Silence in time continuum as a stochastic process in Iannis Xenakis's instrumental work

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Abstract: Silence acquired a functional role in the musical avant-garde dialectics during 1950-60. Until recently, the use of silence through implicit organizational procedures in Xenakis's instrumental music remained totally unknown. Nevertheless, the data in *Xenakis Archives* that are accessible nowadays permit us novel ways to contextualize silence in his work. This contextualization based on mathematical models and graphics goes beyond known research areas.
Pithoprakta (1956) is a nodal work in Xenakis's production and contemporary music as well. This work outlines the overall composition planning, which is mainly realized through Cartesian graphs. In these graphs ordinate and abscissa denote time and pitch height respectively. The partition of time continuum, that is the distribution of sound events' differential durations on the time x-axis, is governed by the probability *P*, which is computed via density δ (maximum number of events in a measure), number of time units *x* and step of displacement *dx* in the equation $P = \delta \cdot e^{-\delta x} \cdot dx$. Silence, then, is a lack of sound events that is a product of event formalization based on the probabilistic computation already discussed. Thus, there are two kinds of silence: a) rests with no required formalization that are graphically assigned to an instrumental line or to a number of lines, as in measures 45-51, and b) rests deriving from previous event formalization that are assembled in specific sets and distributed among existing events according to a new formalizing process, as in measures 16-41.
This paper shows that Xenakis did not use rests as an uncontrolled void of sound. Instead, he incorporates silence in the time flow via stochastic distribution throughout sonorities using graphic planning and formalization. The return of musicological research to formalization questions makes silence a regulating agent of the course of composition in Xenakis's works.

For the first time in history, Xenakis applied *stochastics* in music in a number of his recognized instrumental works[1], such as *Pithoprakta* (1955-56). In his theoretical texts dated around the period of composition of *Pithoprakta* as well as in his writings related to that nodal work[2], Xenakis makes no particular mention to silence, neither as a kind of structure nor as a part of time continuum. Until recently, the use of silence through implicit organizational procedures in his instrumental music remained totally unknown. Yet, the data accessible nowadays in *Archives Iannis Xenakis*[3] permit novel ways[4] to contextualize silence in his work.

I. Sonic events and stochastic computation in *Pithoprakta*

As a physical phenomenon, musical time[5] is perceived through the juxtaposition of sonic events on an imaginary straight line on which the occurrence of fortuitous events is signified by no material points. Single as well as simultaneous events are graphically represented by a point on the *time axis*. A fragment of that axis which is delimited by two consecutive points is assigned to the time elapsed between two successive events. As a result, a segment of the time axis amounts to the *differential duration* of a single sound event or to that of a number of concurrent ones.

Silence in music could be described as the lack of sonorous activity. As silence can easily be represented by a segment of the time axis, the graphic aspect of sound void is similar to that of a sound event; rests then, considered as fragments of time during which no sonorous activity is taking place, correspond to differential durations. Thus, according to Xenakis's physical and graphic conception of time flow, silence in music has to be considered as a sonic event, that is, as a kind of event in the same manner as sound events themselves.

Pithoprakta [http://drawingcenter.org/3Pithoprakta.mp3] outlines the overall composition planning, which is mainly realized through Cartesian graphs. In these graphs the ordinate and the abscissa denote time and pitch height respectively. As far as durations of sound events and of rests are concerned, we should focus on the partition of time continuum, that is, on the distribution of their differential durations on the time x-axis exclusively. It is a stochastic[6] process governed by the probability P which is computed using density δ (or number of events per measure), number of time units x, exponential constant e = 2.71828 and step of event displacement dx in the equation $P_i = \delta \cdot e^{-\delta x} \cdot dx$ [Xenakis, 1963, 26 & 1992, 12]. This very equation, called "formule radium" by Xenakis himself, rules the number of particles emitted out of a radioactive body [Gamow, 173-175][7].

Time units derive from the subdivision of a 2/2 measure in 20 uneven parts. Therefore, the term "time unit" is used by convention for computational reasons. The inequality of time unit segments derives from the superposition of three standard rhythm patterns, α, β and γ[8], which are assigned in advance to fix instrumental sets all the work through:

α = 10 quintuplet quavers,
β = 8 quavers,
γ = 6 triplet crotchets.

