The Use of Stochastic Distributions in the Instrumental Works of Iannis Xenakis: Between Chance and Intuition[1]

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Abstract

Relying on various examples, some of which inspired by documents or sketches found in the composer's archives, this presentation explores how Xenakis incorporates and deals with the results of his stochastic distributions in his instrumental works, discussing the degree of freedom implicit in his compositional choices. It focusses on examples taken from works where the stochastic distributions were calculated by different means: *Achorripsis* (1956-57) for chamber orchestra, *Morsima-Amorsima* (1962) for violin, violoncello double bass and piano, and *Mists* (1980) for solo piano. In *Achorripsis*, the stochastic distributions of durations and intervals were calculated by hand and expressed as tables of numbers. They appear as outside-time proportions. This is probably why Xenakis felt the need to represent them linearly, inside-time, as classes of durations and intervals as an intermediate stage in the compositional process. He then had to choose, intuitively, the intervals and durations in order to arrange them in lexicographic time. Later, at the beginning of the 60s, Xenakis designed a computer program (*ST*) that implemented the theories and ideas he had developed for *Achorripsis*. The *ST* program generates lists of data where each line corresponds to the definition of an individual note. The moment of occurrence and the pitch of each note are determined. But the program does not always take into account all the necessary parameters for the final results to be playable on the instruments. And the higher the density of the sound events, the more adjustments is needed. This is shown in *Morsima-Amorsima* by comparing the provisional results of the stochastic distributions with the final score. Finally, at the beginning of the 70s, Xenakis introduced probability theory in the field of sound synthesis when he suggested that the sound pressure be based on probability distributions. These new proposals also had an impact on his instrumental works. In *Mists*, he programmed a pocket calculator to obtain similar stochastic distributions where the occurrence and the pitch of each note were calculated separately. The input data were then modified to generate series of clouds of different densities. But the results were also altered by hand to fit different transpositions of the main sieve of the work. Whether he did his calculation by hand or resorted to technological means, Xenakis always seems to leave a gap between the output of his calculations and the traditional score. A gap that is filled manually. In the end, the composer decides, guided by his own intuition, which elements to assemble.

1. Free Stochastic Music

Iannis Xenakis is well known for having used mathematical models in his compositions. His first reference to probability theory dates from the 50s. And in his work *Pithoprakta* (1956-57) for orchestra, he already conceived masses of sounds where various musical parameters could be

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organised following different laws of probability. But it is in his next piece that he fully developed the ideas he had explored in *Pithoprakta*.

Achorripsis

Achorripsis (1957) is scored for 21 instruments and relies on the stochastic distribution of seven sonic events, each one associated with a group of instruments or their playing techniques: 1. flute (clarinet and bass clarinet), 2. oboe (bassoon and contrabassoon), 3. string glissando, 4. percussion, 5. pizzicato, 6. brass, 7. string arco. We know from his book *Formalized Music* that Xenakis (1992, 28-32) calculated the probability of occurrences of these sonic events using the Poisson distribution (which is the law of appearance of rare random events), and that he represented them by a matrix[2] where each line corresponds to a 'timbre' and each column to a unit of time of about 6,5 bars (Figure 1).[3]

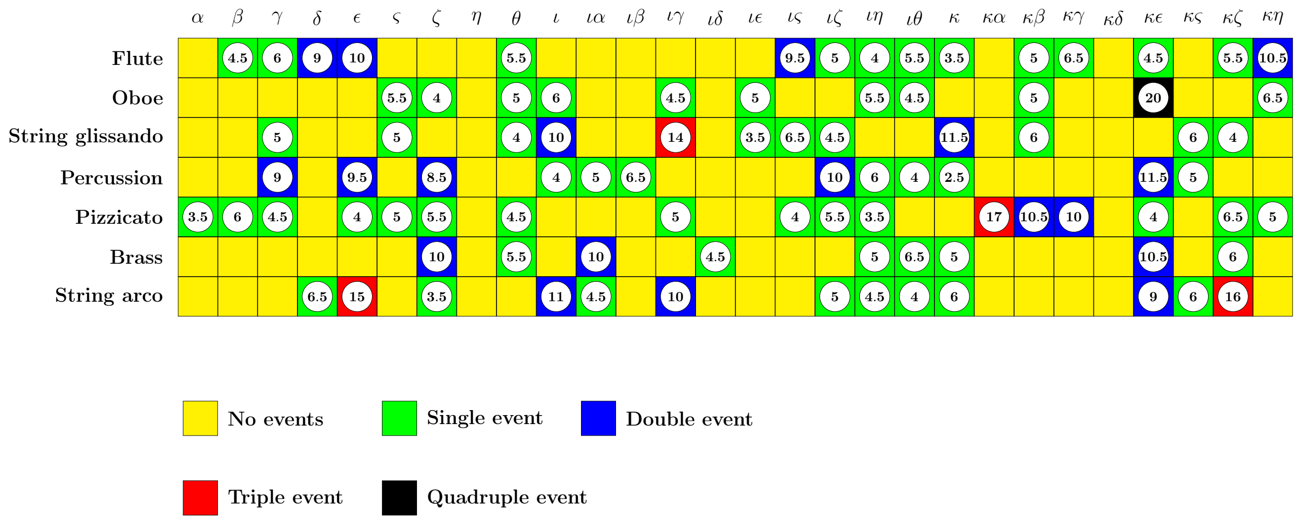

Figure 1: Matrix of Achorripsis.

