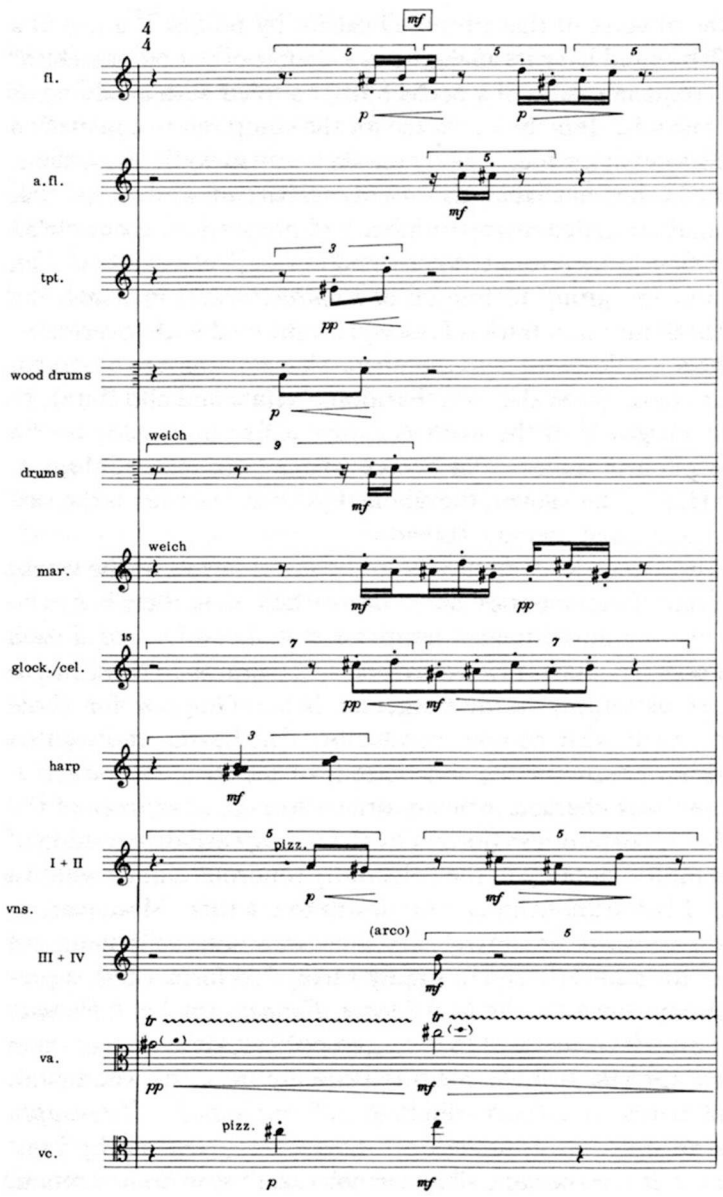


Figure 7. Stockhausen, *Gruppen*: rhythmical "formants": a fundamental (the half note of the violas) and its 9 "harmonics" (quarter note in the cellos, triplet in the harp, etc.). © Universal Edition.

0; 0,111; 0,125; 0,143; 0,167; 0,2; 0,222; 0,25; 0,286; 0,333; 0,375; 0,4; 0,429; 0,444; 0,5; 0,555; 0,571; 0,6; 0,625; 0,667; 0,714; 0,75; 0,778; 0,8; 0,833; 0,857; 0,875; 0,889.

Figure 8. Division of a rhythmical unity by 1, 2, 3 … 9.

