Xenakis' use of Stochastic Form

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“As
a result
of the impasse
in serial music, as
well as other causes, I
originated in 1954 a music constructed
from the principle of indeterminism; two years
later I named it “Stochastic Music”. The laws of the
calculus of probabilities entered composition through
musical necessity. But other paths also led to the same crossroads
first of all, natural events such as the collision of hail or rain with hard
surfaces, or the song of cicadas in a summer field. These sonic events are made
out of thousands of isolated sounds; this multitude of sounds, seen as totality,
is a new sonic event. This mass event is articulated and forms a plastic
mold of time, which itself follows aleatory and stochastic laws. If one
then wishes to form a large mass of point-notes, such as string
pizzicati, one must know these mathematical laws, which,
in any case, are no more than a tight and concise
expression of chains of logical reasoning.
Everyone has observed the sonic
phenomena of a political
crowd of dozens of
hundred of
thousands
of
people.
The human
river shouts a
slogan in a uniform rhythm.
Then another slogan springs
from the head of the demonstration;
it spreads toward the tail, replacing the
first. A wave of transition thus passes from the head
to the tail … the statistical laws of these events, separated
from their political or moral context, are the same as those of the
cicadas or the rain. They are the laws of the passage from complete order
to total disorder in a continuous or explosive manner. They are stochastic laws.”

- XENAKIS -

Introduction

Xenakis' premise for composing was "music has a fundamental function, which is to catalyze the sublimation that it can bring about through all means of expression." To bring about this sublimation he infused his music with logic and mathematics, aspiring to capture the energy of naturally occurring mass sound events such as a crowd chanting or a city being bombed. "He was looking for vast configurations in which the individual speck or leaf on the tree would not be so important in itself as its position relative to other objects in the field, as part of a gigantic moving tapestry where the aggregate is more than the sum of its parts."[1]

While originally conceived only on the microstructural level, in his early compositions Metastasis and Pithoprakta, Xenakis soon applied stochastics to the macrostructure of the piece as well, resulting in the formal construction for the piece Achorripsis. This stochastic trend eventually led to the creation of a computer algorithm that took a few parameters from the composer, made vastly complicated probability calculations, and resulted in a ready to perform score (and later, a ready to play sound file).

In his interdisciplinary marrying of left-brain organization and right brain inventiveness, (or as Xenakis put it, "When it serves music, as all human creative activity, scientific and mathematical thought should amalgamate dialectically with intuition."[2]) he opened many avenues for further exploration into the formal constructions possible in a musical system.

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[1] Nouritza Matossian, *Xenakis* (New York: Taplinger Publishing Company, 1986): 90.
[2] Iannis Xenakis, *Formalized Music* (Hillsdale, New York: Pendragon Press, 1992): 181.

Xenakis' use of probability to determine microscopic and macroscopic events followed a largely logical progression. He began using probability to create mass sound events within a preconceived macroscopic form. He then used probability to create larger formal structures, creating the form of the entire work based on the probable density of sound in a single time segment. He capped his stochastic output with a computer program that, given a few simple guidelines, created a piece of music in the form of a ready to play audio file.

1954 - Metastasis, "Transformations"

While an aspiring composer at heart, Xenakis began his professional life as an engineer and architect working under Le Corbusier in Paris. Throughout his compositional output he retained obvious signs of this background. His forms, temporal blueprints, were always measured and perfected before a note was engraved, just as an architect maps out every possible detail of a building before a single brick is cast. Xenakis remained an architect through his whole life and built his constructions in the temporal/audible domain instead of the visual/visceral.

Upon meeting Messiaen in 1951, Xenakis expressed his concern with his lack of training in harmony, counterpoint, and theory. To this Messiaen replied, "You have the good fortune of being Greek, of being an architect, and having studied special mathematics. Take advantage of these things. Do them in your music."[3] Xenakis attended Messaien's classes at the Paris conservatory regularly in 1952. His compositions in this period were largely incidental, small chamber ensembles and songs.

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[3] Matossian, 48.

Xenakis published a paper in 1955 criticizing serialists for their focus on complicated polyphony and the relationships of individual note events that are quickly lost by the listener. "Xenakis was looking instead for an aerial view to gain some distance from the cramped perspective of the close-up imposed by serialism."[4] Xenakis' 1954 breakthrough composition, Metastasis, is the result of injecting architectural ideas into his workings with Messiaen in order to achieve this more aerial view.