To illustrate how Xenakis deals with the results of his stochastic distributions in *Achorripsis*, we shall analyse a column that contains only one sonic event: column number 14 (ιδ).[4] It represents the sounds of the sonic event 'Brass,' which includes two trumpets and a trombone. Its density is 4,5 sounds per bar, so it comprises 29 points (4,5 sounds times 6,5 bars).

Time

For Xenakis (1992, p. 12), "The following formula, which derives from the principles of continuous probability, gives the probabilities for all possible lengths when one knows the mean number of points placed at random on a straight line, in which δ is the linear density of points, and x the length of any segment."

$$\mathrm{P_x} = \delta \mathrm{e}^{-\delta \mathrm{x}} dx \qquad \delta = 4,5$$

From the law formulated above, it is possible to create a table of durations for any sonic event, provided that its linear density is known. Here, the values of x are grouped by class: $x = 0$ means that x is included between 0 and 1 ($0 < x \leq 1$) tenth of a bar.[5] Table 1 reproduces the data that Xenakis notated in his notebook.[6]

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[2] The matrix shown in Figure 1 is based on the one reproduced in Mâche (2001, 55-56) but includes minor adjustments drawn from documents found in the Xenakis Archives and catalogued as Œuvres Musicales [OM] 3-12.
[3] Linda Arsenault (2002) provides further details on how the matrix was calculated.
[4] In the matrix, Xenakis numbers the columns using an ancient Greek alphabetic numeral system.
[5] It should be noted that, in *Achorripsis*, the values of x vary according to the density of the sonic event.
[6] The data are reproduced as they appear in Xenakis' Notebook 18 [Carnet 18, p. 008]. They contain some deviations.

Table 1: Table of durations for Achorripsis*, brass instruments, bars 84-91 (ιδ)*

x	δx	$e^{\delta x}$	$\delta e^{\delta x}$	$\delta e^{\delta x} dx$	· 28
0	0,00	1,000	4,5000	0,362	10
0,10	0,45	0,638	2,8700	0,231	7
0,20	0,90	0,407	1,8300	0,148	4
0,30	1,35	0,259	1,1650	0,094	3
0,40	1,80	0,165	0,7430	0,060	2
0,50	2,25	0,105	0,4730	0,038	1
0,60	2,70	0,067	0,3015	0,024	1
0,70	3,15	0,043	0,1935	0,016	1
[...]					
	Totals		12,4152		28
		$\delta x =$	0,0805		

Intervals

A table of intervals can be obtained the same way, using a different law (Xenakis 1992, 13):

$$\Theta(j)\ dj = \frac{2}{a}(1 - \frac{j}{a})dj \qquad a = 44$$

Figure 2 shows the probability of the interval *j* taken at random from a range *a* of 44 semitones. Here, Xenakis represents the intervals of the brass sonic event in classes (multiples) of three semitones.[7]

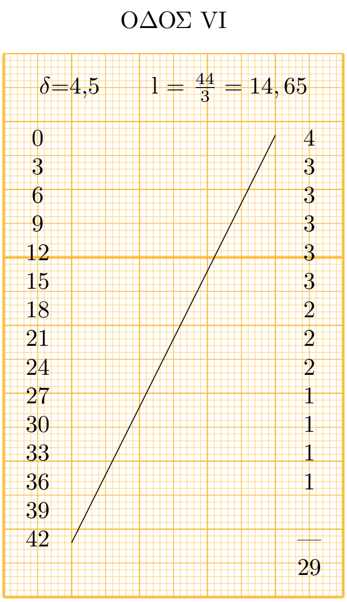

Figure 2: Table of intervals for Achorripsis*, brass instruments, bars 84-91 (ιδ).*

In Xenakis' terms, the tables that calculate the distributions of durations and intervals are outside-time. They do not prescribe any order. They must be arranged in lexicographic time. Other documents found in the composer's archives show that Xenakis represented these data linearly, inside-time, as classes of durations and intervals. In her thesis, Linda Arsenault (2000) gives an example of how Xenakis proceeded from his tables of proportions to the final score. We can illustrate this process

[7] Figure 2 is also based on a document found in the Xenakis Archives: OM 12-1, p. 035.

relying on another example.

Figure 3 is a transcription inspired by a document catalogued as OM 3-12_1-037 in the Xenakis Archives. Classes of intervals and durations are written out above and below the line respectively. The colours shown on the sketch indicate on which part of the beat the note will fall. Red represents a subdivision by 5 (quintuplets), green, by four (quavers), and blue by three (triplets). Black strikes fall on the beat. This sketch is still an intermediate stage in the process of composing *Achorripsis*. It determines the dates of departure of each sound, as they will appear in the score, but the melodic intervals are still defined as classes (multiples of 3 semitones). Furthermore, we do not know if these intervals are ascending or descending, and which instrument is going to play each note.

