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► To cite this version:

Guillaume Rochais. Randomness, Rule, Program: How the issues of generative art take shape in prealgorithmic music. 27th Generative Art Conference, Celestino Soddu and Enrica Colabella, Dec 2024, Venice, Italy. pp.212-228. <hal-04878025>

HAL Id: hal-04878025

<https://hal.science/hal-04878025v1>

Submitted on 9 Jan 2025

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Randomness, Rule, Program: How the issues of generative art take shape in pre- algorithmic music

ABSTRACT

Although the 1960s marked the birth of computer art¹, numerous examples in art history outline issues that still inform the practice and theory of generative art today. This is particularly true in the field of music, the first art form to fully embrace the computer.

Algorithmic music, which emerged in the 1950s, is part of a path that stretches from Greek antiquity to integral serialism, a path in which the intertwining of music and mathematics, which has been the object of many different approaches, recurs as a leitmotif.

Other themes of particular interest to generative art also punctuate this path: the programmatic nature of the score, the recurrence of combinatorics, the generative dimension of the isorhythmic process or of Steve Reich's phasing, the different views of randomness, from the *Musikalische Würfelspiele* to John Cage or Iannis Xenakis, the formal and systematic components of serial music, the computational and algorithmic ones of set theory, the relationship between *micro* and *macro*, element and structure, or the opposition between inspired genius and objective aesthetics that runs through 20th century art.

On the one hand, the prodromal precedents of algorithmic music shed relevant light on the entire field of generative art. On the other hand, by placing generative art in a historical perspective, they contribute to the recognition of its full belonging to the artistic field.

INTRODUCTION

As early as the 1950s, music was the first artistic discipline to embrace the computer, and more specifically programming, to produce artworks. This precocity can be explained by two main factors.

First, the close relationship between music and mathematics, which has been amply demonstrated throughout history, from the first observations

¹ In this paper, the label "computer art" refers less to an art form that uses computers than to the decade in which this usage emerged: from the few years preceding the historic 1965 exhibitions by Georg Nees - *Computergrafik* in Stuttgart — and A. Michael Noll and Bela Julesz - *Computer-Generated Pictures* in New York — to the early 1970s.

of Pythagoras² to electronic music, through medieval harmonies, the contrapuntal complexity of Johann Sebastian Bach's compositions, serialism, or again Olivier Messiaen's modal research.

Second, the two-stage separation of the creative process in music—composition/performance—presents a striking similarity with the times of writing and then performing the program. The score is in fact nothing more than a set of symbols that encode a series of predefined instructions, the execution of which produces the musical work, with the nuance, of course, that the sensitivity of the instrumentalist or conductor brings a subjectivity to the final rendering that the computer is incapable of.

1.1 EARLY ALGORITHMIC MUSIC

The 1950s saw the appearance of the first algorithmic compositions created on a computer, the most famous of which is undoubtedly the *Illiatic Suite* by Lejaren Hiller and Leonard M. Isaacson (1957³). Originally titled *String Quartet No. 4*, the piece consists of four experiments with various musical and mathematical concepts—rhythm, pitch, dynamics, but also stochastic processes with the use of Markov chains⁴.

Composed entirely on the University of Illinois's computer—Illinois Automatic Computer, abbreviated to Illiac—the *Illiatic Suite* was intended to be performed by traditional instrumentalists, in this case, a string quartet. In fact, this was the case for most algorithmic compositions of the time, as the capabilities of computers at the time did not allow for the automated production of sounds of sufficient quality.

Research into algorithmic sound synthesis did exist, most notably at Bell Laboratories, initiated by Max Vernon Mathews—the “Max” of Max/MSP

² Although the liberal arts were not formalized until the 3rd century, the ancient Greeks, and later the Romans, already considered music to be an indispensable part of human education, on a par with arithmetic and rhetoric. Around 270 AD, Porphyry classified the seven liberal arts into two categories. The trivium covers the arts related to language - grammar, rhetoric and dialectics - while the quadrivium covers those related to mathematics: arithmetic, geometry, astronomy and music.

³ There are precedents, such as Martin Klein and Douglas Bolitho's short *Push Button Bertha* in 1956, but these have remained little or undocumented. On this subject, see Moreno Andreatta's article:

ANDREATTA, Moreno, 2013. Musique algorithmique. In: DONIN, Nicolas and FENEYROU, Laurent (eds.), *Théories de la composition musicale au XXe siècle*. Lyon : Symétrie. pp. 1239-1268. Symétrie recherche, 21.

⁴ Theorized at the beginning of the 20th century by Andrei Markov, these chains are sequences of numbers in which the value at time $t+1$ is determined by the value at time t according to the probabilities - fixed in advance in a transition matrix - of the different possibilities. The chain is said to be of order one when only the previous state is used to determine the next state. If both previous states are taken into account, the chain is of order two, and so on.

The advantage of these chains is that they can be used to set possibilities, as well as obligations and prohibitions. For example, taking the three notes C E G, the transition matrix can impose that a C will be followed 75% by an E and 25% by a G - so never by a C -, that an E will always be followed by a G, and that a G will be followed 50% by another G, 25% by a C and 25% by an E.

software—but it was still in its infancy. In 1957, the American engineer wrote his first sound-generating program, *Music I*, running on an IBM 704⁵. The program was used to produce what would go down in history as the first computer-generated piece of music, a minimalist seventeen-seconds sound sequence composed by Newman Guttman: *In the Silver Scale*⁶. Max Mathews and Newman Guttman produced a more accomplished piece the same year with *Pitch Variations*⁷, a one-minute piece published by Bell Laboratories in 1962 in the anthology *Music From Mathematics*⁸.

Max Mathews improved his program significantly over the next few years with several versions, but the insufficient sound quality on the one hand and the impossibility of generating music in real time on the other hand largely limited its use outside the field of experimental research⁹. Real-time algorithmic music production did not appear until the mid-1970s, thanks in particular to John Chowning's invention of FM synthesis in 1973, and mainly in the 1980s, with the advent of the MIDI standard in 1983, followed by the first Atari ST in 1985.