"In architecture Xenakis observed a formal principle which posed an alternative to the organic model [that of a general motif which is developed]; juxtaposition or collage"[5] The form he adopted for this work had no hierarchy; there was no departure, no return, only ideas. It is comparable to the "moment form" of Stockhausen developed used in pieces such as Momente, but in contrast his "moments" are quite long, and each possesses a strong sense of motion and development within themselves.

The piece is scored for a large orchestra, with the strings completely divisi. Xenakis described the driving force for the piece: "I became more interested in the idea of continuous and discontinuous change. In Metastasis the former is represented by glissandos, the latter by the permutation of intervals and also the organization of time based on the golden section."[6]

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[4] Matossian, 90.
[5] Matossian, 64.
[6] Balint Andras Varga, *Conversations with Iannis Xenakis* (London: Faber and Faber, 1996), 72-73.

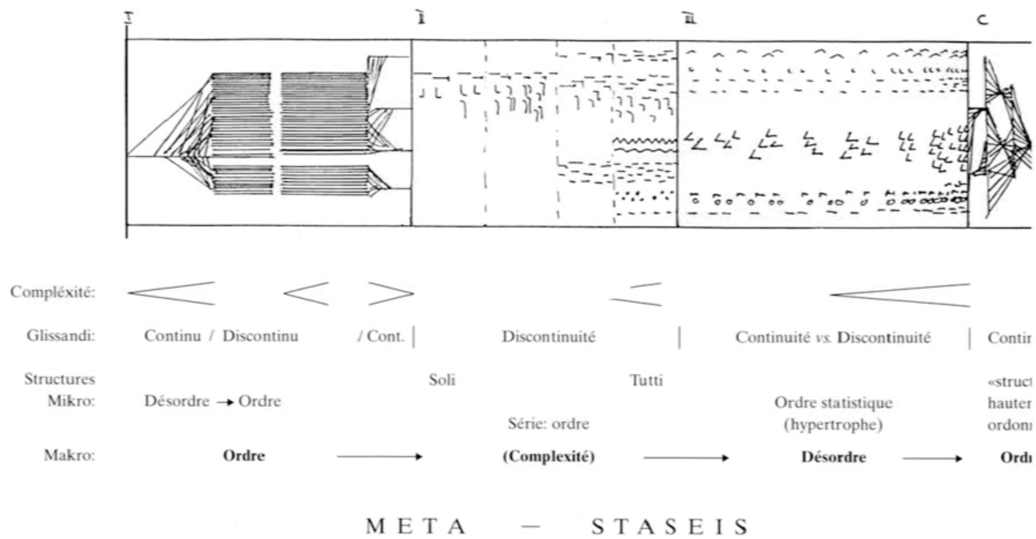

Figure 1 - Graphic Outline of Metastasis

Formally, *Metastasis* is conceived as the juxtaposition of 3 sections with a coda (which is very similar to section 1). Section 1 consists of continuity represented by glissandi, section 2 embodies discontinuity with quasi-serial polyphony, and section 3 is an overlapping of the two, with a final return to continuous glissandi for the coda. The form is very simply conceived, as a canvas on which to paint "fields of sound…created by varying the quantities and directions of the forces, i.e. dynamics, frequency, intensity, duration."[7]

The piece is his first attempt to create 'living sounds'. He analyzed compound sound events like rain, crowds chanting, crashing of waves on cliffs, trying to discover what made these sounds so dynamic and inherently beautiful. These sounds are not at all static, they grow and swell and transform, and he wanted to inject his music with that organic sense of plasticity. He took advantage of his ability to draw in sketching the piece out on graph paper, allowing him to visually represent the compounded effect of each instrument's

[7] Matossian, 58.

individual line. By using the graphic notation (as a compositional tool), he was able to sculpt the events and maintain his aerial, architectural perspective of them.

Metastasis was the seed for Xenakis' stochastic output. In it he experimented with how math could inform musical decisions, notably using the Fibonacci series to define intervallic relationships between pitches and create rhythms. But more importantly, it was his first experiment in controlling mass sound events. A 'living sound' is one that is constantly evolving and morphing, and after composing *Metastasis* he concluded, "I had to control so many events at the same time that I realized only probabilities could help."[8] Probability created a degree of disorder within a controllable aggregate, and this was exactly what he observed in naturally occurring mass sounds. So he began turning over various compositional decisions to probability, not to make the piece easier to control, but to inject an element of instability into the microstructural events to make the macrostructural sound masses sound more natural.