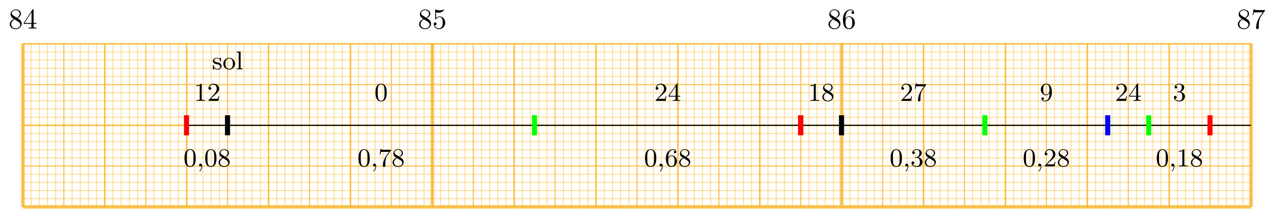

Figure 3: Sketch representing classes of intervals and durations for bars 84-86 of Achorripsis*, brass instruments.*

Other choices are made when these data are drawn on a two-dimensional plane, a Cartesian coordinate system, where the abscissas represent time and the ordinates, pitch. As he had done for *Metastaseis* (1953-54) and *Pithoprakta*, Xenakis also represented *Achorripsis* graphically, in a pitch versus time domain, before he would transcribe it into traditional notation. In Figure 4, Xenakis indicates the instruments and the intervals within each class. The numbers (3, 4, or 5) before each instrument correspond to the subdivision of the beat on which the sound falls, as did the colours in the previous example.

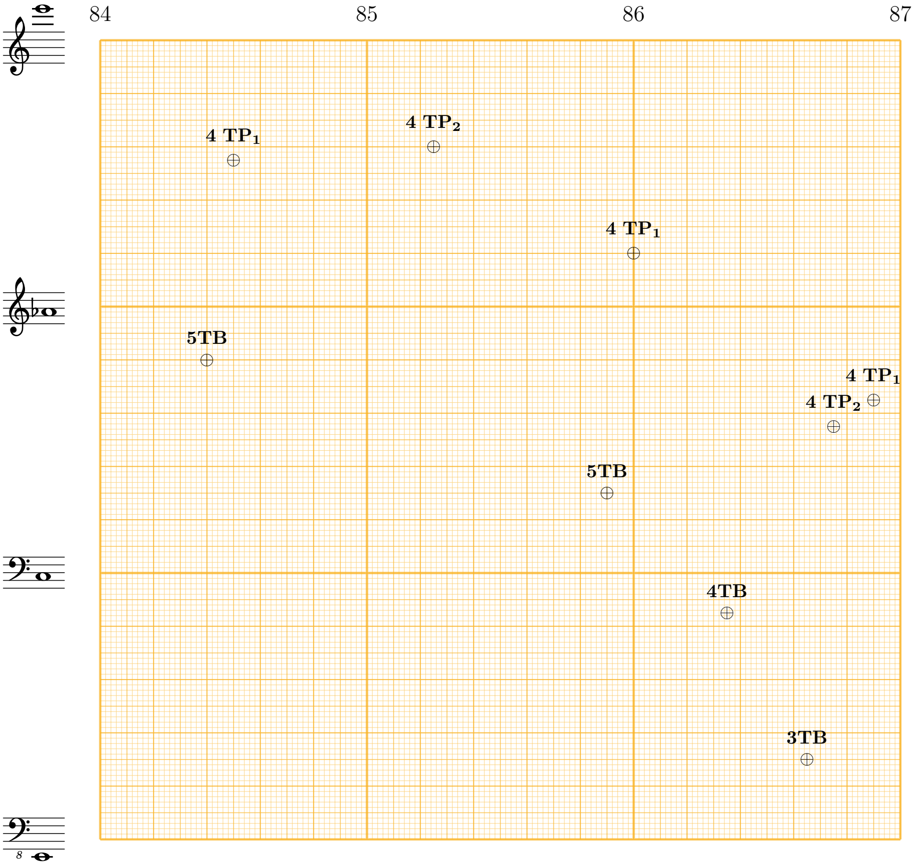

Figure 4: Graphic representation of Achorripsis*, bars 84-86.*

This is the ultimate stage before transcribing the data into traditional notation (Figure 5), where Xenakis determines the dynamics and durations of the individual notes.[8]