In Xenakis's graph paper a whole-note or a 2/2 measure is equal to 50 mm and therefore:
1 quintuplet quaver in pattern α = 1 whole-note/10 = 50mm/10 → α = 5mm
1 quaver in pattern β = 1 whole-note/8 = 50mm/8 → β = 6.25mm
1 triplet crotchet in pattern γ = 1 whole-note/6 = 50mm/6 → γ = 8.33mm
Superimposing the rhythms 20 uneven subdivisions of the measure are obtained (**Fig. 1**).

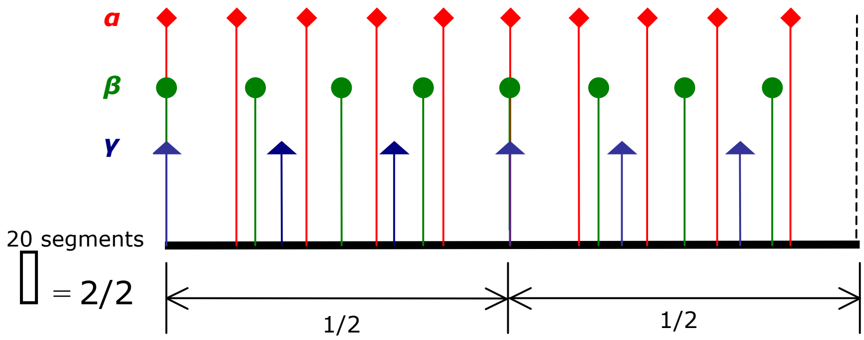

Figure 1. Rhythm patterns *α*, *β* and *γ* divide the measure in 20 uneven segments

The length of a particular time segment represents the distance between two consecutive events in millimeters, or in other words, the differential duration of the first event. Computing the durations leads to the series: | 0.1 – 0.025 – 0.042 – 0.033 – 0.05 | 0.05 – 0.033 – 0.042 – 0.025 – 0.1 || 0.1 – 0.025 – 0.042 – 0.033 – 0.05 | 0.05 – 0.033 – 0.042 – 0.025 – 0.1 | (**Fig. 2**).

𝅗𝅥: | 0.1 – 0.025 – 0.042 – 0.033 – 0.05 | 0.05 – 0.033 – 0.042 – 0.025 – 0.1 |

𝅗𝅥: | 0.1 – 0.025 – 0.042 – 0.033 – 0.05 | 0.05 – 0.033 – 0.042 – 0.025 – 0.1 |

Figure 2. Table of differential durations in a 2/2 theoretical 20 event measure

Linear density δ stands for the maximum value of n points (events) in the length l of a measure: $\delta = n/l$. Linear density, arbitrarily chosen by the composer, never exceeds 18 events per measure: $\delta \leq 18/20 \rightarrow \delta \leq 0.9$

x_i is a computation unit equal to a differential duration or to the sum of a number of adjacent differential durations. Thus, x_i represents a class of differential durations. In example: $x \leq 0.033$, $x \leq 0.033 + 0.05$ etc.

The step of computation unit displacement dx is always equal to 1: $dx = 1$, meaning that a) no matter what the unit x is equal to, no time segment can be leaped over nor ignored and b) during computation, we should make use of successive values of x_i classes, that is, proceed from x_1 to x_2, then to x_3 and so forth.

P_i is the probability of occurrence of a differential value x_i in a certain time length, that is, in a certain number of measures with predetermined linear density. Therefore, $P_1, P_2, \ldots, P_n$ provide the theoretical occurrence of the differential durations $x_1, x_2, \ldots, x_n$ within that very number of measures. As occurrences can be expressed only by whole numbers, decimal ones are rounded up or down; in example: $P_{11} = 2.31857 \approx 2$, $P_{12} = 1.52193 \approx 2$.

Since both sonorous activity (sound events) and silence (rests) constitute equivalent expressions of the time flow and since both are graphically represented by means of identical processes concerning their differential durations, their distribution should be subject to the same probabilistic computation rules. In consequence, the so called "formule radium", which governs the distribution of event points on the time x-axis, can be applied to sound events as well as to rests. Let us note that Xenakis did never make reference to the computation of rest durations; besides, no rest computation can be traced at all in his manuscripts. As a result, a differential duration in Xenakis's *graphic scores* includes both the duration of a pitched or of an unpitched sound event and of the silence that follows, when it does. A long pizzicato event[9], for instance, is heard as an instant pitch rather than as a lasting one. In that case, although the length occupied on the time axis by that pizzicato pitch may correspond to a half-note in the graphic score, it often appears as a crochet or a quaver followed by rests in the orchestral score. This practice applies to all long non continuous durations[10], such as those produced by tapping the back of the instruments, by pizzicato and by various bowing techniques[11]. The general conclusion thus reached is that rests require no previous computation. This is not the only possibility, however.