1956 – Pithoprakta, "Actions by Probabilities"

"In the next step – that was Pithoprakta – I wanted to process the problem of mass more thoroughly"[9] *Pithoprakta* was composed for a smaller ensemble of strings, two trombones, a xylophone and a woodblock. The string-dominated texture is diversified with many extended techniques. Notably, the opening consists of violinists tapping on the underside of their instruments. The trombones are used very little, accenting the strings with brassy glissandi.

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[8] Balint Andras Varga, *Conversations with Iannis Xenakis* (London: Faber and Faber, 1996): 73.
[9] Varga, 75.

David Jones described stochastic music as "a theory of composition derived from the mathematical calculation of probabilities"[10] It is a carefully constructed funnel to guide the atoms of music, without absolute precision, but artful molding of the aggregate. The composer becomes a herder, shuffling notes across the plains towards a specific destination, but without controlling each cow-note exactly.

The law of large numbers, a foundational principle of *Pithoprakta*, states that the more events of a single type that occur, the closer the aggregate will tend toward the probable outcome of a single event. (The more times a coin is flipped, the closer the running average will approach 50%.) He applies this law in the creation of his sound events noting, "Densities, duration, register, speeds, etc, can be made to submit to the laws of large numbers, with the necessary approximations. With the means and derivations we can shape these collections and make them evolve in different directions"[11] This discovery took him even further away from the micro polyphony of serialism. What was important was not an individual event, but the frequency of occurrence, intensity, duration, etc. of that event in comparison with what else was happening around it. He began to see musical phenomena in very scientific terms, breaking them down into their indivisible components.

He was in effect abstracting music from the intuition, but all the while maintaining, "What is obtained by calculation always has limits. It lacks inner life, unless very complicated techniques are used. Mathematics gives structures that are too regular and

[10] David Jones, "The Music of Xenakis," *The Musical Times* 107, no. 1480 (June 1966): 495.
[11] Iannis Xenakis, *Formalized Music* (Hillsdale, New York: Pendragon Press, 1992): 16.

that are inferior to the demands of the ear and the intelligence"[12] This was to be a recurrent theme in his writing and composing: the insufficiency of math to create music alone. Rather he considered it a tool, especially to create 'living sound mass' events.

In measures 53-60 of Pithoprakta, Xenakis uses Boltzmann's kinetic gas theory, which calculates the probability of molecules moving at various speeds within a gaseous body at a constant temperature. Each of the pizzicato notes in the strings is considered a molecule of this gas moving around and the speed of the glissando is determined with kinetic gas theory. Thus Xenakis has created a sonic event that is overtly tied to a naturally occurring phenomenon. While even the most discerning listener would probably not draw this direct connection, it is still a successful example of how nature can inform artistic decisions. Xenakis wanted a way to govern the change of a mass sound event, in this case a cloud of pizzicati, and in kinetic gas theory found a suitable organizing strategy.

The formal design of Pithoprakta is akin to Metastasis: a juxtaposition of mass sound events. However in this inception Xenakis is less rigid with the boundaries of events. There are many more events, the timbres are diversified, and the events are enveloped and cross-faded. So while remaining a large-scale form conceived from an architectural standpoint, it's juxtapositions are considerably advanced in inception.

Pithoprakta represented a solution to the problems raised in Metastasis. However in solving that problem he discovered another one waiting to be explored: "This time it is these stochastic tools that pose a fundamental question: 'What is the minimum of logical

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[12] Roberta Brown, John Rahn Iannis Xenakis, "Xenakis on Xenakis," *Perspectives of New Music* 25, no. 1/2 (1987): 23.

constraints necessary for the construction of a musical process?'"[13] In other words, how many stochastic rules *must* be established to create a piece of music? He wanted to reduce the formal architecture of music to its simplest terms; therefore discovering exactly what made music, music. To achieve this minimum of rules he again found a solution in the mathematics of probability.