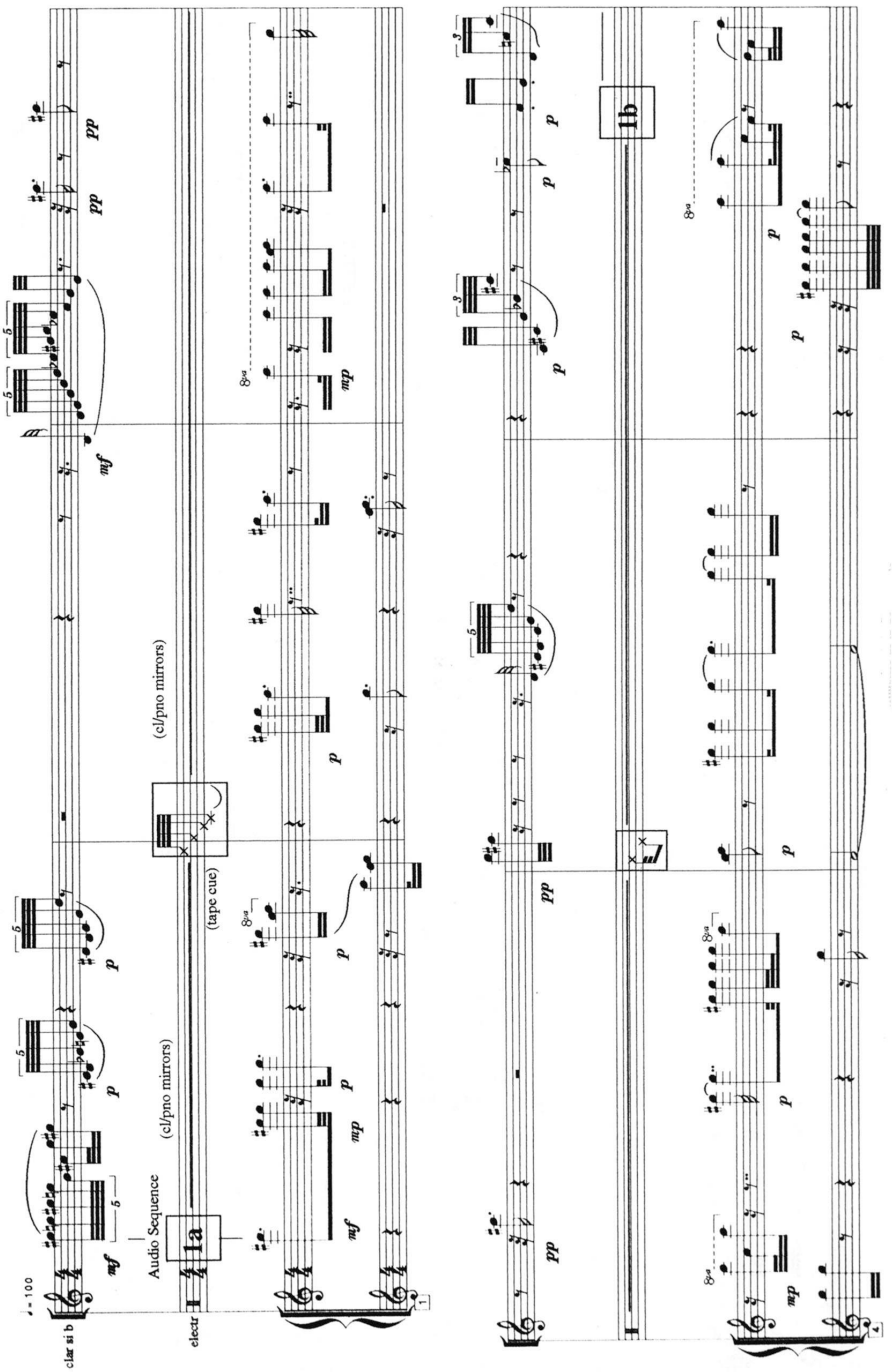
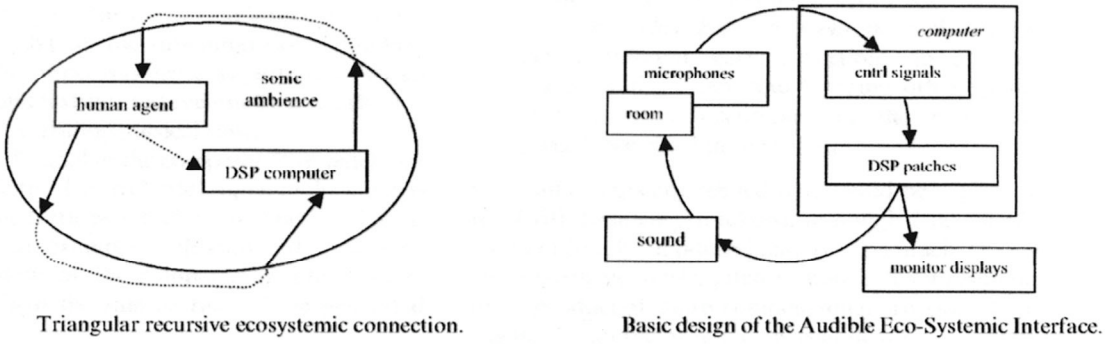


Figure 9. Horacio Vaggione, *Phases* (clarinet, electroacoustics, piano, 2001): p. 1. © H. Vaggione.



Triangular recursive ecosystemic connection.

Basic design of the Audible Eco-Systemic Interface.

Figure 10. Agostino Di Scipio [2003b: 272]: composed interactions for the Audible Eco-Systemic Interface.