The term “algorithmic music”, used to describe these new forms of creation that emerged in the late 1950s, refers strictly to music composed following a series of pre-established instructions:

“[...] algorithmic composition is the art of creating music using a set of pre-determined rules. It can be called meta-composition, since the composer produces a system, a set of rules that in part produce the music for him. While randomness is very often part of the process, it is not always indispensable¹⁰.”

As Christophe Robert points out, algorithmic music often makes use of randomness, but does not require it. Here, we need to distinguish between three notions whose frequent intermingling is a source of confusion: the

⁵ MANNING, Peter, 1985. *Electronic and computer music*. [1987]. Oxford: Clarendon Press. p. 217 ff.

⁶ GUTTMAN, Newman, 1957. *The Silver Scale* [online]. New York : Bell Labs, 1957. [Accessed September 19, 2024]. Available at: <https://www.youtube.com/watch?v=PM64-lqYyZ8>

⁷ GUTTMAN, Newman, 1957. *Pitch Variations* [online]. New York : Bell Labs, 1957. [Accessed September 19, 2024]. Available at: <https://www.youtube.com/watch?v=TExxv1-j42Y>

⁸ VARIOUS ARTSISTS, 1962. *Music From Mathematics* [online]. [12" vinyl]. Decca / Bell Labs, 1962. [Accessed September 19, 2024]. Available at: <https://www.youtube.com/watch?v=pusmHRTbXQ>

This is a second edition; the first is poorly documented, dating from 1960 or 1961 according to sources.

⁹ We do not include here hybrid systems such as GROOVE - also developed in 1969 by Max Mathews for Bell Labs - in which the computer controls analog synthesizers. Although these systems operate in real time, they are not algorithmic synthesis.

¹⁰ ROBERT, Christophe, [no date]. Qu'est-ce que la musique algorithmique ?. *MusicAlgo* [online]. [Accessed April 19, 2023]. Available at: <http://musiquealgorithmique.fr/quest-ce-que-la-musique-algorithmique/>

Christophe Robert is a doctoral student at the Université Côte d'Azur. His research, entitled *Esthétique générative et musique acousmatique : une relation en question* focuses in particular on algorithmic music. See : <https://theses.fr/s318612>

term algorithmic music is not synonymous with either aleatoric or generative music, although a musical creation may well fall within these three fields.

If the composition of the *Illiad Suite* is based on randomness, it is perfectly possible to imagine a program that does not use any random functions at all; the music produced in this way will correspond in every detail to the composer's prescriptions. In this case, the computer is used only for its computational capabilities, to automate a series of calculations that would be too tedious to perform by hand.

Moreover, the fact that the score of the *Illiad Suite*, like that of other algorithmic works of the same period, is fixed once and for all, also excludes it from the field of generative music: apart from the variations in execution—which are found in all written music—the piece is identical for each performance. To approach a generative dimension, it would have been necessary, for instance, to run the program before each concert, in order to redraw all the random parameters and thus generate a new score, different from the previous ones.

1.2 ISORHYTHM

As in the visual arts, the use of algorithms in music long predates the advent of the computer. An early trace of this can be seen in the isorhythmic process used in the late Middle Ages, in which a rhythmic motif—*talea*—and a melodic motif—*color*—begin together and repeat until they end together¹¹. If the *talea* has five durations and the *color* has six notes, then the *talea* must be repeated six times and the *color* five times, a sequence of thirty notes/durations, to reach the initial configuration.

The process is not without similarities to the phasing Steve Reich used as early as 1965 for *It's Gonna Rain*, a piece for two tape recorders playing the same sound loop at slightly different speeds. The two tapes start in unison, then gradually slip out of step until they return to unison, and so on. The composer frequently reused this technique, most notably in 1967 for *Piano Phase*, in which he had his score performed by two pianists shifting their playing before reuniting¹².

¹¹ COPE, David, 2000. *The Algorithmic Composer* [online]. Madison, Wisconsin : A-R Editions. [Accessed July 4, 2024]. Available at: <http://archive.org/details/DavidCopeTheAlgorithmicComposer> pp. 3-4

¹² For more details on these two pieces, see Steve Reich's *Notes on Compositions 1965-1973* (pp.49-53) in : REICH, Steve, 1974. *Writings about music* [online]. Halifax : Press of Nova Scotia College of Art and Design. [Accessed July 3, 2024]. Available at: <http://archive.org/details/writingsaboutmus0000reic>

Whether we're talking about isorhythm or phasing, we can hardly speak of algorithms, but rather of devices. In these two examples, however, the premises of the generative approach emerge: from the interaction of two fundamental elements—*talea* and *color*, sound loops, melodic motifs—a larger form is born that exposes a whole series of different configurations.

1.3 MUSIKALISCHE WÜRFELSPIELE

The use of randomness in musical creation aroused great enthusiasm in Europe in the second half of the 18th century, through a collection of composition games intended for a musically ignorant audience.

One of the most famous, published by Johann Julius Hummel in 1793 and Nikolaus Simrock in 1796¹³, is a system of instructions for composing waltzes which both publishers attribute to Wolfgang Amadeus Mozart, although this authorship is not clearly established¹⁴. This variant is commonly referred to as *Musikalisches Würfelspiel*—Musical Dice Game—a name that has been extended to the whole family of random musical games of the 18th century.

These games proved very popular in the salons of the time, and there were numerous versions: some twenty are listed, some of which gave rise to multiple editions in different languages¹⁵. Despite their differences, these *Musikalische Würfelspiele* are based on more or less the same principles: from a predetermined set of musical motifs, the players roll the dice in succession to create an original piece.

The version attributed to Wolfgang Amadeus Mozart is based on 176 one-bar motifs. The composition is divided into two parts of eight bars each. For each bar, eleven motifs can be selected corresponding to the eleven possible outcomes of a throw of two dice¹⁶. Such a system generates 11¹⁶ possible combinations, i.e. about 46 million billion.