1957 – Achorripsis, "Jets of Sound"

The breakthrough of his stochastic output was the conceptualization of form as a relationship between timbre, time and density. He identified these three elements as the "minimum of constraints", the things that a composer *must* specify to create a piece of music. In composing Achorripsis he divided the chamber orchestra into seven timbre groups and created a matrix representing the density levels of those timbre groups (each group being represented by a rows of the matrix) over time blocks (the columns of the matrix). He realized that a cell of this density matrix fit into the requirements for the use of a probability distribution created by Simeon Poisson. Using Poisson's law he guided the density levels of the relative timbre groups, and for the first time "every musical element is stochastically determined – including the overall form"[14].

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[13] Xenakis, *Formalized Music*: 16.
[14] Linda Arsenault, "Iannis Xenakis's Achorripsis: The Matrix Game," *Computer Music Journal* 26, no. 1 (2002): 58.

The law created by Simeon Denis Poisson (1782 – 1840) predicts the probability for multiple occurrences of an event over a given time interval given the probability of that event occurring once in that same interval. It can be used to project the likelihood of a multiple soldiers dying a year in peacetime from being kicked by a horse (the rather eclectic question around which Poisson based his formula), or predicting the number of cars that will break down in a year (with the probability of a single car breaking down).

Xenakis applied this to predict the number of times that events of a given density would occur. He conceptualized five different density levels possible for each timbre group in each cell to equal a total of 196 events in his 7x26 matrix. Starting with a proposed average density of .6 he used Poisson to calculate that his matrix would have 107 'zero' events, 65 "single" events, 19 "double", 4 "triple", and 1 "quadruple". (This is analogous to proposing that an event has a 30 percent chance of occurring and there are 100 possible places for events to occur, therefore the event will occur 30 times. It is a very pure form of probability.)

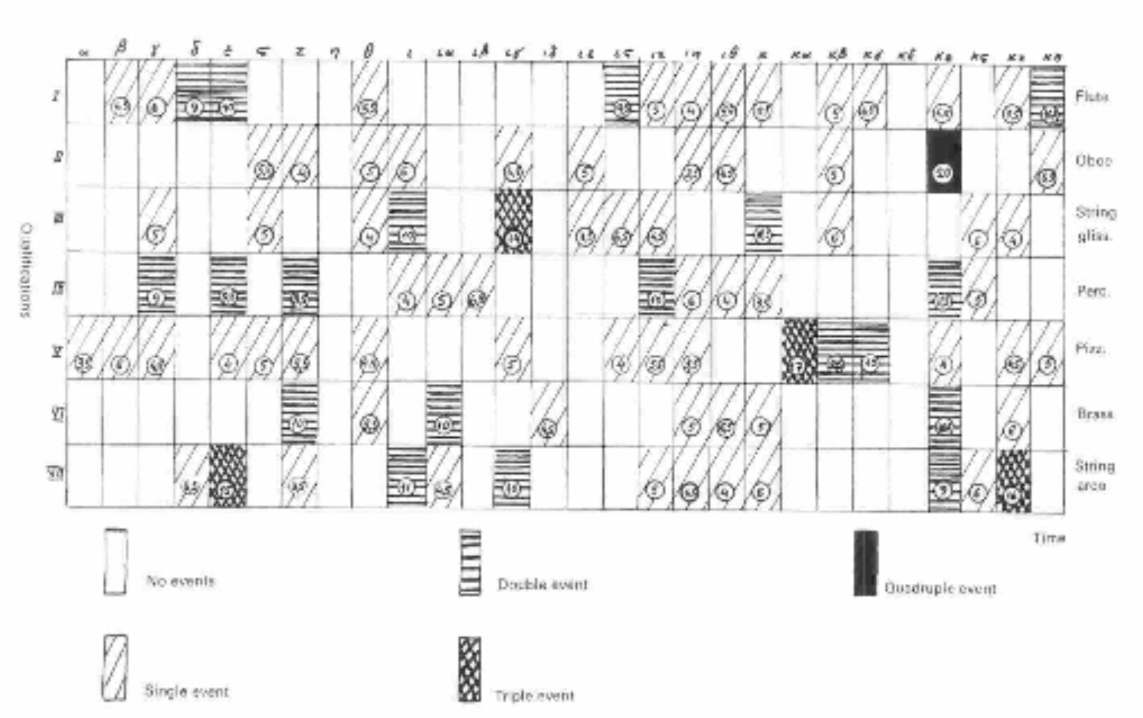

Figure 2 - Xenakis' Matrix M, the formal plan for Achorripsis

Having determined the total number of each event type, he took Poisson a step further. Dividing the 107 zero events into the total number of columns (28) he arrived at an average "zero event density" of 3.82 per column. Plugging this number into the Poisson formula he calculated the number of columns that will contain 1,2,3,4,5 or 6 "zero" events. Following this procedure for all event types, he derived the data in table 1: the number columns that will contain k number of each event type. He followed the same procedure to obtain the parallel information for the rows.

