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THE GRANULARITY PARADIGM IN THE ELECTROACOUSTIC MUSIC OF IANNIS XENAKIS[1]

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SUMMARY. The cultural legacy left to us by composer Iannis Xenakis (1922–2001) is impressive and undoubtedly had a massive impact on some generations of musicians. His artistic ideal stands as proof. Fueled by science and engineering, his inheritance has been eagerly discussed in numerous books, studies, and doctoral theses. Our study underlines the viability of I. Xenakis's compositional model. Xenakis painstakingly circumscribes scientific theories and laws in his method of composition in the instrumental and electroacoustic genres. We will emphasize the hypothesis that the granularity paradigm traverses his musical works *Concret PH*, *Analogique B*, and *GENDY3*.

Keywords: Granularity paradigm, stochastic synthesis, random walk, architecture, mathematics, music

Introduction

Before evoking the personality of Iannis Xenakis, a few terminological clarifications would bring more clarity. In this study, the terms *granular sound*, *sound granule*, *sound grain*, *sound point*, and *sound particle* refer to an acoustic micro-event with a duration close to the threshold of aural perception.

Table 1

Romanian	French	English
• granularitate • granular, granulos • granulă • granulație	• granularité • granulaire, granuleux • granule • granulation	• granularity • granular, grainy • granule • granulation

The family of words of the granularity paradigm

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Motivated by the same objective, we would say that the family of words *granularity*, *granular*, *grain,* and *granulation*, with their French and Romanian equivalents (Table 1), is supplemented with definitions: granularity denotes a set of characteristics of a sound structure of a granular nature. In other words, granular or grainy indicates the feature of a larger sound structure that has sound granules in its composition. Of course, granule means a particle of sound resulting from the shattering of a complex sound. Last but not least, granulation refers to a compositional process of breaking up a complex sound structure into sound granules and, at the same time, directs to a perceptual property of the granules.

Our study aims to highlight the viability of I. Xenakis's compositional model. This approach meticulously circumscribes scientific theories and laws in his practice of instrumental and electroacoustic composition. We will suggest that the granularity paradigm passes through from *Metastasis* and *Pithoprakta* to works of *musique concrète*, electronic music, and algorithmic music, namely *Concret PH*, *Analogique B*, and *GENDY3*.

Iannis Xenakis

In the year celebrating the centenary of the birth of composer, researcher, architect, and programmer Iannis Xenakis (1922–2001), his inheritance culture is impressive and will remain controversial, we would say. It has had a tremendous impact on some generations of musicians. The proof is his artistic ideal. Propelled by science and engineering, probability theory, in particular, has been eagerly examined in numerous books, studies, and doctoral theses.

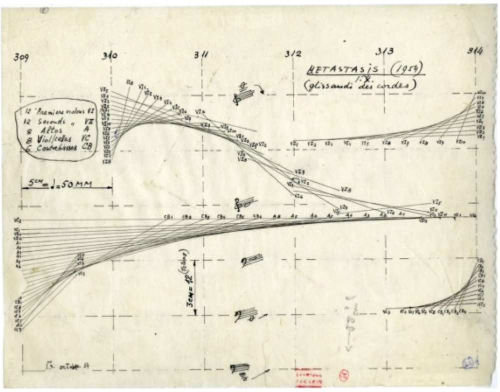
The biography of I. Xenakis is well-known and well-documented. We remind here that he was born on May 29, 1922, in a family of Greek residents in Brăila (Romania). At the age of 10, he was sent to the boarding school of the Anargyrio-Korgialenio School on the island of Spetses (Greece) in the Mediterranean Sea. After graduating from the School at the age of 18, he was going to specialize in architecture and civil engineering at the Technical University (Polytechnic) of Athens. But, soon after, his studies were interrupted by the Italian invasion in 1940. He joined the (unarmed) resistance movement against the German and Italian occupation – the National Liberation Front (Greek E.A.M.), in 1941, during World War II. In 1946 he graduated from the Polytechnic, and in 1947 he left Greece to save his life, as he had been sentenced to death for his past in the E.A.M. He settled the same year in Paris (France) as a political refugee, where he spent the rest of his life until he was almost 78 years old, unfulfilled at the time of his death on February 4, 2001.

Architecture And Music

At the age of 25, I. Xenakis, therefore, decided to dedicate himself to architecture and music. The meeting with the French architect (of Swiss origin) Le Corbusier (1887–1965) allowed him to collaborate on major architectural projects for a decade and more. One of the projects was the Philips Pavilion, designed for the Universal and International Exhibition in Brussels (Belgium) in 1958 (Expo 58, for short). Inspired by experimentation with *glissandi* in his work *Metastasis* composed at the age of 31, I. Xenakis had suggested to Le Corbusier an architectural plan for the Philips Pavilion.