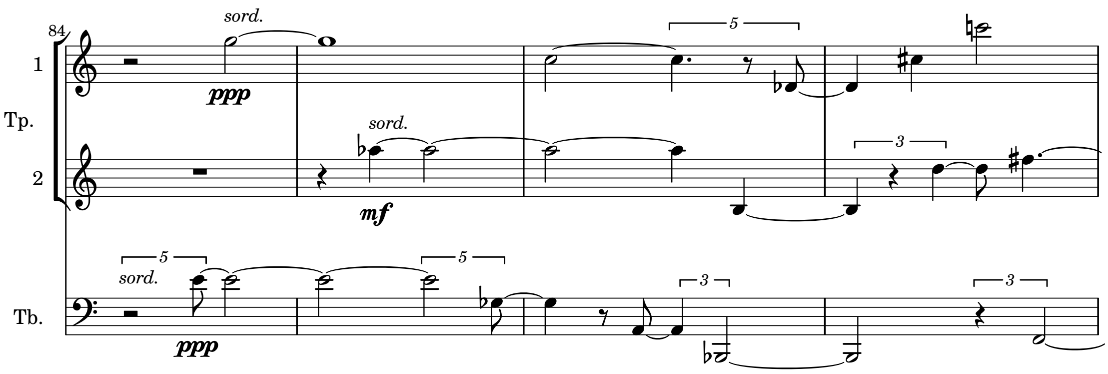

Figure 5: Excerpt from Achorripsis, bars 84-87.

The analysis of *Achorripsis* shows us the extent of the degree of liberty given to the composer. The stochastic distributions, expressed as tables of numbers, are outside-time proportions that constitute only one step of the compositional process. Each time, for each cell, Xenakis had to decide in which order to put the intervals, durations, and speeds if glissandi are involved. This is what Mikhail Malt (2005) refers to as "l'espace d'écriture." Since the matrix of *Achorripsis* comprises 10 cells with a

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[8] The published score of *Achorripsis* contains many errors or deviations regarding the manuscript (OM 3-15). Here, the first note of the trombone has been corrected to E_4.

density of 4,5 sounds per bar, Xenakis had to reordered (permuted) these values nine times. How? Émile Borel (1937), whose work Xenakis (1992, 39) cites, believed that human mind cannot imitate chance. Be it as it may, to create his stochastic clouds of sounds Xenakis must have relied heavily on his intuition, as he did in other pieces of the same period.[9]

2. Free Stochastic Music by the Computer

Xenakis is also acknowledged as being one of the pioneers in the field of computer music. At the beginning of the 60s, he designed a computer program that implemented the theories and ideas he had developed for *Achorripsis*. It took Xenakis many months of contacts before he could gain access to a computer, the IBM-7090 located at Place Vendôme in Paris. Luckily, he was granted access for free.

The stochastic computer program *ST* (which stands for stochastic) was written in the FORTRAN programming language. For Xenakis, using a computer offered many advantages. One of them was to free the composer from tedious calculations, even though, as he admitted: "It took several months to transcribe the program into language that the machine's organization could assimilate" (1992, 142). Then you only save time if you repeat the process several times, changing the input data to explore the possibilities of the program. And this is what Xenakis did. Eight of his instrumental pieces are based entirely or in part on the stochastic computer program *ST*: *ST-48* (1956-62), *ST/10* (1956-62), *ST/4* (1956-62), which is a version of *ST/10* for string quartet, *Amorsima-Morsima* (1956-62) (withdrawn from the composer's catalogue), *Morsima-Amorsima* (1956-62), *Atrées* (1956-62), *Stratégies* (1962) and *Eonta* (1964). The title or subtitle of each piece indicates the number of instruments, the version and the date when the work was calculated by the IBM-7090. The dates associated with the works suggest that Xenakis had recourse to the IBM-7090 at least five times between January and October 1962.

The output of the *ST* program generates lists of data where each line corresponds to the definition of an individual note. Examples of "provisional results of one phase of the analysis" are reproduced in Xenakis' (1992, 153) text "Free Stochastic Music from the computer." The examples provided by Xenakis for the French and English editions of *Musiques formelles* (*Formalized Music*) are not the same. But in both editions, they are followed by an excerpt from bars 1-5 of *ST-10-1, 080262*. In both cases, the "provisional results of one phase of the analysis" provided by Xenakis do not correspond to the music example that follows. But knowing the classes of timbre, the instruments, the origin, and the intensity forms, it is possible to transcribe these data into traditional musical notation.[10]

Morsima-Amorsima

The output of the *ST* program for *Morsima-Amorsima*,[11] like the one reproduced in *Formalized Music*, shows sequences that take the form of a list of data where each line corresponds to the definition of an individual note (Table 2).

[9] For a good example of the dialectic between formalisation and intuition in Xenakis' music, see Agostino Di Scipio's (2005) text on *Analogique A et B*.

[10] André Baltensperger (1996, 634) gives detailed examples of how to transcribe these data into musical notation.

[11] The data for *Morsima-Amorsima* were found in the Xenakis Archives.