Table 1 –Distribution of Event Types the columns of Matrix M (Arsenault 2002)

Frequency	*Zero Events*		*Single Events*		*Double Events*		*Triple Events*		*Quadruple Events*	
K	*No. of Columns Containing k Events*	*No. of Events (k × No. of Columns)*	*No. of Columns Containing k Events*	*No. of Events (k × No. of Columns)*	*No. of Columns Containing k Events*	*No. of Events (k × No. of Columns)*	*No. of Columns Containing k Events*	*No. of Events (k × No. of Columns)*	*No. of Columns Containing k Events*	*No. of Events (k × No. of Columns)*
0	0	0	3	0	14	0	24	0	27	0
1	2	2	6	6	10	10	4	4	1	1
2	6	12	8	16	3	6				
3	5	15	5	15	1	3				
4	5	20	3	12						
5	4	20	2	10						
6	4	24	1	6						
7	2	14								
Totals	28	107	28	65	28	19	28	4	28	1

Using Poisson, he computed not just the number of each event type in the overall matrix, but the number of columns and rows that will contain a given number of each event type. With this data, he assembled Matrix M like a jigsaw puzzle, arranging events to satisfy both the row and column requirements. The Poisson formula allowed him to look at probability macroscopically, instead of flipping coins to determine each individual event, he considered the entirety of the piece and discovered how many of each event type were probable to happen. More importantly, he established a relationship between simultaneously occurring relative density, (the columns) and the density levels within each timbre group over the whole piece (the rows). He had therefore achieved a formal construction, using probability as an organizing concept that created temporal relationships between events.

Musically, the piece was essentially a study in sound density. Zero events are logically silences, and then the single events are assigned an average density, and the remaining classes are multiples of this established constant. He lets each column of the matrix equal 15 seconds, or 6.5 measures at the tempo half note equals 52. He employs further probability distributions to calculate the time between notes in an event, interval between successive pitches, and the "speed" of glissandi if appropriate. It is noteworthy that Xenakis is more interested in relationships between events than the events themselves, not specifying pitches, but intervals; not rhythms, but the time between events.

Achorripsis embodied the most significant innovation in his stochastic output: the derivation of form based on probable density. Having discovered how a form could be included in the calculation of the piece, he further abstracted his aesthetic from the architecture of his music. He describes the development: "In contrast to Pithoprakta, Achorripsis is a closed entity, which I created with interlinked stochastic rules…In Achorripsis I applied the macroscopic approach, from the viewpoint not of the senses but of the internal structure. It was my aim to create a homogeneous construction based on probabilities which would be interesting for the listener."[15] Achorripsis is his departure from intuitive form, from a Messaeian-influenced juxtaposition model to a conception of form as a realization of probable density.

1956-62, Computer generated scores

While throughout the remaining pieces conceived in stochastic terms, the architecture did not alter significantly; the realization of that design developed considerably. The first development of this kind was accomplished with the help of the IBM-7090 computer. While still investigating the possibility of producing music with "the

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[15] Varga, 79.

minimum of constraints, causalities and rules.,"[16] he desired to incorporate more advanced models, requiring increasingly complicated calculations. With the advancement of computing technology, he was able to do this. The "ST" scores were largely composed algorithmically; thus given further layers of complexity than would have been possible to calculate by hand.