Music and architecture were, in this way, in a close connection. For example, in measures 309–314 of *Metastasis* (Figure 1-a), *glissandi* were drawn as intersecting straight lines to obtain a *sound space* in a continuous evolution [Xenakis 1992, p. 10]. The metaphor sound space used by I. Xenakis refers to a ruled surface generated by moving a line with the sense of geometric transformation. The two-dimensional surface devoid of volume is sonically expressed in a system of two coordinates: time and pitch. The lines are associated one by one with the *divisi* of the string instruments. The conceptual transfer of straight lines into the three-dimensional space of the Pavilion (Figure 1-b) involves the generation of double-ruled surfaces called *hyperbolic paraboloids*. The three-dimensional shape of a hyperbolic paraboloid is concave on one axis and convex on the other axes.

Figure 1a



Iannis Xenakis: *Metastasis*, m. 309–314[3]

Figure 1b

Expo 58: Philips Pavilion[4]

[3] Image source: www.iannis-xenakis.org
[4] Image source: https://commons.wikimedia.org

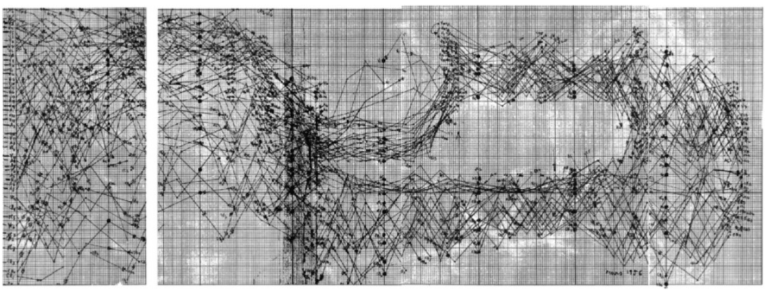
The architectural ensemble of Expo 58 has incorporated, in the walls, a myriad of loudspeakers, which were used to playback the famous *Poème électronique* (1957–1958) by Edgard Varèse (1883–1965). The intention of Le Corbusier and I. Xenakis was to achieve the "spatial sound" of a "technological poem" of lights and image projections. Incidentally, I. Xenakis composed *Concret PH* (1958) to be heard at the entrance to the Pavilion; it was preparing the audience for a unique sensory experience and a linear multimedia presentation – sound, image, and light, as we understand it today.

After the premiere of the revolutionary Metastasis at the Donaueschingen Festival (Germany) in 1955, which was a catalyst in the emergence of Iannis Xenakis as one of the most influential modern composers, the event at Expo 58 convinces us that his creative force, embedded in the soil of architecture and music, has sprouted from Geometry.

Music and Mathematic

The application of Markov chains, binomial (Bernoulli) distribution, Brownian motion, and Gaussian distribution extended the mathematical foundations of his music from compositional strategy to stochastic sound synthesis. His fascination for indeterminism also infuses the orchestral work *Pithoprakta* for two trombones, percussion, and strings (1955–56), which premiered in Munich (Germany) in 1957. The probabilistic logic is embodied in the granular pitch organization. The distribution of the well-known 1148 *pizzicati-glissandi*, drawn on graph paper (Figure 2), is calculated according to Gauss law. I. Xenakis postulates that one can control "continuous transformations of large sets of granular and/or continuous sounds" [Xenakis 1992, p. 16].

Figure 2



Iannis Xenakis: *Pithoprakta*, m. 52–59[5]

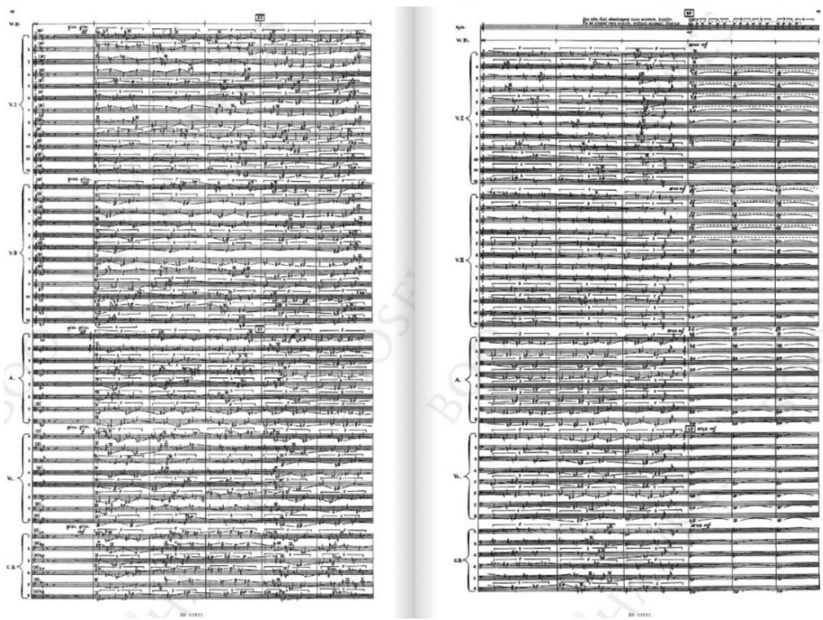
5 Image source: I. Xenakis, *Formalized Music*, 1992 and Rob Wannamaker, *Mathematics and Design*, 2012.