II. Organization of non formalized silence in *Pithoprakta* meas. 45-51

The overall form of *Pithoprakta* falls roughly into four parts[12]: meas. 0-51, meas. 52-121, meas. 122-207 and meas. 208-268. Long rests of 1, 2 and 3½ measures respectively detach them from each other: meas. 51, meas. 120-121, meas. 204.5-208.5. All parts are pieced together from a number of different passages, some of them shifting abruptly after a silent break: meas. 113, meas. 187-189.0, and meas. 195.5-200.0. We should also make special mention of the "risky" rests in meas. 250-268[13]. Fulfilling formal and stochastic functions, all of these rests constitute a sort of "landmarks"[14] in the course of the work.

Observing the great cluster, meas. 45-51 **(Fig. 3)**, we might wonder how the obviously well structured "depression" affecting all violins and violas has been created. Are rests in meas. 48.5-50.0[15] **(Fig. 4)** the result of a stochastic process or not?

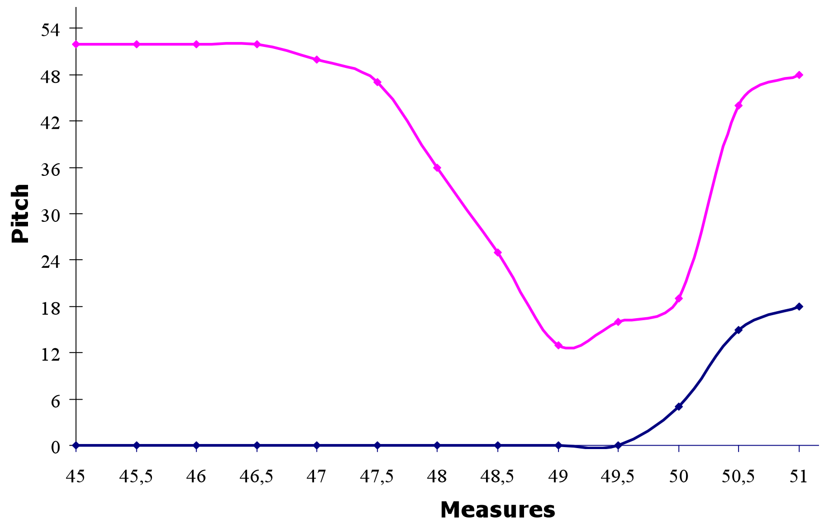

Figure 3. *Pithoprakta*, measures 45-51: rests assigned to 32 instruments in meas. 48.5-50.0

45 46 47 48 49 50 (51)