The prospect of computers creating music causes a general uneasiness with many composers, asserting that it is the incalculable aspects of music that makes it valid as art. There is an unspoken understanding that the intuitive aspect, the composer exercising their aesthetic, is paramount. Xenakis describes his reasons for using computers: "With the aid of electronic computers the composer becomes a sort of pilot: he presses the buttons, introduces coordinates, and supervises the controls of a cosmic vessel sailing in the space of sound, across sonic constellations and galaxies that he could formerly glimpse only as a distant dream. Now he can explore them at his ease, seated in an armchair."[17] He was creating scores based on complex probability calculations, which stemmed from simple musical premises. Achorripsis was the realization of an extended probability algorithm. He saw the computer as a way to speed up the composing process, because the probability calculations were not the interesting part of the music – which was the inception of the piece, the *question* asked by the composer. By delegating the procedural aspect of composing, he became free to explore the overall strategy of musical composition more fully. The program itself was a formal device, it was *the strategy* for composing (similar to the procedures governing canon, rondo…), and this form could be altered to

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[16] Xenakis, *Formalized Music*.
[17] Xenakis, *Formalized Music*, 144.

contain whatever instruments, whatever density, whatever timbres desired, and whatever length. So this form, embodied in a computer program, was quite dynamic; a plastic building that created itself based on the specifications of the architect-pilot. In this way it was like a fugue, as the denouement of a premise (in the former: the fugue subject, the latter: the density and instrumentation).

To create a piece Xenakis inputted the desired length of the composition, average length of a section, range of densities, and the musicians to be written for (this is therefore his 'minimum of constraints', or the fundamental properties necessary to produce music). The computer took this range and divided it into density levels from 0 to 6. To compose the individual notes, his algorithm first determined the length of the sequence, density, and what instruments play the sequence (timbre class). Steps 4-6 define attack time, specific instrument (from already defined timbre class).

He created several pieces with this program, such as the 1962 orchestra piece ST/48 – 1.240162 (a very computerized way of titling the piece 'Stochastic music for 48 instruments number 1 created on January 24th of 1962'). Atrees, ST/4, Morisima, ST/10, are additional examples, all composed in the early 1960s.

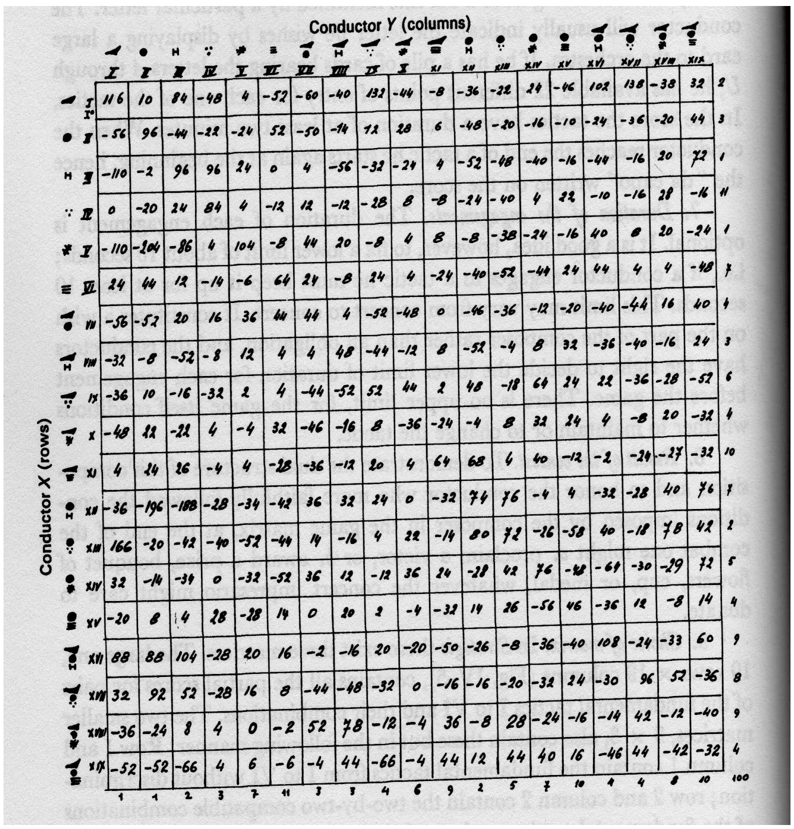
It is noteworthy that there were not hundreds of compositions of this nature. Xenakis was still very concerned with the quality of music that he attached his name to, and was not content to churn out piece after piece with his composing algorithm. What he had accomplished was the ability for the composer to explore sonic landscapes created stochastically, and having reached this level of sophistication he largely moved on from the use of stochastically created form in his compositions. He had taken stochastically created form as far the questions had driven him. The ST pieces were the final step in his goal of deconstructing music into its most fundamental aspects. Having reached this goal, he turned his attention to organizational strategies other than stochastics to manipulate those building blocks.(namely, the use of calculus and symbolic logic to create form).