Table 2: Morsima-Amorsima, *annotated provisional results produced by the* ST *program.*

JW= 1 A= 8.13 NA= 59
Q(I)= 0.32/0.05/0.13/ 0.10/ 0.10/0.05/0.15/0.10/

N	TA	CLAS	INST	H	VGL1	VGL2	VGL3	DUREE	DYNAM
1	0.	5	2 ~~1~~	34.0	-19.0	16.0	-11.0	0.92	16
2	0.02	4	3	37.6	0.	0.	0.	2.05	46
3	0.03	5	1	42.3	-4.0	2.0	-2.0	0.31	40
4	0.07	1 ~~4~~	1 ~~2~~	51.7	0.	0.	0.	0.86	4
5	0.21	5	1	52.2	28.0	-13.0	-16.0	1.21	50
6	0.37	1	1	26.7	0.0	0.	0.	1.31	63
7	0.38	1 ~~4~~	1	82.8	0.	0.	0.	0.38	16
8	0.43	1	1	50.3	0.	0.	0.	1.18	9
9	0.60	4	2	35.1	0.	0.	0.	2.10	57
10	0.64	5	1	59.4	23.0	-10.0	13.0	1.11	56
~~11~~	~~0.80~~	~~5~~	~~1~~	~~68.8~~	~~-8.0~~	~~6.0~~	~~-5.0~~	~~0.75~~	~~28~~
12	1.05	5	1	43.3	30.0	-12.0	-17.0	1.45	52
. . .									

The following abbreviations and variables apply to Table 2:

JW: Ordinal number of the sequence calculated

A: Duration of each sequence in seconds

NA: Number of sounds calculated for the sequence

Q: Probability of the classes of timbre

N: Line number

TA: Moment of occurrence of the sound within the sequence

CLAS: Class of timbre

INST: Instrument of the class (choice of instrument)

H: Pitch

VGL1, VGL2, VGL3: Glissando speed

DUREE: duration

DYNAM: Intensity form (dynamic)

CLAS 1 = piano

CLAS 2 = arco sul ponticello

CLAS 3 = harmonic

CLAS 4 = arco normal

CLAS 5 = glissando

CLAS 6 = ponticello tremolo

CLAS 7 = pizzicato

CLAS 8 = frappé col legno

INST 1 = (CLAS 1) piano

INST 1 = violin

INST 2 = cello

INST 3 = double bass

From a compositional perspective, the stochastic distributions used in *Morsima-Amorsima* differ from those of *Achorripsis*, where Xenakis had to decide intuitively the order of durations and intervals based on global proportions. Here, it is the *ST* program that determines the moment of occurrence and the pitch of each note, in decimal numbers, with two decimal places.[12] We should add that intensity forms are used freely, and that the difference between classes 2 and 6 is not always clear in the score. Also, only the first glissando speed (VGL1) is taken into consideration.

In Table 2, the first line indicates a glissando with a speed of -19 semitones per unit of time (minim) starting at the beginning of the bar and played by the violin. It has a duration of 0,92 unit of time and starts with G_4, the lowest note on the violin. Probably because the glissando prescribed by the program falls outside the range of the violin, Xenakis changed the instrument of the first line and crossed out the eleventh one. If we look closely at the provisional results for the beginning of *Morsima-Amorsima*, there are six glissandi attributed to the violin in the first bar (CLASS 5, INST 1), each with its own speed and duration. To cope with this situation, Xenakis combines two of them into a parallel ascending fifth and makes many other adjustments. In general, the higher the density, the more adjustments are needed to combine the sounds. In fact, much of what Xenakis does when he transcribes the data of the *ST* program into musical notation amounts to what Makis Solomos (1996, 112) refers to as "bricolage".

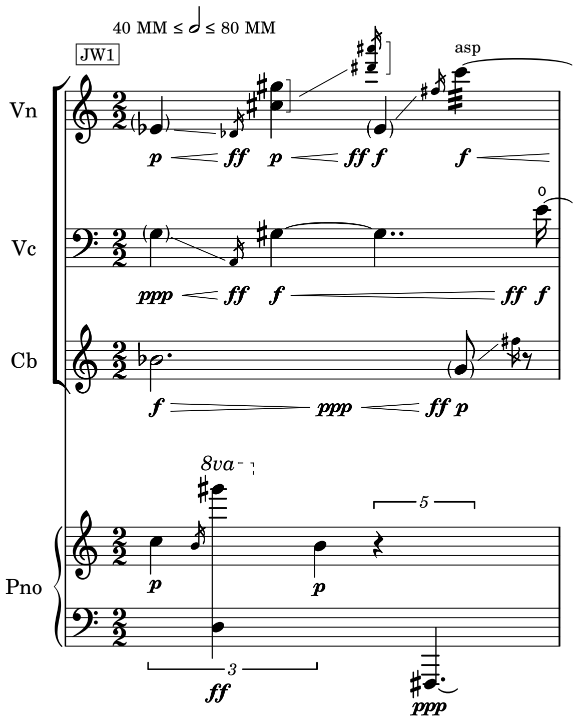

Figure 6: Morsima-Amorsima, bar 1.