¹³ MOZART, Wolfgang Amadeus [attributed to], 1796. *Instruction pour composer autant de Walzer ou Schleifer que l'on veut, par le moyen de 2 dés sans savoir la musique ou la composition* [online]. Bonn: Nikolaus Simrock. Available at: <https://gallica.bnf.fr/ark:/12148/bpt6k316645m/f1.item>

¹⁴ HEDGES, Stephen A., 1978. Dice Music in the Eighteenth Century. *Music & Letters*. 1978. Vol. 59, no. 2, pp. 180-187. DOI 10.1093/ml/59.2.180. p. 183

¹⁵ TROCHE, Sarah, 2015. *Le hasard comme méthode: figures de l'aléa dans l'art du XXe siècle*. Rennes : Presses Univ. de Rennes. Aesthetica. p. 194

¹⁶ 2 parts x 8 mesures x 11 variations = 176 motifs

Note by the way that the 11 possible motifs for each measure are not equiprobable: 1/36 for motif 2 versus 1/6 for motif 7.

Numerous websites now offer implementations of these games, enabling the score to be generated in a fraction of a second, and even played. See for instance: <https://dice.humdrum.org/> [Accessed July 5, 2024]

ZAHLENTAFEL.
TABLE de CHIFFRES.

	A	B	C	D	E	F	G	H
Erster Theil.								
Premiere Partie.								
2	96	22	141	41	105	122	11	30
3	32	6	128	63	146	46	134	81
4	69	95	158	13	153	55	110	24
5	40	17	113	85	161	2	159	100
6	148	74	163	45	80	97	36	107
7	104	157	27	167	154	68	118	91
8	152	60	171	53	99	133	21	127
9	119	84	114	50	140	86	169	94
10	98	142	42	156	75	129	62	123
11	3	87	165	61	135	47	147	33
12	54	130	10	103	28	37	106	5
Zweiter Theil.								
Seconde Partie.								
2	70	121	26	9	112	49	109	14
3	117	39	126	56	174	18	115	83
4	66	139	15	132	73	58	145	79
5	90	176	7	34	67	160	52	170
6	25	143	64	125	76	136	1	93
7	138	71	150	29	101	162	23	151
8	16	155	57	175	43	168	89	172
9	120	88	48	166	51	115	72	111
10	65	77	19	82	137	38	149	8
11	102	4	31	164	144	59	173	78
12	35	20	105	92	12	124	44	131

Figure 1: Table for determining *Musikalisches Würfelspiel* motifs.

Columns correspond to bars, rows to dice outcomes.

Illustration from Nikolaus Simrock's 1796 edition, p. 2.

Available at: <https://gallica.bnf.fr/ark:/12148/bpt6k316645m/f2.item>

These systems can be assimilated to algorithms: a set of well-defined rules is applied step by step, ultimately producing a musical sequence. Moreover, the use of randomness brings them into the generative realm, as each game session generate as many original compositions. Indeed, due to the combinatorial explosion resulting from successive throws of the dice, the probability of the same sequence being repeated is so low as to be considered zero.

Combinatorics, which according to Pierre Barbaud characterizes the algorithmic¹⁷ approach, was already at the heart of these salon games. At the time, this interest echoed the research of Gottfried Wilhelm Leibniz¹⁸, who defined combinatorics as that part of mathematics that aims to study and formalize relationships between objects. The German mathematician identified this “combinatorial art” with the art of invention, which in his view consisted in creating original arrangements of already known elements in order to discover new truths¹⁹. A vision that still resonates two centuries later in the permutational art developed by Abraham Moles in 1971²⁰, a theory which asserts, among other things, the playful aspect of art.

Beyond their interest as precursors of generative music, two aspects of the *Musikalische Würfelspiele* deserve a closer look: their primarily playful dimension, and the nuance they introduce into the notion of randomness, between aleatory and luck.

The relationship between art and play would merit an in-depth study beyond the scope of this paper, but it’s worth noting that *Musikalische Würfelspiele* are foremost board games. While they do indeed produce musical pieces, they are not designed as methods of composition or learning, but as entertaining activities whose goal is simply to give players pleasure. It’s a very special kind of game, one that completely dispenses with the idea of competition—there can be no winners or losers—and focuses on the wonder that arises when a series of throws of the dice produces a seductive piece of music. It is this playful pleasure that leads Sarah Troche to distinguish two modalities of randomness in *Musikalische Würfelspiele*:

“The millions of minuets are equal before the dice, but unequal before the quality of the sound results: they are *more or less beautiful*, even if they are all *equally correct*. In other words, ludic pleasure is based on the conjunction of two types of randomness: ‘the aleatory’, which makes all possibilities equal, and ‘luck’, which will bring out a successful piece. The aleatory is the structural condition for the emergence of luck, the levelling of data from which the inequality of the fortuitous arises. These musical dice games offer a singular opportunity to consider the relationship between randomness and invention:

¹⁷ BARBAUD, Pierre, 1960. Musique algorithmique. *Esprit* [online]. 1960. N° 280, pp. 92-97. [Accessed July 5, 2024]. Available at : <https://www.jstor.org/scd-rproxy.u-strasbg.fr/stable/24255071> p. 92

¹⁸ LEIBNIZ, Gottfried Wilhelm, 1666. *Dissertatio de arte combinatoria*. Lipsiae : J. S. Fikium et J. P. Seaboldum.

¹⁹ COUTURAT, Louis, 1901. *La logique de Leibniz : d'après des documents inédits*. [online]. Paris : Félix Alcan. [Accessed July 5, 2024]. Available at : <https://gallica.bnf.fr/ark:/12148/bpt6k110843d> p. 279

²⁰ MOLES, Abraham A., 1971. *Art et ordinateur*. [New revised and expanded edition 1990]. Paris : Blusson.

how does randomness, as an aleatory variable in a self-contained process, contribute to a systematization of invention closely linked to the problem of genius²¹?”

This crucial issue runs through all generative art. For if the multiple actualizations of a generative process, although all conforming to the initial prescriptions, are not equal from an aesthetic point of view, when it comes to extracting one or more singular configurations from the multitude, it is ultimately up to the artist to decide, often on the basis of subjective criteria, judgments of the value of a particular iteration which, at the end of an automated process, give the hand back to the creator.