1959 – Duel & Strategie , Stochastic Indeterminacy

Though not directly related to his chain of formal stochastic developments, *Duel* and *Strategie* represent worthy side notes. In these pieces, created as a competition between two conductors (and their orchestras), Xenakis created a stochastic form based on timbre combinations.

To create the rules of the game, Xenakis identified 6 orchestral timbral ideas, (such as "percussion sounds" or "parallel sustained strings with fluctuations"), and 13 of their possible combinations (such as percussion sounds with string pizzicati), as available tactics for each conductor. He then outlined every possible combination of these 19 tactics between the two orchestras and assigned each of these combinations a point value based on his judgment of the aesthetic quality of that combination. He assembled the Matrix found in figure 3, as a chart for all possible point values (with positive and negative points representing the two different conductors). Using his knowledge of game theory, he created the matrix is such a way that it would be statistically fair to both competitors. The symbols on the outside of the matrix represent the available timbre groups for each conductor, and the score can be found in the cell that represents the timbre choices of both conductors at any given moment.

For example, if conductor Y first choose strings striking sound boxes (represented by an "H"), and conductor X countered with woodwinds (a triangle) the score (84 points) is found in the third cell from the left on the top row of the matrix. Conductor Y would then be free to select another tactic, perhaps they would choose "strings sustained", which would score them 52 points (represented in the matrix as the sixth cell on the top row, the value "-52" represents a loss to conductor X; the use of negative and positive point values mandates only one score be kept, (if the final result is positive, conductor X wins, if negative, composer Y is the victor.))



	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	XIII	XIV	XV	XVI	XVII	XVIII	XIX	
I	116	10	84	-48	4	-52	-60	-40	132	-44	-8	-36	-22	24	-46	102	138	-38	32	2
II	-56	96	-44	-22	-24	52	-50	-14	12	28	6	-48	-20	-16	-10	-24	-36	-20	44	3
III	-110	-2	96	96	24	0	4	-56	-32	-24	4	-52	-48	-40	-16	-44	-16	20	72	1
IV	0	-20	24	84	4	-12	12	-12	-28	8	-8	-24	-40	4	22	-10	-16	28	-16	11
V	-110	-204	-86	4	104	-8	44	20	-8	4	8	-8	-38	-24	-16	40	8	20	-24	1
VI	24	44	12	-14	-6	64	24	-8	24	4	-24	-40	-52	-44	24	44	4	4	-48	7
VII	-56	-52	20	16	36	44	44	4	-52	-48	0	-46	-36	-12	-20	-40	-44	16	40	4
VIII	-32	-8	-52	-8	12	4	4	48	-44	-12	8	-52	-4	8	32	-36	-40	-16	24	3
IX	-36	10	-16	-32	2	4	-44	-52	52	44	2	48	-18	64	24	22	-36	-28	-52	6
X	-48	22	-22	4	-4	32	-46	-16	8	-36	-24	-4	8	32	24	4	-8	20	-32	4
XI	4	24	26	-4	4	-28	-36	-12	20	4	64	68	4	40	-12	-2	-24	-27	-32	10
XII	-36	-196	-188	-28	-34	-42	36	32	24	0	-32	74	76	-4	4	-32	-28	40	76	7
XIII	166	-20	-42	-40	-52	-44	14	-16	4	22	-14	80	72	-26	-58	40	-18	78	42	2
XIV	32	-14	-34	0	-32	-52	36	12	-12	36	24	-28	42	76	-48	-64	-30	-29	72	5
XV	-20	8	4	28	-28	14	0	20	2	-4	-32	14	26	-56	46	-36	12	-8	14	4
XVI	88	88	104	-28	20	16	-2	-16	20	-20	-50	-26	-8	-36	-40	108	-24	-33	60	9
XVII	32	92	52	-28	16	8	-44	-48	-32	0	-16	-16	-20	-32	24	-30	96	52	-36	8
XVIII	-36	-24	8	4	0	-2	52	78	-12	-4	36	-8	28	-24	-16	-14	42	-12	-40	9
XIX	-52	-52	-66	4	6	-6	-4	44	-66	-4	44	12	44	40	16	-46	44	-42	-32	4
	1	1	2	3	7	11	3	3	4	6	9	2	5	7	10	4	4	8	10	100

Figure 3 - Game Matrix for *Strategie*

When performed, the conductors of each orchestra duel each other, trying to score the most points over a set number of turns or time. Xenakis notes there are various ways to execute the rules, and highly suggests that the conductors not pre-plan the route they will take, and let the performance have the atmosphere of a spectator sport. The strategy called for is in fact very complex, as in chess, as what seems like a good move at the moment may lead to one's opponent scoring more in the long run. So the conductors must think much ahead of time, projecting what each other may do and having contingency plans.