The normal distribution or Gaussian distribution, named after the German mathematician Carl Friedrich Gauss (1777–1855), is a mathematical expression describing the distribution probability of a set of randomly produced values. The distribution of values depends on two mathematical variables, the arithmetic mean and the standard deviation. The graph of a Gaussian distribution is symmetrical about the median value, and its curve resembles a bell shape. The proportion of numbers in the set that falls within certain standard deviations from the median of the bell-shaped curve is expressed as follows:

(1) in the interval $(\mu - \sigma, \mu + \sigma)$ are 68.2% values
(2) in the interval $(\mu - 2\sigma, \mu + 2\sigma)$ are 94.5% values
(3) in the interval $(\mu - 3\sigma, \mu + 3\sigma)$ are 99.7% values

If the random values of the set are granular sounds (i.e. *pizzicati*), if their arithmetic mean, in measures 52–59 of *Pithoprakta*, is 144 *pizzicati* $(1148 \div 8)$ and if the standard deviation is, say, 5 *pizzicati*, there is a probability that 68.2% of the eight-measure will be distributed between 139–149 *pizzicati* (30 ± 5), 94.5% between 134–154 *pizzicati* $(30 \pm 2 \times 5)$ and 99.7% between 129–159 *pizzicati* $(30 \pm 3 \times 5)$.

Figure 3



Iannis Xenakis: *Pithoprakta*, m. 51–62[6]

[6] Image source: ©Boosey & Hawkes, 1956.

It can also be noted effortlessly that “(metric) [musical, a.n.] time is considered a straight line on which are marked the points corresponding to the variations of other components”, such as pitch. I. Xenakis also states that “the [mathematical, a.n.] interval between two points is identical to the [sound, a.n.] duration” [Xenakis 1992, p. 13]. *Pizzicato* – a sound point or a granular sound, is, viewed in this way, the idealization of the extremities of a closed line segment drawn on two Cartesian coordinates. Then, *glissando* signifies the set of granular sounds contained between two *pizzicati* of well-determined pitch, written in the score of *Pithoprakta* (Figure 3) with the direction and inclination of the straight segment. Granular sounds are, in reality, I. Xenakis also tells us, “a particular case of sounds in continuous variation” [Xenakis 1992, p. 13].

The other ingredients of the score are meaningful for the expression *mass of notes* [Xenakis 1992, p. 8] or *sound mass* [Xenakis 1992, p. 255], whose perceptual attribute is the sound surface. Its depth structure contains abstract hierarchical levels. In this regard, the polyrhythmic organization has an arithmetic mean of a 4th note in each of the measures 52–59 of the *Pithoprakta* score. Throughout them, the delta time interval and note duration are constant at each *divisi*; the relative dynamics between *mf*–*fff* do not evolve, and the *pizzicato-glissando* remains unchanged for each instrument. Thus, the homogeneity of the eight-measure fragment is ensured.

We conclude with a first generalization: one of the facets of the compositional model of I. Xenakis (which can be revealed from the short fragments extracted from *Metastasis* and *Pithoprakta*) is to incorporate the geometric transformations and statistical calculations in pitch structures. Geometry and Statistics become vehicles through which *glissandi* and *pizzicati-glissandi* are probabilistically distributed and plotted on the geometric pitch-time plane. A granular sound is not a mere figure of speech but reflects fundamental notions – the point, the line, and the two-dimensional plane of Euclidean Geometry.

Electroacoustic Music and Granulation

Our discussion was focused up to this point on concepts highlighted in instrumental music. In the Salabert catalog of I. Xenakis’s opus, we have found over 150 compositions; only 15 of them are electroacoustic. Until the end of the `50s, I. Xenakis composed electroacoustic music in a favorable ratio to the instrumental genre. Four versus seven works: *Metastasis* (1953–54), *Pithoprakta* (1955–56), *Achorripsis* (1956–57), *ST/4* (1956–62), *Diamorphoses* (1957–58), *Concret PH* (1958), *Analogique A* (1958), *Analogique B* (1959), *Syrmos* (1959), *Duel* (1959), and *Orient-Occident* (1960).

Is his electroacoustic music detached from the stochastic processes experienced in the instrumental genre?