A problematic attitude for many generative artists, who consider that any subjective choice made after the program has been executed contradicts the very concept of programmed art. As we shall see, this was the subject of a profound disagreement between Pierre Barbaud and Iannis Xenakis in the early 1960s.

1.4 TWELVE-TONE MUSIC AND SERIALISM

If the music of the 20th century, in the wake of Claude Debussy, is characterized by the overcoming of Romanticism, it is more singularly disrupted in its writing by the principle of atonality, of which Josef Matthias Hauer and Arnold Schönberg are the main architects. Since the 1910s, Josef Matthias Hauer had been developing this new approach, which he detailed in *Vom Wesen des Musikalischen*—the essence of musical fact—published in 1920²².

Fundamentally, the idea was to free oneself from the notion of tonality by composing from the twelve semitones of the chromatic scale in such a way that a note could only reappear once the other eleven had been used, a principle that forged the name dodecaphony. For Pierre Barbaud, Josef Matthias Hauer’s systemic and combinatorial approach makes him a forerunner of algorithmic music, despite his late recognition:

“Josef Matthias Hauer’s dodecaphonic system aroused little curiosity at the time it was conceived, and the life of its inventor was always marked by great material distress. However, through the rigor of his thinking, and the

²¹ TROCHE, Sarah, 2015. *Le hasard comme méthode: figures de l'aléa dans l'art du XXe siècle*. Rennes : Presses Univ. de Rennes. Aesthetica. p.196

²² HAUER, Josef Matthias, 1920. *Vom Wesen des musikalischen, ein Lehrbuch des atonalen Musik* [online]. Leipzig : Waldheim-Eberle. [Accessed July 14, 2024]. Available at: <http://archive.org/details/vomwesendesmusi00hauegoog>

possibilities opened up by his writing system for the mechanization of musical composition, it heralds the most recent research²³.”

An authorship that Moreno Andreatta also affirms, while specifying:

“The systematic work on hexachord structures, whose exhaustive enumeration [Josef Matthias Hauer] completed in the early 1920s, contributed to the establishment of a truly algorithmic approach to composition, the result of which would be a series of ‘dodecaphonic games’ or Zwölftonspiele²⁴.”

In the 1920s, another composer took an interest in twelve-tone music: Arnold Schönberg, who composed the five pieces of his *Piano Suite* between 1921 and 1923. Here, he took up the principle of series—a particular sequence of twelve sounds—introduced by Josef Matthias Hauer, and placed it at the center of his approach.

Although both composers practice twelve-tone music, their perspectives diverge sharply. While Josef Matthias Hauer strives for a form of abstract music, stripped of expressivity and emotion, behind which the artist disappears, Arnold Schönberg seeks above all to free himself from the dictates of tonality, while remaining strongly influenced by the notion of Romantic genius.

It was Arnold Schönberg who set the standard, and it was under his guidance—as well as that of Alban Berg and Anton Webern, who were his students—that twelve-tone music evolved into serialism: the series at the origin of the work goes beyond chromaticism, structures itself into subgroups, explores symmetry or the play of intervals... The series constituted can be used in its original form, but also in reverse order—retrograde series—, in inversion—the notes, represented by numbers from 1 to 12, are replaced by their opposites modulo 12—or in recurrence of inversion²⁵. The rules of classical tonal harmony are thus replaced by a whole formal system that draws much of its inspiration from mathematics.

Whether one prefers the approach of Arnold Schönberg or that of Josef Matthias Hauer, it has to be said that their music, despite its undeniable

²³ BARBAUD, Pierre and LENGAGNE, Rémi, 1999. Musique contemporaine - La musique sérielle et le dodécaphonisme. *Encyclopædia Universalis* [online]. [Accessed July 8, 2024]. Available at: <https://www.universalis.fr/encyclopedie/musique-contemporaine-la-musique-serielle-et-le-dodecaphonisme/>

²⁴ ANDREATTA, Moreno, 2013. Musique Algorithmique. In: DONIN, Nicolas and FENEYROU, Laurent (eds.), *Théories de la composition musicale au XXe siècle*. Lyon : Symétrie. pp. 1239-1268. *Symétrie recherche*, 21. p. 1242
Note Josef Matthias Hauer's invocation of the notion of play.

²⁵ AGON, Carlos and ANDREATTA, Moreno, 2008. La musique mise en algèbre. *Pourlascience* [online]. November 2008. [Accessed July 9, 2024]. Available at: <https://www.pourlascience.fr/sd/mathematiques/https://www.pourlascience.fr/sd/mathematiques/la-musique-mise-en-algebre-1879.php>

numerical and systematic components, is neither truly computational nor algorithmic..

1.5 JOHN CAGE AND RANDOMNESS

Algorithmic music was born at the end of a decade that saw the almost simultaneous emergence of three musical approaches that can be linked to the generative one: the aleatory experiments of John Cage, the open works of the neo-serialists, and the stochastic music of Iannis Xenakis. Although, at first glance, these practices may be united by their search for the unexpected, their methods and intentions are distinct, and there are many polemics between the proponents of one or the other.

With *Music of Changes*, in 1951, John Cage—who had been a student of Arnold Schönberg—inaugurated a practice that was to become his hallmark: the introduction of randomness at the heart of the compositional process. For while his earlier pieces, notably the *Sonatas and Interludes* for prepared piano (1948), may present accidental variations in performance, they remain marginal and insignificant:

“[...] the objects between the strings of the prepared piano are not arranged ‘at random’, but precisely disposed between certain strings indicated by the score: the aim is to make the piano more percussive, to modify the timbre by integrating more complex sounds, and not to introduce unintentional noises. The very relative element of the unforeseen does not act on the overall structure of the music, which is always composed, but locally in the complexity of the sonorities obtained²⁶.”

The intention behind *Music of Changes*, a four-part piece for solo piano, is quite different, as demonstrated by the method used. All of the compositional decisions, from the *macro* to the *micro*—the structure of the piece, the method of sequencing the notes, the parameters of the sonic material²⁷—are the result of randomly drawn hexagrams from the *Yi Jing*—or *I Ching*—a Chinese divinatory book dating from the Zhou period (circa 1045–256 B.C.), known in English as the *Book of Changes*, which gives John Cage’s work its title.