Figure 4. ***Pithoprakta*****, measures 45-50 (51). B&H 19583, p.9**

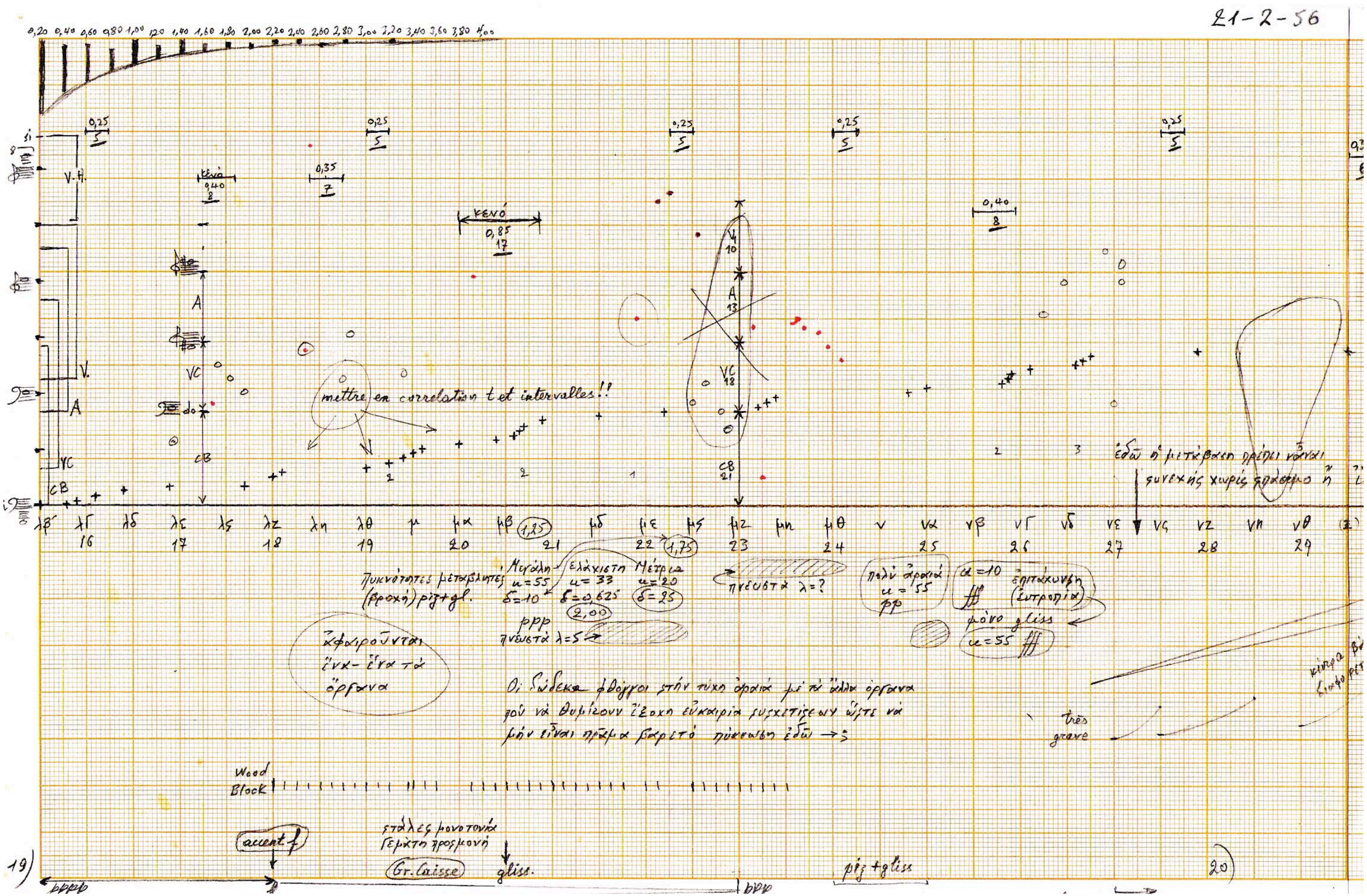

Figure 5a. ***Pithoprakta*, measures 15.5-29.5: handmade copy of fol. 19, file 1/13, Archives Iannis Xenakis**