Eonta

Xenakis also used sequences calculated for *Morsima-Amorsima* for the piano solo at the beginning of *Eonta*. *Eonta* was written in 1963-64 for piano, two trumpets and two trombones. Since Xenakis only uses the data for the piano part, he ignores the Class and Instrument variables. He also ignores the durations, for the music is adapted to a predefined rhythmic grid which superposes sextuplet in the right hand and quintuplet in the left (Figure 8). We're left with time abscissas (moments of

[12] The numbers that correspond to pitches are rounded off to whole numbers, not necessarily the nearest.

occurrence), pitches and simplified intensity forms. There are no crescendo or diminuendo on individual notes, but each note has its own dynamic.[13] The origin is the same, the lowest note on the piano: A_0.

The data reproduced in Table 3 indicate that the first note starts at 0 time abscissa (TA) on C_1 (rounding up 2.7 to 3). "D" means the right pedal; and Sigma (Σ), all the sounds of the piano.[14] The second line corresponds to the upper G-sharp; and the third line, to the D-sharp in the right hand, etc.

As opposed to the other *ST* pieces, in *Eonta* Xenakis represented the music graphically before writing down the score. And if we look closely at the graphic representation of the first three bars (Figure 7), we can see that it is based on the output of the program and not on the score. This can be seen from the alignment of the time abscissas.

Eonta is likely to be the last instrumental piece where Xenakis used the *ST* program. It marks the end of a period that Xenakis (1992, 182) summarized as follows: "Today these ideas [Stochastic Music] and the realizations which accompany them have been around the world and the explorations seems closed for all intents and purposes."

Table 3: Provisional results for Eonta

JW= 18 A= 78.52 NA= 1512
Q(I)= 0.54/0.05/0.10/ 0.06/ 0.04/0.04/0.09/0.07/

N	TA	CLAS	INST	H	VGL1	VGL2	VGL3	DUREE	DYNAM
1	0.	1	1	2.7	0.	0.	0.	1.52	33
2	0.12	1	1	70.5	0.	0.	0.	5.66	29
3	0.14	7	1	53.8	0.	0.	0.	0.	2
4	0.15	7	3	22.8	0.	0.	0.	0.	4
5	0.20	1	1	42.9	0.	0.	0.	6.32	0
6	0.30	1	1	63.9	0.	0.	0.	1.65	30
7	0.42	1	1	24.4	0.	0.	0.	0.	33
8	0.55	7	1	34.3	0.	0.	0.	0.	6
9	0.75	1	1	5.3	0.	0.	0.	4.74	17
10	0.82	1	1	9.1	0.	0.	0.	1.45	32
11	0.85	1	1	2.4	0.	0.	0.	3.76	61
12	0.92	1	1	21.0	0.	0.	0.	6.12	5
...									

[13] The six dynamics are approximately used.
[14] Other parts of *Eonta* rely on sets of pitches.