As a piece of music, Xenakis has not overtly determined the form. But he has made certain timbral combinations more likely to occur. This is another, very subtle application of stochastics. Competition, largely unheard of within a musical composition, could potentially add a lot of excitement to the concert. To play to this unique atmosphere, he suggested that the victor be given some kind of prize…… "a prize, bouquet of flowers, cup, or medal whatever the concert impresario might care to donate." Perhaps the element of competition would drive up orchestral ticket sales (after all, how many people would pay to see Larry Johnson score touchdowns if no one was trying to stop him?)

1991 – Gendy3, Dynamic Stochastic Synthesis

Furthering the premise of Achorripsis and the ST pieces, he wrote a computer program that would stochastically produce a sound file that stood alone as a piece of electronic music. The program was named Gendy, a word compounded from 'GENeration DYnamics'. The major innovation of this piece Xenakis called "dynamic stochastic synthesis". This was a method to vary stochastically chosen polar coordinates (as plotted time vs. amplitude) of a waveform from one occurrence to the next, allowing the sounds to grow and evolve based on chance. As in previous stochastically conceived pieces, he used a number of voices, happening simultaneously, and their relative density throughout the piece generates the formal structure. In Gendy3 he used 16 voices, each with a unique starting timbre.

So in this final inception of the stochastic, density-driven architecture, the sounds themselves are given a larger degree of autonomy. Whereas in *Pithoprakta*, the sounds are at first conceived and then their components calculated, in Gendy3 the sounds are free to evolve as probability will have it.

The evolution in stochastic form in the music of Xenakis is presented below.

Work	**Formal organization**	**Creation of individual sound events**
Metastasis	Juxtaposition	Intuitive
Pithoprakta	Advanced Juxtaposition	Calculated
Achorripsis	Probable Density	Calculated
ST – pieces	Probable Density	Computed
Gendy3	Probable Density	Computed
Duel, Strategie	Stochastic indeterminacy	Looped sound grains

CONCLUSION

Xenakis' use of stochastic theory to create form lies in the formalization of density relationships between timbre groups within a composition. There are doubtless many more ways a formal structure could be realized using chance, and many composers have done so. James Tenney's 1963 "Stochastic String Quartet" created form as multiple divisions of the whole into sections and sub sections, and all the way down the individual gesture. Herbert Brun's 1964 *Soniferous Loops,* took a much more linear approach. Form was not given a lot of forethought; rather the piece consists of a succession of computer-calculated events.

Xenakis' work is exceptional in that its probability driven is more than just a collection of events that happen in an unimportant order. "Probable density" is a unifying concept comparable to a tonal center in that it provides the music a context for existing. The success of the listener's ability to grasp that form is not directly relevant to the value of the formal innovation. (Just as a listener's ability to identify formally important moments in a sonata form is not required for those moments to be in fact formally important.)

Christopher Butchers suggests that "The laws of abstract logic, because universally valid for all mental operations, can form a true axiomatic basis for a universally acceptable musical common language".[18] Far from using math to abstract music from the human experience, Xenakis' oeuvre points to a music that draws its material from the human experience itself. He rejected creating music *about* life, but rather created sounds that followed the complicated model of life itself encapsulated in mathematical models.

Xenakis' innovative approach to the formalization of music will doubtless lead to much future collaboration between math and music in the minds of young composers. He worked as a scientist, breaking down music into its smallest molecules and examining how those molecules fit together in meaningful ways, forming vastly complicated mathematical

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[18] Christopher Butchers, "The Random Arts: Xenakis, Mathematics and Music," *Tempo*, no. 85 (1968): 3.

models to aid and inform his efforts to compose music that served to catalyze the experience of the sublime. Certainly many scientists are yet to come to further the Pythagorean preposition that gave birth at once to math and music:

There is geometry in the humming of the strings; there is music in the spacing of the spheres.

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