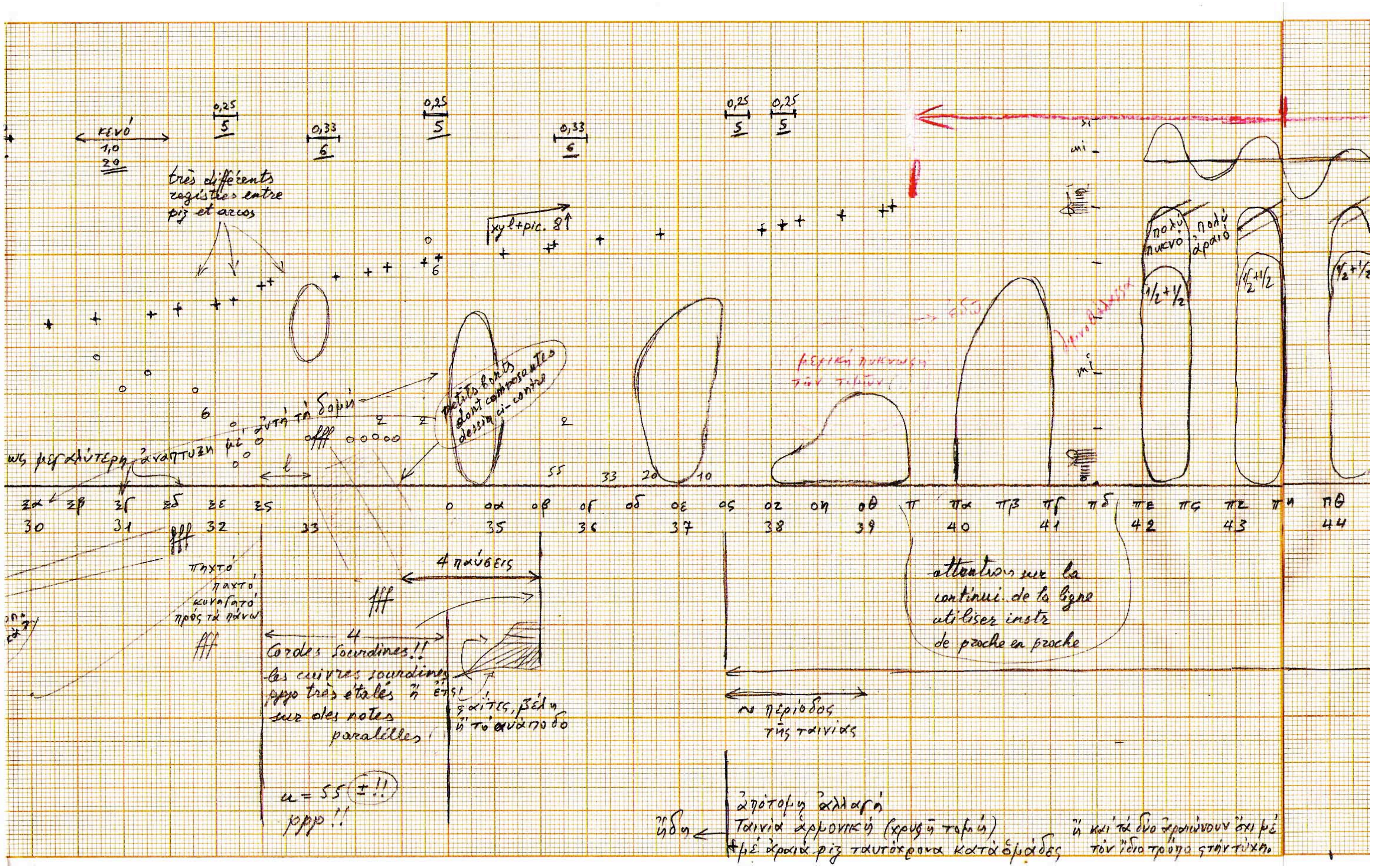

Figure 5b. *Pithoprakta*, measures 29.5-43.5: handmade copy of fol. 20, file 1/13, Archives Iannis Xenakis