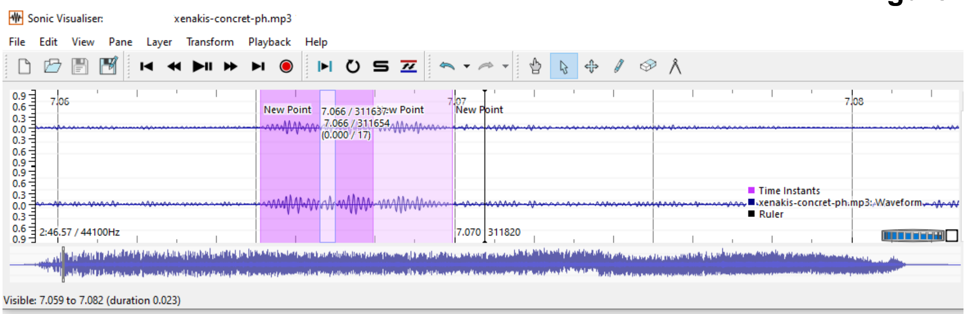
The answer to this question is detailed in *Formalized Music: Thought and Mathematics in Composition* (a treatise where scientific construction meets artistic creation). We learn about the close connection between Geometry and *Metastasis* and between Statistics and *Pithoprakta* in Chapter I, entitled *Free Stochastic Music*. As we can see, ample pages in Chapter III of *Formalized Music* are devoted to the diptych *Analogique A* for 9 string instruments and *Analogique B* for magnetic tape. It can be stated that the stochastic science was applied even earlier by *Analogique A et B*. We are pointing to his first composition of electroacoustic music, named *Diamorphoses*, to *Concret PH* which we have referred to contextually, then to *Orient-Occident* (the music for the film of the same name, directed by Enrico Fulchignoni) [Xenakis 1992, p. 43].

On the other hand, is his electroacoustic creation disconnected from the paradigm of granularity?

We will say that granular sound, in its primary characteristics, transits some works of concrete music, electronic music, and algorithmic music.

I. Xenakis's ability to see in granulation a creative spring led him to *Concret PH*. The 2:45 work incorporates magnetic tape manipulation techniques specific to concrete music. As a compositional process, breaking into sound granules is intrinsically linked to the sounds produced naturally, the crumbly burning coals. I. Xenakis did not have sophisticated technology at hand. The first step of the process was to tape the sounds of burning fuel. Then countless fragments of tape, several tens and hundreds of milliseconds long, were cut and glued, processed, and merged to assemble them into an evolving sound texture [Di Scipio 1998, p. 204].

Figure 4



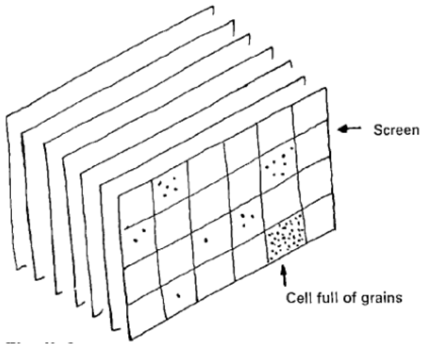
Iannis Xenakis: *Concret PH*, segment of 0.023 seconds

With the current computational technology of digital signal visualization, we aim to raise from the shadow the structure of a 0.023-second audio material (Figure 4). Plotted on amplitude and time coordinates, the material exhibits sound grains of about 1–2 milliseconds, namely 1.49 μsec, 0.38 μsec, 0.95 μsec, and 1.99 μsec. Expressed in samples, they have 66 (Cycling74 Max: 71.52), 17 (18.24), 42 (45.6), and 88 (95.52) values. Although the digital signal of 230 milliseconds was arbitrarily selected from the first ten seconds of *Concret PH*, the sounds convincingly mark their presence in tiny time intervals. One can observe that, in this sense, the envelope of a granule surprises with its curved outline. The granule also reflects the energy of a single crackle of charcoal, which burns in flames, more or less noisily. If we isolate one μsec of the original material, the grain partially loses its spectral identity since its duration is below the threshold of auditory perception. To firmly perceive a sense of spectral identity, the human hearing mechanism needs a processing time of at least 200 milliseconds [Roads 2001, p. 22].

All these observations try to favor the idea that the compositional process called granulation, that is, of breaking up or cutting the pre-recorded material into sound granules, might also be described as a perceptual property in electroacoustic composition.

Let us turn our attention to a different work of electronic music signed by I. Xenakis. In *Analogique B* the approach was systematic. The analog signal, with a sinusoidal waveform, was recorded on magnetic tape and later cut into short fragments arranged temporally on *screens* [Xenakis 1992, p. 54]. Theoretically, a screen represents a collection of granular sounds with frequency and amplitude values but with a constant duration of 0.04 seconds (Figure 5). The values are arranged in a *grid* whose *cells* contain homogeneously distributed sounds or are even empty [Xenakis 1992, p. 51]. The simultaneity of sounds is only allowed when the density is high enough. The sequence of screens, called a *book* by I. Xenakis, suggests the inner life of a complex sound [Xenakis 1992, p. 57]. In other words, *a cloud of evolving points* [Roads 2001, p. 66]. The practical solution for connecting the screens in a book is to glue and overlap portions of magnetic tape with each other, depending on the number of channels of the tape recorder. Of course, I. Xenakis offers a set of transformations applicable to screens, such as intersection, union, and difference, with the aim of the micro-structural organization of sound. He also invites interchangeable use of the words screen and cloud, with the same connotative meaning [Xenakis 1992, p 58].

Figure 5



Iannis Xenakis: a book made of screens[7]

The second generalization: granulation was the analog prototype, in the early `60s, of what would become a spectral model of digital synthesis towards the end of the `70s: the granular (digital) synthesis.