For the American composer is deeply imbued with Eastern influences—Indian music, Hindu spirituality, Zen Buddhism, etc.—and we can see the organization of the work into four parts—“books” in John Cage’s

²⁶ TROCHE, Sarah, 2015. *Le hasard comme méthode: figures de l'aléa dans l'art du XXe siècle*. Rennes : Presses Univ. de Rennes. Aesthetica. p. 378

²⁷ CAGE, John, 1961. *Silence: lectures and writings* [online]. Middletown, Connecticut. Wesleyan University Press. [Accessed July 10, 2024]. Available at : <http://archive.org/details/silencelecturesw1961cage> p. 18

terminology—as a reference to the *Four Books* which were, in the 13th century, the final addition to the thirteen classics—*Jing* in Chinese—whose study was compulsory in China until the early 20th century.

The *Yi Jing* is based on the fundamental figure of the trigram, composed of three continuous lines—*yin*—or discontinuous lines—*yang*—arranged one above the other. There are thus eight possible trigrams, and their paired combinations make up the 64 hexagrams of *Book of Changes*.

U+4DC0	U+4DC1	U+4DC2	U+4DC3	U+4DC4	U+4DC5	U+4DC6	U+4DC7	U+4DC8	U+4DC9	U+4DCA	U+4DCB	U+4DCC	U+4DCD	U+4DCE	U+4DCF
☰	☱	☲	☳	☴	☵	☶	☷	☰	☱	☲	☳	☴	☵	☶	☷
U+4DD0	U+4DD1	U+4DD2	U+4DD3	U+4DD4	U+4DD5	U+4DD6	U+4DD7	U+4DD8	U+4DD9	U+4DDA	U+4ddb	U+4DDC	U+4DDD	U+4DDE	U+4DDF
☰	☱	☲	☳	☴	☵	☶	☷	☰	☱	☲	☳	☴	☵	☶	☷
U+4DE0	U+4DE1	U+4DE2	U+4DE3	U+4DE4	U+4DE5	U+4DE6	U+4DE7	U+4DE8	U+4DE9	U+4DEA	U+4DEB	U+4DEC	U+4DED	U+4DEE	U+4DEF
☰	☱	☲	☳	☴	☵	☶	☷	☰	☱	☲	☳	☴	☵	☶	☷
U+4DF0	U+4DF1	U+4DF2	U+4DF3	U+4DF4	U+4DF5	U+4DF6	U+4DF7	U+4DF8	U+4DF9	U+4DFA	U+4DFB	U+4DFC	U+4DFD	U+4DFE	U+4DFE
☰	☱	☲	☳	☴	☵	☶	☷	☰	☱	☲	☳	☴	☵	☶	☷

Figure 2: The 64 hexagrams of the *Yi Jing*, and their corresponding Unicode codes.
(Source: Wikimedia Commons)

The determination of a particular hexagram is the result of six successive random draws that determine whether each line is *yin* or *yang*. It should also be noted that each line can be “stable” or “mutable”, and that this will influence the interpretation of the oracle, as mutable lines refer to secondary hexagrams²⁸. This is why three coins are commonly used to determine each line as follows:

- three heads: old *yin*, or mutable *yin* (probability 1/8)
- two heads, one tail: stable *yin* (probability 3/8)
- two tails, one head: stable *yang* (probability 3/8)
- three tails: old *yang*, or mutable *yang* (probability 1/8)

The *Yi Jing* thus comprises 64 hexagrams, each of which refers to a specific “judgment”, sibylline sentences supposed to shed light on the situation about which the oracle is being consulted. The judgment is completed according to the distribution of the mutable lines. Finally, the mutable lines are transformed into their opposites, generating a new hexagram whose judgment is said to predict the evolution of the situation.

²⁸ WILHELM, Richard, 1968. *Yi king, le livre des transformations - Livre I*. [new revised and updated edition 1973]. Paris: Librairie de Médicis. p. 12.

It's worth noting here that John Cage understood that the *Yi Jing*, although too often reduced to its divinatory aspects, is above all the vehicle for a philosophy of acceptance of change, a recognition of the intrinsically fluctuating nature of the universe, of the vanity of the desire for stability and of the impossibility of achieving a situation of mastery.

John Cage's use of the *Yi Jing* thus expresses his adherence to Zen principles. But it also reflects his desire to impose severe constraints on himself, to neutralize his subjectivity as a composer in order to achieve his goal of an impersonal work:

"If Cage maintains recourse to the *Yi Jing* when he has much faster methods at his disposal for more indeterminate results, it is perhaps precisely because this method demands time, patience and self-sacrifice in the precise, slow accomplishment of a repetitive task. For the slowness, repetitiveness and monotony of the gesture have an effect on those who agree to submit to it²⁹."

As Sarah Troche also points out, whereas the *Musikalische Würfelspiele* are limited to a combinatorial play of pre-written elements in which the composer's touch can be found, the randomness that John Cage introduces at the heart of the creative process produces a music freed from ego, and thus contradicts the idea of inspired genius:

"In one case, randomness produces a composition from pre-composed elements, the general idea of the work comes first and determines the possibilities; in the other, we are in an experimental process that cancels any intentional relationship between cause and effect and produces a globally unpredictable result (we compose and then we hear, these two moments being separate from each other³⁰)."

1.6 INTEGRAL SERIALISM AND SET THEORY

While John Cage introduced chaos at the heart of musical creation, other composers turned to an eminently mathematical formalization of music, pushing serial technique to its paroxysm with integral serialism. In the United States, it was Milton Babbitt who embodied this approach, while in Europe it was Pierre Boulez or Karlheinz Stockhausen.