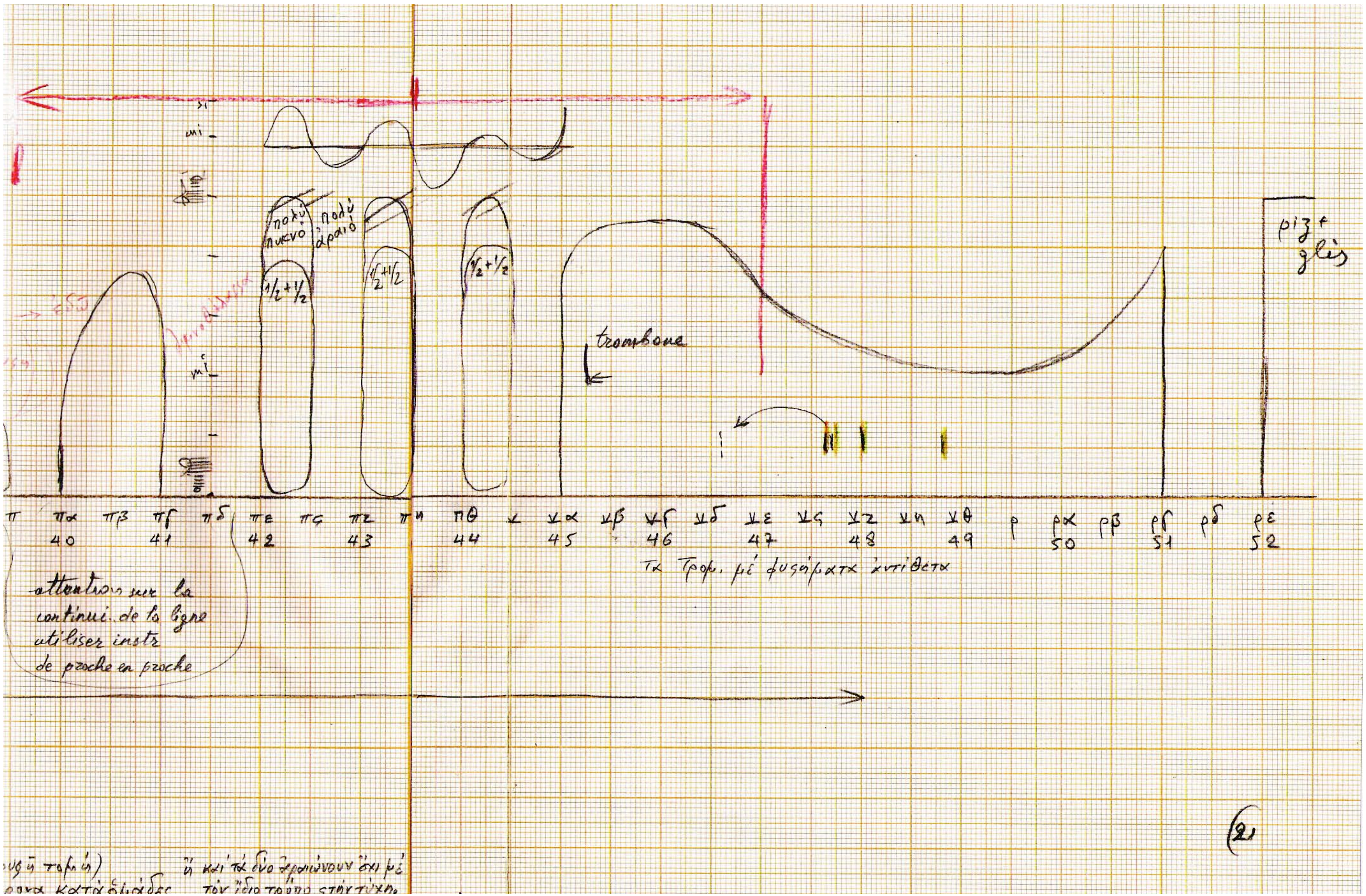

Figure 5c. *Pithoprakta*, measures 39.5-52: handmade copy of fol. 21, file 1/13, Archives Iannis Xenakis

The outline of meas. 45-51 has been conceived and designed on February 21st 1956 within the framework of meas. 16-51 **(Fig. 5a, 5b, 5c)**. Differential durations of pitched and unpitched sounds have been computed afterwards, that is on June 7th 1956[16]. The graphic score, that is, the composition of meas. 45-51, consisting in the final assignment of pitches and of differential durations to the instruments, has been completed on June 10th 1956[17].

Due to the tight connection of computational and graphic procedures, the distribution of rests within an instrumental line is a derivative of the attribution of durations to pitches. What is meant here is that a considerably long duration might be split into a much shorter one plus a rest without telling on the whole distribution. By graphically assigning a number of rests to the same point of each melodic line of an instrumental group, massive silence can be obtained, as in meas. 48.5-50.0.

To summarize, massive silence implies a) the probabilistic distribution of differential durations, namely stochastics, b) the arbitrary split of long durations into shorter ones plus rests ready to be used where needed and c) the assignment of these rests to graphically predetermined instrumental groups, which is purely an aesthetic choice in compatibility with the pointillist[18] style of the entire segment meas. 16-51. Technically speaking, the stochastic part of the subject is analyzed by means of the following operations:

1. Construction of the probabilistic table that provides the theoretically expected numbers of arco pitched events in meas. 16-50[19] (35 measures), with density $\delta = 0.9$: $P_{(35 \cdot 20)} = P_{700} \rightarrow x_1 = 256$, $x_2 = 104$, $x_3 = 42$, $x_4 = 17$, $x_5 = 7$, $x_6 = 3$, $x_7 = 1 \rightarrow \Sigma$: 430. **(Fig. 6)**

x	δx	$e^{-\delta x}$	$\delta \cdot e^{-\delta x}$	**$P_i \cdot 700$**	
1	0.9	0.4065	0.3659	256.1389	**256**
2	1.8	0.1652	0.1487	104.1383	**104**
3	2.7	0.0672	0.0672	42.3394	**42**
4	3.6	0.0273	0.0245	17.2139	**17**
5	4.5	0.0111	0.0099	6.99866	**7**
6	5.4	0.0045	0.0040	2.84544	**3**
7	6.3	0.0018	0.0016	1.15687	**1**
8	7.2	0.00074	0.0006	0.47034	–
				Σ :	430

Figure 6. Probabilistic distribution of expected arco events in *Pithoprakta*, meas. 16-50

2. All 368 differential pitch durations appearing in section meas. 16-50 **(Fig. 7)** are classified according to x_i classes of the theoretical distribution.