We stress the idea the complex sound is made up of analog sound granules in *Analogique B*; these are defined by frequency and amplitude and occupy a small time interval. The statement serves I. Xenakis as a lemma in developing the hypothesis regarding the nature of sound. We quote a fragment: “any sound is an integration of granules, elementary sound particles, sonic quanta. Each of these elementary grains has a threefold nature: duration, frequency, and intensity. Any sound, even any continuous sound variation, is conceived [respectively conceived, a.n] as an assembly of a large number of elementary granules suitably arranged in time. So every sound complex can be analyzed as a series of pure sinusoidal sounds, even if the variations of these sinusoidal sounds are infinitely close, short, and complex” [Xenakis 1992, p. 43].

Sonic Quanta

The origin of I. Xenakis’s lemma regarding the nature of sound would seem controversial. In the preface to the 2nd edition of *Formalized Music* book, its author credits Albert Einstein as having originated the lemma. He also confesses that it was mistakenly attributed to Dennis Gabor [Xenakis 1992, p. xiii]. However, we emphasize that I. Xenakis used the expression *grain of sound* in the article *Elements of stochastic music* from 1960. Indeed, he was the first musician to develop a theoretical and compositional model around granular sound [Roads 2001, p. 65].

[7] Image source: I. Xenakis, *Formalized Music*, 1992.

Figure 6-a

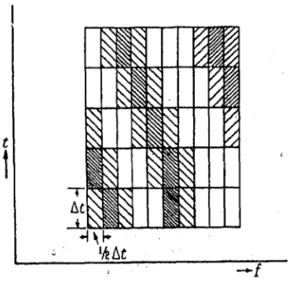
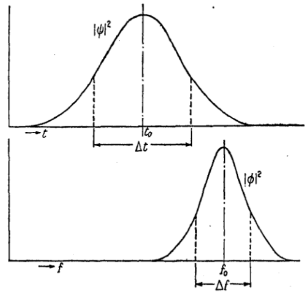


Figure 6-b



Dennis Gabor: *Logons* and elementary signal[8]

Returning to the British physicist and electrical engineer of Hungarian origin (Gábor Dénes, 1900–1979), Dennis Gabor is particularly famous for the invention of the holographic technique, for which he received the Nobel Prize in Physics in 1971. His published article under the name *Theory of Communication* in 1946 is of historical importance. D. Gabor suggests that the signal "is the product of the modulation of an harmonic oscillation of any frequency, with an impulse in the form of a probability function." The signal is decomposed into elementary signals, and each represents a quantum of information called *logon* (Figure 6-a) [Gabor 1946, p. 435].

In other words, "any sound can be decomposed into an appropriate combination of thousands of elementary granules" [Roads 2001, p. 57]. The amplitude envelope of a grain and the envelope of its frequency spectrum are modeled by the Gaussian curve (Figure 6-b).

Granular Synthesis and Stochastic Synthesis

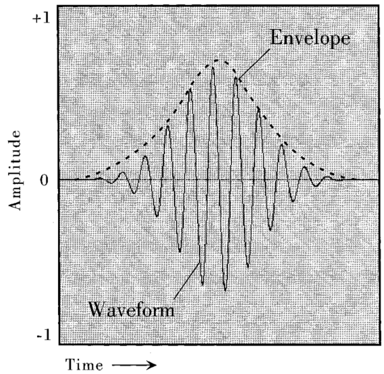
The anatomy of sound, in the light of the theory of D. Gabor and I. Xenakis made us glimpse the dawn of granular digital synthesis. This synthesis technique has been used by Curtis Roads in *Prototype* (1975), *nscor* (1980), and *Field* (1981), for example. Then by Horacio Vaggione in *La Maquina de Cantar* (1978), *Tar* (1987), *Schall* (1995), by Jean-Claude Risset in *Sud* (1984), *Elementa* (1998), by Barry Truax in *Riverrun* (1986), *Wings of Nike* (1987), *Tongues of Angels* (1988), by Agostino Di Scipio in "Punti di tempo" (1988), "Texture-Multiple" (2000), by Stéphane Roy in *Mimetismo* (1992), by Gérard Pape in *Makbénach* (1997), etc. [Roads 2001, p. 303–324].

[8] Image source: D. Gabor, *Theory of communication*, 1946.

What exactly is granular sound in granular synthesis?

Curtis Roads defines it in his book *Microsound* as follows: “a sound grain is a short micro-acoustic event with a duration close to the threshold of human auditory perception, usually between a thousandth of a second and a tenth of a second (from 1 to 100 μsec). Each grain contains a waveform shaped by an amplitude envelope” [Roads 2001, p. 86].

Figure 7



Waveform modeled by an amplitude envelope[9]

Granular synthesis has at its epicenter a network of overlays and juxtapositions of hundreds and thousands of similar granules designed to generate complex evolving sounds. Despite a surface ambiguity, the term granular sound retains an apt description, compositionally, because it captures two perceptual aspects. We refer to sound information in the temporal domain and spectral domain: the shape of the envelope that shapes the amplitude and the frequency spectrum, respectively. The granular sound, with a duration between 1–100 milliseconds, is the metaphoric expression of a waveform with a Gaussian amplitude envelope (Figure 7), according to the model of D. Gabor.