Until then, the series had only affected the pitch of a note, but the neo-serialists applied the principle to other sonic characteristics, an idea that Olivier Messiaen is known to have originated:

²⁹ TROCHE, Sarah, 2012. Structure et méthode dans la musique de John Cage : une discipline d'attention. *Nouvelle revue d'esthétique*. 2012. Vol. 9, no. 1, pp. 91-104. DOI 10.3917/nre.009.0091. p. 101

³⁰ TROCHE, Sarah, 2015. *Le hasard comme méthode: figures de l'aléa dans l'art du XXe siècle*. Rennes : Presses Univ. de Rennes. Aesthetica. p. 400

“In 1942, while teaching serial music to his students Nigg, Boulez and Martinet, he advised them to write serial works not only with series of frequencies, but also with series of timbres, of intensities and of durations. But it wasn't until 1949 that he put his fruitful idea into practice for the piano in ‘Mode de valeurs et d'intensités’. Immediately, all the young people were dazzled and launched into compositions imitating or paraphrasing this work³¹.”

But the first pieces to belong to integral serialism are most commonly considered to be Milton Babbitt's *Three Compositions for Piano*³², written in 1947. The composer also produced numerous theoretical texts, some of whose concepts were taken up by Allen Forte in a musicological analysis known as ‘set theory’ after the author's application of the mathematical set theory to atonal music³³.

Set theory introduces a strong algebraic dimension into musical composition, as illustrated by the analysis of manipulations applicable to a series—transposition, inversion—and the possible relationships between two series—inclusion, complementarity—or the concepts of interval vectors and form matrices. The near disappearance of the boundary between music and mathematics is most clearly demonstrated by the existence of the hexachord theorem³⁴, also known as Milton Babbitt's theorem, which has been proved many times, and which Moreno Andreatta expresses in everyday language as follows:

“In a hexachord and in its complementary, the multiplicity of occurrence of each interval (an interval always being equivalent to its complementary) is the same³⁵.”

We will not go into the practical applications of this theorem or the notion of “combinatoriality” introduced by Milton Babbitt—who applies it particularly to hexachords—as they go far beyond the scope of this study³⁶.

³¹ XENAKIS, Iannis, 1955. La crise de la musique sérielle. *Gravesaner Blätter*. 1955. Vol. 1, n° 1. p. 2

³² BABBITT, Milton, 1947. *Three Compositions For Piano*, ARNONE, Augustus (performer), [online]. [Piano solo]. Boelke-Bomart, 1947. [Accessed 20 September 2024]. Available at: <https://www.youtube.com/watch?v=AcpMR4r2kcQ>

³³ FORTE, Allen, 1973. *The structure of atonal music*. New Haven : Yale University Press.

³⁴ A hexachord is a collection of six different notes - known as *pitch classes* in set theory terminology - from among the twelve of the chromatic scale. For more details, see :

WHITTALL, Arnold, 2008. *The Cambridge introduction to serialism*. Cambridge: Cambridge University Press.

³⁵ ANDREATTA, Moreno, 2003. *Méthodes algébriques dans la musique et la musicologie du XXème siècle : aspects théoriques, analytiques et compositionnels* [online]. PhD thesis in musicology. Paris : École des Hautes Études en Sciences Sociales (EHESS). [Accessed 19 September 2024]. Available at: <https://theses.hal.science/tel-00004074> p. 37

³⁶ For more details on the mathematics of set theory and its musical translations, see the article by Moreno Andreatta and Stefan Schaub introducing the *Autour de la set theory colloquium at IRCAM in 2003*: ANDREATTA, Moreno and SCHAUB, Stéphan, 2003. *Une introduction à la Set Theory : Les concepts à la base des théories d'Allen Forte et de David Lewin*. Musurgia [online]. 2003. Vol. 10, No. 1, pp. 73-92. [Accessed 19 September 2024]. Available at: <https://www.jstor.org/stable/40591272>

The main purpose of these examples is to demonstrate that the resolutely mathematical orientation of American-style integral serialism constitutes a step towards a computational and algorithmic approach to music.

1.7 THE OPEN WORK AMONG THE EUROPEAN NEO-SERIALISTS

On the other side of the Atlantic, the algebraic component consubstantial with serial music is less invested, in favor of an approach marked by the search for the unexpected. Inspired by Stéphane Mallarmé, Pierre Boulez, and the neo-serialists with him, introduced a form of variability into the musical work by including in their scores various options for the performer to choose from³⁷. This is the case, for example, in Karlheinz Stockhausen's *Klavierstück XI* and Pierre Boulez's *Troisième sonate pour piano*, written in 1956 and 1957 respectively³⁸.

Pierre Boulez's approach is that of a "directed" randomness, a freedom of selection or execution that the composer grants in order to put "back into the creative circuit the performer himself, who for many years had only been asked to play the text as 'objectively' as possible³⁹". This directed randomness is also a form of response to the "inadvertent randomness" that Pierre Boulez accused John Cage of. For the French composer does not understand the reasons for the meticulousness with which John Cage sets up his random systems, only to relinquish all control over the final form. And he makes this clear with undisguised contempt:

"[...] the event happens as it can, without control (voluntary absence, though not meritorious, by impotence), BUT within a certain established network of probable events, because randomness must have some contingency. Why, then, choose the network so meticulously, why not leave the network itself to inadvertence? That's what I've never been able to work out. We're playing a half-fair game, but we have the merit of not hiding it. It's a nicely arranged artificial paradise where I believe that dreams are never very miraculous; this kind of narcotic does indeed protect you from the sting inflicted by any

³⁷ This practice of the open work was theorised in 1962 by Umberto Eco who, relying heavily on Stéphane Mallarmé, extended the concept from James Joyce or Franz Kafka to Marcel Duchamp, Alexander Calder, Bruno Munari or even Jesús-Rafael Soto.

ECO, Umberto, 1962 [1965 for the first french edition]. *L'œuvre ouverte*. [1979]. Paris: Editions du Seuil. Points, 107.