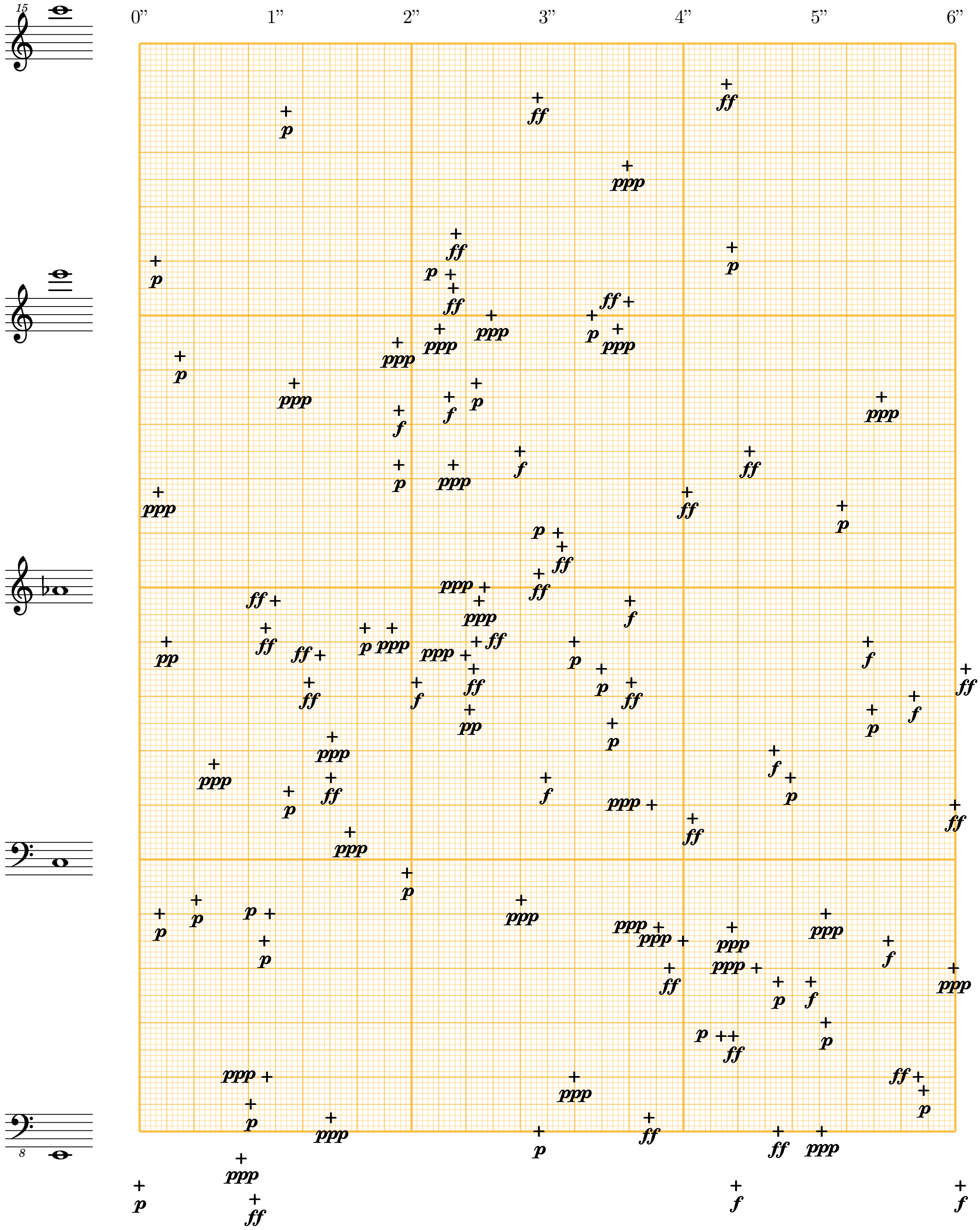

Figure 7: Graphic representation of Eonta, bars 1-3.

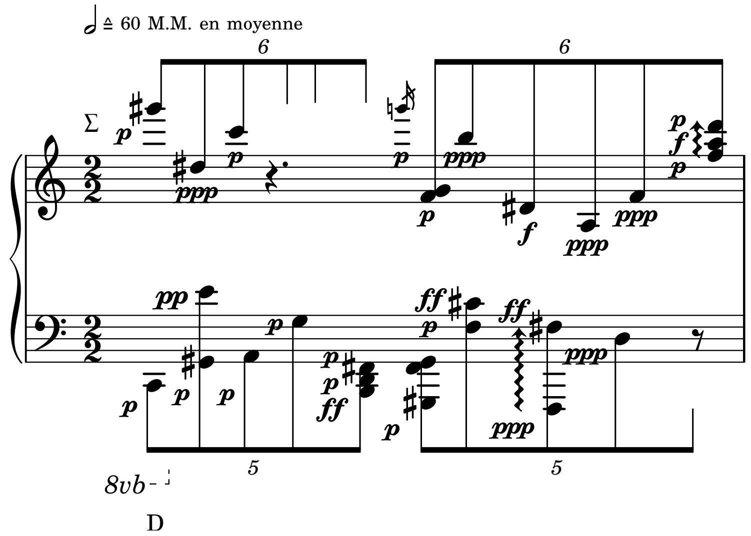

Figure 8: Eonta, bar 1.

4. New Proposals in Microsound Structure

Xenakis reintroduced probability theory in his music at the beginning of the 70s. In his article entitled “New proposals in Microsound Structure” (1992, 242-254), he suggested that the sound pressure be based on probability distributions, creating a stochastic variation of the sound pressure. These new proposals had a great impact on his compositional ideas. Some of the curves developed in the field of sound synthesis were transposed into the pitch versus time domain: “It was with the help of such graphs that I made *Mikka* and *Mikka S. Cendrées*, *N'shima* and *Phlegra* are much more complicated: here, as well as arborescences, I used curves which I call random walk or Brownian movement curves” (Varga 1996, 91).

Mists

There are other instrumental works that benefited from Xenakis’ research in the field of sound synthesis, but without relying on graphic representations. *Mists* (1980) for solo piano appears to be the first example. *Mists* features a new notational device. In many sections of the work, the performer is required to play the notes according to their exact geometric positions relative to indicating semiquaver (sixteenth note) values. According to Xenakis, this kind of approximate notation was used to facilitate the reading of the score (Varga 1989, 155). It was also conceived as a means to transcribe into traditional notation the numerical data (decimal numbers) generated by a program specially designed by Xenakis. These data were printed by a programmable pocket calculator[15] on paper rolls. The data shown in Figure 9 correspond to bar 41 of *Mists*. They represent abscissas and ordinates (moments of occurrence and pitches), and were calculated separately according to two different probability functions: exponential and Cauchy. The unit of time is the semiquaver; pitches are indicated in semitones, with A_0 as origin. The equivalent in sound synthesis would be a sound produced by Exponential x Cauchy Densities with Barriers of 43 semitones and Randomized Time.