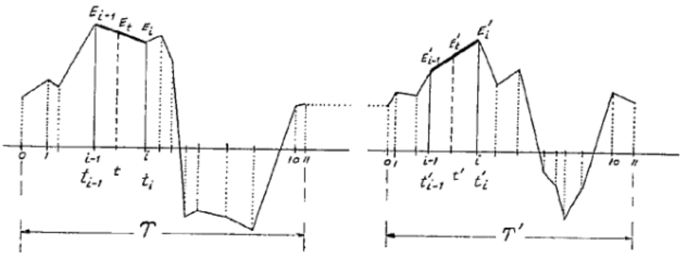
I. Xenakis followed a different path. His model operated only in the temporal domain without resorting to spectral decomposition and reconstruction [Serra 1993, p. 239]. In 1991, 32 years after experimenting with granulation in *Analogique B*, I. Xenakis was expanding his research in sound synthesis in the context of algorithmic music. He developed GENDYN, a computer program that implemented an algorithm he called *dynamic stochastic synthesis* in the BASIC language for the Windows operating system. [Serra 1993, p. 236]. On the other hand, the PARAG

[9] Image source: C. Roads, *Microsound*, 2001.

program could control the structure of the musical work through several synthesis parameters. Hypothetically, the potential of GENDYN was to generate, with judicious resources, all the waveforms that represented changes in acoustic pressure [Xenakis 1992, p. 289].

Dynamic stochastic synthesis assumes that a complex sound is produced by distorting a waveform [Serra 1993, p. 241]. The algorithm computes each new waveform by applying stochastic transformations to the previous one. The mathematical model of the transformation process is called *Random Walk* [Xenakis 1992, p. 289]. An example, in this sense, is Brownian motion, which describes the random fluctuations of the position of particles suspended in gas or liquid. In GENDYN, random variations applied to both time and amplitude coordinates mean the alteration of the fundamental frequency and the spectrum [Di Scipio 1998, p. 228].

Figure 8



Iannis Xenakis: GENDYN, waveform[10]

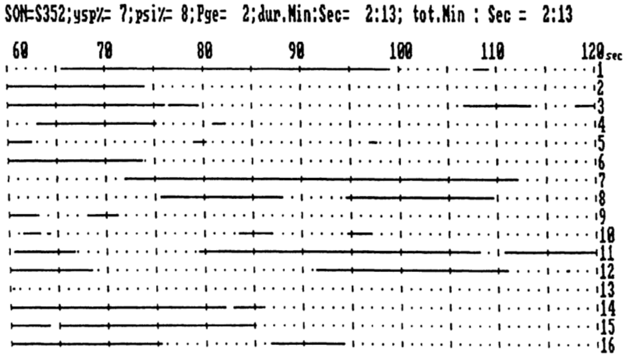
The waveform is represented by a polygon (Figure 8). Each line segment of the polygon is determined by two points, which are located on the abscissa (time) and ordinate (amplitude). Only these explicit points are subject to stochastic transformations. The intermediate points of the line are computed as linear interpolation for reasons of computational efficiency [Serra 1993, p. 241]. So those two points of the segment are interconnected sample by sample. The waveform is, we emphasize, the result of interpolating values between two random numbers. They are expressed in the range 0–44100, and the amplitude accepts variables between −32767 and +32767 [Di Scipio 1998, p. 227]. To avoid saturation, the amplitude is limited in the given interval by a control process named *elastic barrier* [Xenakis 1992, p. 291].

The length of a polygon segment is directly proportional to its number of samples. If the sampling rate is 44100 samples per second, then the *sonic quantum* descriptor is the digital sample himself: 0.022675 μsec.

[10] Image source: I. Xenakis, *Formalized Music*, 1992.

Samples are discrete numbers representing the information about the amplitude that a signal reaches a certain point at an accurate moment in time [Farnell 2010, p. 121].

Figure 9



Iannis Xenakis: PARAG, distribution of time segments[11]

Made at the Center for Mathematical and Automatic Musical Studies (fr. CEMAMu), *GENDY3* (1991) is an algorithmic composition produced entirely with GENDYN, whose duration is 18:54. The premiere took place at the International Computer Music Conference (ICMC), in Montreal (Canada), in the same year. The 11 architectural sections of the *GENDY3* composition were rigorously designed in the context of adjustments of control parameters and synthesis datasets. The algorithmic link between the micro-universe of the synthesis and the formal macro-universe was made in the program. More precisely, with the help of the GENDYN-PARAG program package. The internal structure of the sections resulted from the distribution of time segments (Figure 9), in which 16 synthesis processes from GENDYN ran under the control of the auxiliary program PARAG. One of its tasks was to activate and deactivate those 16 processes asynchronously. The duration of active segments was calculated with the exponential law.