Meas.	**Differential durations of arco events**	Σ :
16	1·0.933	1
17	1·0.4 / 1·0.4	2
18	1·0.112/ 2·(<0.05)/ 2·0.05/ 3·(<0.05)/ 2·0.1/ 3·(<0.05)/ 2·0.05/ 3·(<0.05)/ 1·0.1	19
19	1·2.5	1
20	–	0
21	1·0.1 / 3·(<0.05) / 2·0.05 / 3·(<0.05) / 1·0.1	10
22	1·0.666 / 1·0.0833 / 1·0.75	3
23	1·0.1 / 3·(<0.05) / 2·0.05 / 3·(<0.05) / 1·0.1	10
24	1·0.1/ 3·(<0.05)/ 2·0.05/ 3·(<0.05)/ 2·0.1/ 3·(<0.05)/ 2·0.05/ 1·(<0.05)/ 1·1.366	18
25	–	0
26	1·0.133 / 1·0.066 / 2·0.2 / 1·1.4	5
27	–	0
28	2·0.05 / 3·(<0.05) / 2·0.1 / 3·(<0.05) / 2·0.05 / 3·(<0.05) / 1·0.1	16
29	1·0.1 / 3·(<0.05) / 2·0.05 / 3·(<0.05)/ 1·3.0	10
30	–	0
31	–	0
32	1·0.1 / 1·0.166 / 1·0.0833 / 1·0.05 / 3·(<0.05) / 1·0.1	8
33	1·0.1 / 3·(<0.05) / 4·0.2	8
34	1·0.2 / 1·0.3 / 1·0.1 / 3·(<0.05) / 2·0.05 / 3·(<0.05) / 1·0.1	12
35	1·1.5	1

36	1·0.1 / 3·(<0.05) / 2·0.05 / 3·(<0.05) / 1·0.1	10
37	1·0.1 / 3·(<0.05) / 2·0.05 / 3·(<0.05) / 1·0.1 / 1·0.3 / 2·0.1	13
38	1·0.1/ 3·(<0.05)/ 2·0.05/ 3·(<0.05)/ 2·0.1/ 3·(<0.05)/ 2·0.05/ 3·(<0.05)/ 1·0.1	20
39	1·0.1 / 3·(<0.05) / 2·0.05 / 3·(<0.05) / 1·0.1 / 1·0.5	11
40	1·0.1/ 3·(<0.05)/ 2·0.05/ 3·(<0.05)/ 2·0.1/ 3·(<0.05)/ 2·0.05/ 3·(<0.05)/ 1·0.1	20
41	1·0.1 / 3·(<0.05) / 2·0.05 / 3·(<0.05) / 6·0.1	15
42	1·0.1 / 3·(<0.05) / 2·0.05 / 3·(<0.05) / 1·0.1 / 4·0.1125	14
43	1·0.1 / 3·(<0.05) / 2·0.05 / 3·(<0.05) / 2·0.1 / 3·(<0.05) / 3·0.1	17
44	2·0.1 / 2·0.05 / 3·(<0.05) / 1·0.35 / 1·0.05 / 1·0.075 / 1·(<0.05) / 1·0.1	12
45	1·0.1 / 3·(<0.05) / 2·0.05 / 3·(<0.05) / 2·0.1 / 3·(<0.05) / 2·0.05 / 3·(<0.05) / 1·0.1	20
46	1·0.1/1·(<0.05)/1·0.075/2·0.05/3·(<0.05)/2·0.1/ 3·(<0.05)/ 2·0.05/ 3·(<0.05)/1·0.1	19
47	1·0.666/1·(<0.05)/ 2·0.05/ 3·(<0.05)/ 2·0.1/ 3·(<0.05)/ 2·0.05/ 3·(<0.05)/ 1·0.1	18
48	2·0.1 / 2·0.05 / 3·(<0.05) / 2·0.1 / 3·(<0.05) / 2·0.05 / 3·(<0.05) / 1·0.1	18
49	1·0.112/ 1·0.075/ 2·0.05/ 3·(<0.05)/ 2·0.1/ 3·(<0.05)/ 2·0.05/ 3·(<0.05)/ 1·0.1	18
50	1·0.166/ 1·(<0.05) / 2·0.05/ 3·(<0.05) / 2·0.1/ 3·(<0.05) / 2·0.05/ 3·(<0.05) / 1·0.1	18
51	1·0.1	1
	Σ:	**368**