A comparison between the data printed on these rolls and the score of *Mists* shows that Xenakis followed the moments of occurrence but changed the pitches in order that they correspond to a transposition 36 semitones up of the original sieve of the work. The data are usually rounded off to the nearest pitch of the sieve. Xenakis also modifies the input data of the stochastic distributions to generate series of clouds of different densities.[16]

In his instrumental works, Xenakis had recourse to this notational device about fifteen times, between

[15] The calculator used by Xenakis for *Mists* was a Hewlett-Packard HP 19C.
[16] For further details on the analysis of random walks in *Mists* see Squibbs (1996, 180-202).

1980 and 1987, to create stochastic clouds. And it is very likely that the values of these clouds were also produced with the aid of a similar program.

```
0.32   ***
14.    *** → 15
1.00   ***
13.    *** → 11
1.14   ***
61.    *** → 60
1.21   ***
63.    *** → 62
1.30   ***
1.     ***
6.05   ***
64.    *** → 66
7.15   ***
79.    *** → 80
7.90   ***
83.    *** → 82
11.30  ***
71.    *** → 69
13.74  ***
17.    ***
14.59  ***
40.    *** → 39
15.09  ***
22.    *** → 21
15.44  ***
22.    *** → 21
15.45  ***
17.    ***

[...]  ***
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Figure 9: Annotated output from calculator program for Mists.

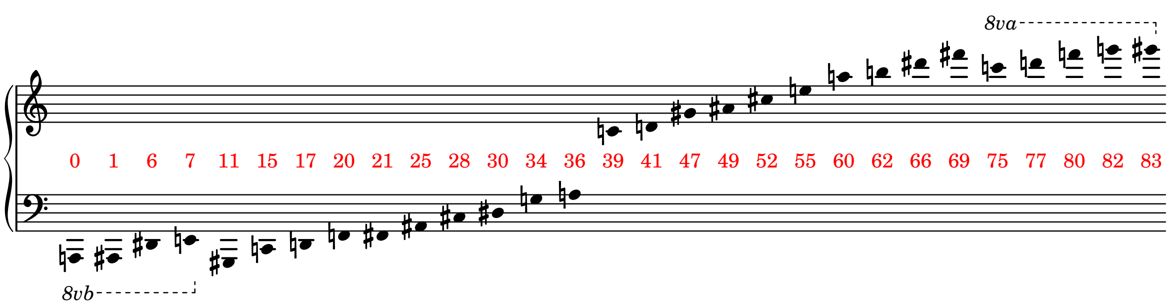

Figure 10: Sieve of Mists in *bar 41.*

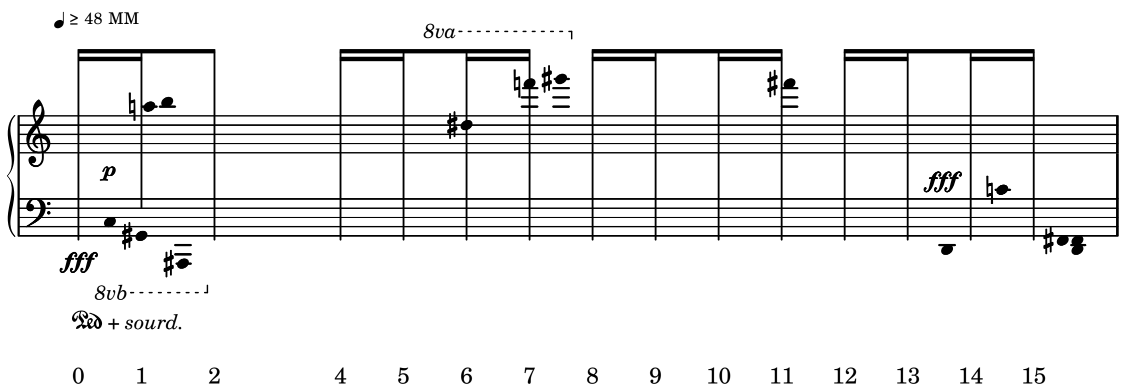

Figure 11: Mists, bar 41 with sequentially numbered semiquavers.

Final remark

With the *ST* program, Xenakis attempted to mechanise the ideas he had developed in *Achorripsis*. For that purpose, he worked with a variety of parameters: classes of timbre, instruments, moments of occurrences, pitches, durations, glissando speeds, intensity forms, etc. But from the 70s onwards, he narrowed the scope of his stochastic distributions. Those used in *Mists* apply mainly to moments of occurrence and pitches, as if Xenakis had learned from the beginning of *Eonta* that it is more practical to work with fewer variables. In fact, the distributions generated by his pocket calculators usually concern a single instrument at a time.[17] They are raw numerical data that the composer can couple with sound characteristics in various ways. That is, even then, when everything could be programmed in advance, Xenakis always seems to leave a gap between the output of his stochastic distributions and the traditional score. A gap that is filled intuitively by hand.

Acknowledgments

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[17] Instrumental works that rely in part on similar distributions include *Waarg* (1988), *Échange* (1989), *Épicycle* (1989), *Oophaa* (1989), *Okho* (1989), *Knephas* (1990) and *Tetora* (1990).

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