We list other programmable parameters in PARAG, namely the number of waveform segments, the type of stochastic functions for transforming the new waveform, and last but not least, the elastic barrier arguments [Di Scipio 1998, p. 230]. If control parameters were reserved for the PARAG program, the samples were calculated in the GENDYN program. It archives them into a mono audio file, ready for playback. Since stochastic synthesis did not operate in real-time, the production of the *GENDY3* work also included file mixing.

[11] Image source: I. Xenakis, *Formalized Music*, 1992.

The sections of *GENDY3* could be described as polyphonic fabrics of more crystalline sounds and others as compact sound textures of noisy sounds. With whatever touch, fine or abrasive, this description might be made, it will remain undeniable that the synthesis with GENDYN was flexible, and the sounds were very different in *GENDY3*. The flexibility was captured in words by I. Xenakis, as follows: “the more numerous and complex (rich) the symmetries and periodicities [of the probabilistic waveform, a.n.], the more the musical result will resemble a held note” [Xenakis 1992, p. 289]. A whole arsenal of ever-evolving sounds has been created this way.

We have reached the third generalization. The originality of the music of Iannis Xenakis culminated in *GENDY3*. The GENDYN program computes sonic quanta – a metaphor for the digital audio signal. Moreover, Xenakis’s radical approach to producing sounds opened the challenging territory of dynamic stochastic synthesis. It aims to generate all waveforms that represent changes in sound pressure.

The Granularity Paradigm

At this point of the discussion, we are trying to conclude with the ideas expressed earlier, and we will discuss the granularity paradigm. The transversal thought, which became crystal clear when we were polishing the title of this study, was that we were taking the paradigm as a criterion for choosing the topic. We were engrossed in it while documenting the investigation around granularity by one of the central concepts of I. Xenakis’s compositional model: the paradigm of granularity—a set of accepted terms, formulas, theories, proofs, and solutions—that borrowed the meaning of paradigm from the philosophy of science.

Scientific paradigms have the meaning that Thomas Kuhn (1922–1996) offered in *The Structure of Scientific Revolutions* in 1962. In the preface of his book, the American philosopher tells us that the paradigms “are universally recognized scientific achievements which for a time provide model problems and solutions of a community of practitioners” [Kuhn 1970, p. viii, Preface].

In our opinion,

1. The paradigm of granularity in Iannis Xenakis was asserted, first in music written in the instrumental genre, then in the electroacoustic genre.

In *Pithoprakta* the probabilistic logic is embodied in the organization of the sound pitch. The work incorporates statistical data into musical structures, which I. Xenakis calls *sound points* or *granular sounds*.

2. The paradigm offered the solution for the granular sound in his electroacoustic music recorded on tape, despite a differentiation of the sound source.

Granulation is a compositional process of fragmentation of the pre-recorded material into sound particles, and it means a perceptual property of the granules. In *Concret PH* the process was intrinsically linked to the naturally produced sounds.

3. The potential of his compositional model to have been developed by different composers was self-evident. Accepted by electroacoustic practitioners, the *granularity paradigm* has been a guide and motivation throughout.

For example, the composer and programmer Curtis Roads showed an interest in granular synthesis in 1972 when he participated in a workshop where I. Xenakis presented his experiments in stochastic synthesis at Indiana University (in Bloomington, Monroe region, United States of America) [Roads 2001, pp. 108–109].

The granular synthesis was developed in the late `90s by Curtis Roads, Horacio Vaggione, Jean-Claude Risset, Barry Truax, Agostino Di Scipio, Stéphane Roy, Gérard Pape, and others [Roads 2001, pp. 303–324].

4. The *granularity paradigm* mirrored, in programming, his algorithm designed for a non-standard, non-real-time type of computer sound generation called *dynamic stochastic synthesis*.

The hypothesis was that complex sound is produced by distorting the waveform and thus can theoretically be generated all the waveforms representing changes in sound pressure. The granularity lies in that the waveforms are calculated sample by sample, in his GENDYN program, by values interpolated between two random numbers. Then the sonic quantum is the digital sample itself, with a duration of ten thousand times less than the human auditory threshold value (if the sampling rate is 44.1 kHz).

Tribute to Xenakis: Random Walk

Random Walk is the mathematical model of waveform transformations in GENDYN, as we said. It is a fundamental topic in probability theory, and it is defined as the stochastic process formed by the successive summation of identically distributed independent random variables, according to Gregory Lawler in his book *Random Walk: A Modern Introduction* published by Cambridge University Press, 2010 [Lawler 2010, p. 6].

Consider a walk in one dimension. There are two possible directions from the walk starting point: forward or backward. A random choice in the direction can be accomplished by flipping a coin. The head represents walking in the forward direction, and the toss means walking backward. After each toss of the coin, one step of the walk is chosen in one or the opposite direction. The resulting step is always added to the current walk position. Therefore, the ongoing walk position is modified by the previous step.

In the jargon of mathematicians it is said that *steps* X_1, X_2 ... X_n are independent random variables, while the *positions* S_0, S_1 ... S_n of the sequence are not. Variable S_n marks the position of the *random walk* at a given time n. The random walk starts with the variable z, according to the formula shown below:

$$S_n = z + X_1 + \cdots + X_n$$

for $n \geq 1$.