³⁸ For more details on these pieces:

Karlheinz Stockhausen, *Klavierstück XI* (1956)

see: <https://brahms.ircam.fr/fr/works/work/12123/>

Pierre Boulez, *Troisième sonate pour piano* (1957) :

see: <https://www.musiquecontemporaine.info/zpiece-Boulez-TroisiemeSonate.php>

³⁹ BOULEZ, Pierre, 1966. *Relevés d'apprenti* [online]. Paris : Seuil. [Accessed 4 July 2024]. Available at: <https://archive.org/details/relevsdapprenti0000unse/page/n7/mode/2up> p. 55

invention, and you have to admit that its action is overly soothing, sometimes hilarious, just like what hashish addicts describe⁴⁰."

Here, then, is John Cage, clearly targeted, though not mentioned by name, reduced to the rank of a hippie lover of artificial paradises, his "philosophy tinged with Orientalism [masking only a] fundamental weakness in compositional technique⁴¹". This accusation of resignation from the role of composer, which Pierre Boulez levelled at John Cage was also levelled at him by Iannis Xenakis, for whom the process of directed randomness was a mere pretense:

"The performer is a highly conditioned being, so we cannot accept the thesis of unconditional choice, of the performer as a roulette wheel. [...] The composer resigns when he admits several possible and equivalent circuits. In the name of the scheme, the problem of choice is betrayed, and it is the performer who is promoted to the rank of composer by the composer himself. There is therefore a substitution of authors⁴²."

1.8 THE STOCHASTIC MUSIC OF IANNIS XENAKIS

Iannis Xenakis's approach to randomness is indeed resolutely different from the two previous ones: with the notion of stochastic music⁴³, he introduces randomness governed by probability theory⁴⁴, an idea inherited from the development of statistical physics and the only way, in his opinion, to get music out of the rut of integral serialism:

"Stochastics studies and formulates the laws of large numbers, as well as the laws of rare events, the various random processes, and so on. This is how, in 1954, out of the dead end of serial music, among other things, was born a form of music based on the principle of indeterminism, which two years later I called stochastic music. The laws of the calculus of probabilities entered the composition by musical necessity⁴⁵."

In *Musiques formelles*, Iannis Xenakis details a model of musical creation in eight phases⁴⁶, specifying that their order is not rigid and their application

⁴⁰ *Ibid.* pp. 41-42

⁴¹ *Ibid.* p. 41

⁴² Xenakis, Iannis, 1963. *Musiques formelles: nouveaux principes formels de composition musicale*. Paris: Richard-Masse. La Revue musicale. p. 48

⁴³ The modern meaning of stochastic is "which depends on, which results from chance", and more specifically in the mathematical field "which comes under the domain of randomness, the calculation of probabilities". The word comes from the ancient Greek *stokhastikós*, which means "that aims well, that tends directly towards" but also "skilful at conjecturing, penetrating". It derives from *stokhastês*, meaning diviner.

For the Greek etymology, see : BAILLY, Anatole, 1935. *Greek-French dictionary* [online]. [Accessed 27 February 2024]. Available at: <http://archive.org/details/BaillyDictionnaireGrecFrancais> or the online application: <https://bailly.app/stochastikos>

⁴⁴ In the same way, Iannis Xenakis conceived "strategic music" and "symbolic music" on the basis of game theory for the former and (mathematical) set theory for the latter. See chapters 3 and 5 respectively of *Musiques formelles* (*op. cit.*).

⁴⁵ *Ibid.* p. 19.

⁴⁶ *Ibid.* pp. 33-34

is often unconscious: on the basis of his intuitions (phase a), the composer defines sound beings—instrumental sounds, electronic sounds, noises, etc.—and their associated symbols (phase b). The next two phases concern the structure of the piece and the constitution of musical motifs—*macro* and *micro* composition (phases c and d). Next comes the sequential programming of the previous two phases (phase e), followed by the calculations, as schemes and patterns requires algebraic, logical or stochastic operations (phase f). The results of the first six phases are then formalized in symbolic form: traditional partitions, numerical listings, diagrams, graphical partitions, etc. (Phase g). This leads to the final stage: the embodiment in sound of the work thus composed (phase h).

An initial comment is in order: this model is very similar to a program, and could easily be presented in the form of a flow chart. Iannis Xenakis's formalization thus comes close to the approach of algorithmic music, and the composer explicitly states that the last three phases are intended to be “taken in hand by computers”. He also expressed his regret that, in his time, the final embodiment could only be achieved through human operators, while prophesying that “in the very near future [...] advanced mechanization [would] do away with orchestral performers or tape recorders, and [would]—take over the mechanized production of sound beings and their transformations⁴⁷.”

However, Iannis Xenakis's approach differs from that of Pierre Barbaud, a key figure in algorithmic music for both his theoretical contributions and his compositions. Firstly, because the programmatic approach to music is only one facet of Iannis Xenakis's work, whereas it is the central axis of Pierre Barbaud's work from 1958 onwards.

Secondly, and most importantly, because the former, when using a formal model to generate a score, allows himself to retouch it, whereas the latter categorically excludes this option.

In *Nomos alpha* (1966), Makis Solomos⁴⁸ measured a deviation rate between the formalized score and its final version of 18.5%. These discrepancies can be explained in different ways: some are simple mistakes—in transcription or calculation—others are corrections deemed necessary for errors in the theoretical model, and lastly others are changes to details based on entirely

⁴⁷ *Ibid.* p. 34

⁴⁸ Solomos, Makis, 2023. Bricolage. *Site officiel Iannis Xenakis* [online]. 2023. [Accessed 11 July 2024]. Available at: <https://www.iannis-xenakis.org/en/bricolage/>

subjective aesthetic preferences. In so doing, Iannis Xenakis fully accepts that the hand may return at the end of the computational process:

“What we obtain by calculation always has its limits. It lacks an internal life, unless you use very complicated techniques. Mathematics produces structures that are too regular, below the requirements of the ear and the intelligence. The great idea is to be able to introduce randomness in order to break the periodicity of mathematical functions, but we are only at the beginning. The hand lies between randomness and calculation. It is both the executor of the mind—very close to the head—and an imperfect tool⁴⁹.”