Our intention was not to rebuild the GENDYN program but to capitalize on the mathematical model used by I. Xenakis in sound synthesis. In the author's program, *Real Time Waveshaping Synthesis* (Figure 10), the waveform of the complex sound is a product of the distortion computed in real-time according to the Random Walk iteration.

Figure 10

Adrian Borza: The Real Time Waveshaping Synthesis Software

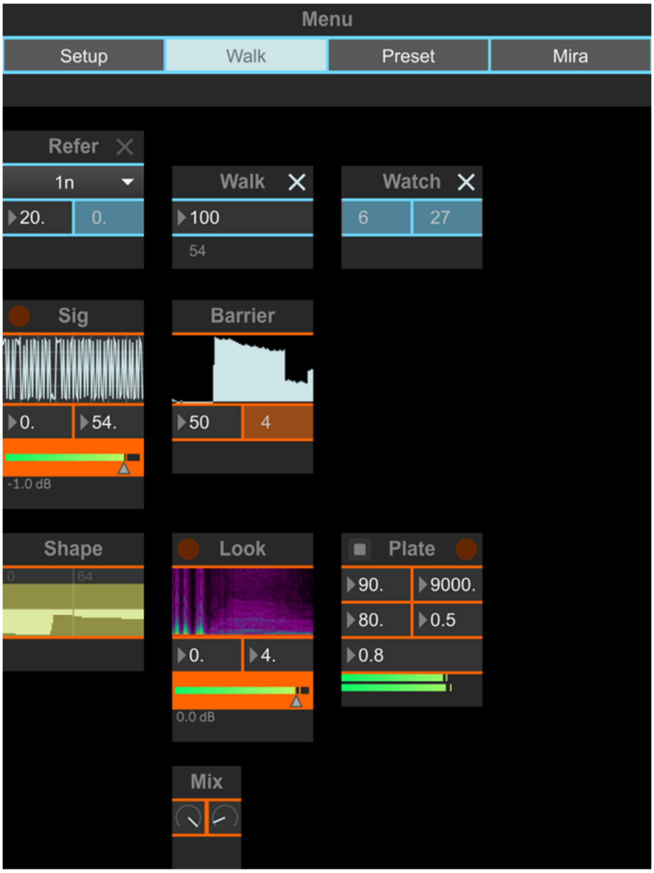
The audiovisual recording of the author's composition *Tribute to Xenakis:: Random Walk* can be found on YouTube:
https://www.youtube.com/user/HeySmorfe

Steps | Steps to Unknown

On the other hand, the author's composition *Steps to Unknown* or *Steps* for short, concludes a group of works elaborated in 2022 on the occasion of the Xenakis Centenary.

Naturally, *Steps to Unknown* explores the relatively familiar territory of non-standard stochastic synthesis and exploits the mathematical model Random Walk in unique directions, as far as we are concerned. Under an almost identical name, *Randomwalk* (Figure 11) is a type of generative music software.

Figure 11



Adrian Borza: Randomwalk Software, Walk GUI

One of the abstractions of the *Randomwalk* program has the task of implementing this model using a minimal package of computing objects of the MAX programming environment:

$$decide$$
$$if\ \$i1 == 0\ then\ -1\ else\ 1$$
$$expr\ \$i1\ +\ \$i2$$

and $number$ injected in $expr$.

From Sound Synthesis to Musical Structure

Random numerical variations, applied to the time and amplitude coordinates, mean spectrum alteration. The phenomenon is perceived as a sound with a constantly evolving timbre.

The iteration also changes the fundamental frequency concerning a variable unit of time called a *step* which is in turn altered by the random variations. The phenomenon is comparable to a *glissando* and in some rare cases to *portamento*.

The complex sound, resulting from the distortion of the waveform and the constant change of the fundamental frequency, is multiplied by a different frequency, practically emanating from the iterative calculus. The operation produces vital amplitude modulation known as *ring modulation*.

Another ingredient to enhance the intimate life of the sound is its position in the stereophonic image. Indeed, the parameter is under the control of the Random Walk iteration.

The random variation is fractured by an *elastic barrier* – the *modulo* operation in MAX language to find the remainder of the division. Elastic barrier imposes unpredictable changes in the timbral evolution of the complex sound. This robust tool constitutes a rudiment of organization in the micro-structural surface of the composition *Steps to Unknown*.

Another pack of abstractions rounds out the composition process with abrasive yet energetic sounds. These abstractions are remarkable tools that rigorously articulate musical sections every minute based on a meticulous selection of control data sets associated with a musical form. The data sets alongside abstractions are the outcome of the author's effort. The transition from one set to another is executed automatically in the software by interpolation.

Seemingly autonomous, the *Randomwalk* software is no more than an algorithmic, formalized expression of the author's compositional process from the morphological to the syntactical aspect of the musical language.

The absolute first public audition and onstage real-time composition of *Steps to Unknown* took place during the 2022 edition of the International Conference of Contemporary Music in Brașov (Romania).

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