This practice is contested by Pierre Barbaud, who sees it as an abuse of power, but also a sign of the imperfection of Iannis Xenakis’s formal models—a disagreement not unlike that between Josef Matthias Hauer and Arnold Schönberg. For the algorithmic composer, any choice made after the computational process is unjustifiable, because it contradicts the initial concept of creation:

“The solutions received at the output of the machine are decoded and, in the case of Xenakis, analysed and filtered: the unplayable is eliminated, pure reasoning clothed in sensitivity... Here the composer has the last word. This intervention is no longer desirable for algorithmic musicians who, prior to and in parallel with Xenakis’s research, developed research based on the use of a more complex language and allowing a more universal and total transcription of the program and the data⁵⁰.”

1.9 PIERRE BARBAUD AND THE ALGORITHMIC MUSIC

The purpose pursued by Pierre Barbaud is clearly established through the substantial corpus of his theoretical writings. The aim was to return to “pure” music, i.e. music based on “ingenious arrangements of sounds⁵¹”, and to break away at last from the cult of expression inaugurated by the vogue for opera, which had subjected music to the domination of passion:

“In the minds of those who make it or listen to it, music has definitively become the medium of an emotional scenario, the pretext for expressing who knows

⁴⁹ Iannis Xenakis in: REY, Anne, DUSAPIN, Pascal, Si Dieu existait, il serait bricoleur, *Le Monde de la Musique* no. 11, May 1979, pp. 92-97.

Quoted by Makis Solomos in

SOLOMOS, Makis, [no date]. Iannis Xenakis. *Ressources.IRCAM* [online]. [Accessed on 11 July 2024]. Available at: <https://brahms.ircam.fr/fr/iannis-xenakis#parcours>

⁵⁰ BARBAUD, Pierre et PHILIPPE, Robert, 1969. L'ordinateur et la musique. *Communication et langages*. 1969. N° 3, pp. 17-25. DOI [10.3406/colan.1969.3744](https://doi.org/10.3406/colan.1969.3744). pp. 20-21

⁵¹ BARBAUD, Pierre, 1960. Musique algorithmique. *Esprit* [online]. 1960. No. 280 (1), pp. 92-97. [Accessed on 3 July 2024]. Available at: <https://www.jstor.org/stable/24255071> p. 93

what torments, regardless of the invention that presides over the arrangement of the sounds that make up the work⁵².”

To those who are indignant about the use of computers for creative purposes, Pierre Barbaud argues that the compositional process, whether it be “serial music, post-serial music or even, why not, just plain music”, carries within it the seeds of algorithmic music:

“We implicitly submit to a system of thought designed to produce a result, which we hope will be unpredictable, from a practically infinite number of possible results considered to be banal in the name of criteria yet to be defined. [...] Writing music is above all a matter of defining the limits within which the combinatory imagination of the elements brought into play can manifest itself. [...] It is the most lucid possible formulation of these constraints that characterizes algorithmic music in the first place⁵³.”

For Pierre Barbaud, algorithmic music is perfectly conceivable without the computer, as demonstrated by Michel Philippot’s compositions for “imaginary machine⁵⁴”, a concept taken up a few years later by his friend Vera Molnár. However, there were two reasons for using computers: the neutrality of the machine, which defused the temptation to retouch in the manner of Iannis Xenakis, and above all the impossibility, when the program grew in size, of carrying out the necessary calculations by hand.

Pierre Barbaud’s stance can sometimes seem overly rigorist, as in his criticism of Iannis Xenakis. Yet it rests on solid conceptual foundations, inherited from Josef Matthias Hauer: the rejection of music dictated by emotion in favor of composition built on the exercise of reason:

“It is about, by means of a machine, making a music of a machine, that is to say where the laws of logical thought, exercised on a set of data within a program, are implacably respected, without the intervention, at any moment, of a decision that is not the result of a premeditated calculation⁵⁵.”

CONCLUSION

Pierre Barbaud’s influence extends beyond the field of music. His meeting with Gottfried Honegger at the end of the 1960s led the latter to introduce

⁵² *Ibid.*

⁵³ BARBAUD, Pierre and PHILIPPE, Robert, 1969. L'ordinateur et la musique. *Communication et langages*. 1969. No. 3, pp. 17-25. DOI 10.3406/colan.1969.3744. pp. 22-23

⁵⁴ PHILIPPOT, Michel, 1963. Composition pour double orchestre (1960). In: XENAKIS, Iannis, *Musiques formelles: nouveaux principes formels de composition musicale*. Paris: Richard-Masse. pp. 53-56 La Revue musicale.

⁵⁵ BARBAUD, Pierre and PHILIPPE, Robert, 1969. L'ordinateur et la musique. *Communication et langages*. 1969. No. 3, pp. 17-25. DOI 10.3406/colan.1969.3744. p. 24

randomness into his working process and then to use the computer in preparatory phases⁵⁶. The two men would later appear together at the same event organized by the Groupe Art et Informatique de Vincennes (GAIV) in Angers in 1974⁵⁷. It was also after making the acquaintance of Pierre Barbaud in 1967 that Manfred Mohr—also inspired by the aesthetics of Max Bense—abandoned his painting practice to turn definitively to algorithmic visual creation from 1969 onwards⁵⁸.

The debates opened up by the practice of algorithmic music fed into those of the nascent computer art. Thus the different modalities of the unexpected, the opposition between randomness and luck, the organized variability of a program's output, the full appropriation of the computer, the mobilization of scientific advances, the questioning of the intrinsic infallibility of the artist as a demiurge or the search for an objective aesthetic, irrigated the theoretical substratum on which computer art would flourish.

⁵⁶ Extract: Gottfried Honegger: Homo scriptor, [no date]. *Les presses du réel* [online]. [Accessed 24 July 2024]. Available at: <https://www.lespressesdureel.com/extrait.php?id=490&menu=>

⁵⁷ LENGLOIS, Camille, 2023. Chronologie des manifestations du GAIV. In : *Le Groupe art et informatique de Vincennes (GAIV)*. Éditions du Centre Pompidou. pp. 70-81. Recherches. p. 73

⁵⁸ MOHR, Manfred, [no date]. Statement. *Manfred Mohr official website* [online]. [Accessed 12 July 2024]. Available at: <http://www.emohr.com/tx101.html>