Figure 7. Table of differential durations of effective arco events in *Pithoprakta*, meas. 16-51

3. Classified events are compared to the 430 theoretically expected events **(Fig. 8)**:

Differential durations	**Occurrence**	**P_i·700**	**x**
3.0	**1**	**1**	**7**
2.5 – 1.4	**3**	**3**	**6**
1.366 – 0.35	**7**	**7**	**5**
0.3 – 0.112	**21**	17	**4**
		42	**3**
0.1 – 0.075	**80**	104	**2**
<0.05 – 0.066	**256**	**256**	**1**
Σ :	368	430	

Figure 8. Table of effective and theoretical arco events in *Pithoprakta*, meas. 16-50

We should keep in mind that not all of the expected events are to be used in practice: the number of effective values can be equal or inferior to the number of theoretical values. But if an effective value is exceeding its corresponding theoretical one, the whole operation has to be revised.

Long events are rare (low probability): x_5 = 1.366 – 0.35 occurs 7 times, x_6 = 2.5 – 1.4 occurs 3 times and x_7 = 3.0 occurs only 1 time. Linear event rarity is not equivalent to score effective rarity, because a number of simultaneous long arco events projected on the time x-axis will be registered as a single differential value. Considering that long linear events can easily be transformed into much shorter ones followed by relatively long or very long rests and tracking inversely our previous steps, we can produce a multimeasure rest affecting larger instrumental groups. A differential duration x = 2.5, for instance, is equal to 2.5 measures or to five half-notes. The selected linear duration, then, can be split into an arco half-note pitch plus a double whole-note rest which will next be assigned to a certain number of instruments sharing the same rhythmic pattern. This is exactly the case of meas. 48.5-50.0, included in section meas. 45-51. Rests here are assigned to the entire body of violins and violas following aesthetic choices and graphic criteria rather than strict formalization principles.

III. Formalized silence in *Pithoprakta* meas. 15-44: "empty durations"

The upper side of the document fol. 19-21 in File 1/13 **(Fig. 5a, 5b, 5c)** provides intriguing information: 17 short horizontal lines coupled with small numbers, all multiples of 0.05, are dispersed in disorder from meas. 16 through meas. 38. The 11th short line, in particular, is longer than the others and is followed by "void" in Greek ("κενὸ"). This indication, combined with the out of pitch-range positioning of the ensemble, made us think that a special kind of durations is here concerned. Consultation of the eventual graphic score, fol. 60-65 in File 1/13, unveiled one more short line in meas. 41. Comparing available graphic data with the orchestral score, we came to the conclusion that all of the short lines in question represent rests. Their durations are multiples of time unit t = 0.05[20] **(Fig. 9)**.

Number of time units	5·0.05	6·0.05	7·0.05	8·0.05	16·0.05	18·0.05	
Durations of rests	0.25 / 0.26	0.30 / 0.33	0.35	0.40 / 0.41	0.80	0.90	
Occurrences	10	3	1	2	1	1	Σ : 18

Figure 9. Rest durations expressed in time units and their occurrences in *Pithoprakta*, meas. 16-41

Graded by size, rest durations can be classified in three classes: [0.25-0.26]-[0.30-0.33-0.35-0.40]-[0.41-0.80-0.90]. 1st class durations occur 10 times, members of the 2nd class occur 5 times and those of the 3rd occur 3 times, namely a series: 10-5-3 **(Fig. 10)**.

Durations of rests	Occurrences	
8·0.25 / 2·0.26	8+2	**10**
0.30 / 2·0.33 / 0.35 / 0.40	1+2+1	**5**
0.41 / 0.80 / 0.90	1+1+1	**3**
	Σ :	**18**

Figure 10. Table of classified rest durations and of their occurrences in *Pithoprakta*, meas. 16-41

Assuming that the occurrence series 10-5-3 is part of a possible probabilistic distribution P_i, need is to define the linear density $\delta = n/l$, whereas $n = 18$ events (rests). The time segment l in which the events in question might occur contains 30 measures, meas. 15-44; thus, $l = 30$. In this case, however, we have to accept a new computation unit, the whole measure[21]. This is quite reasonable, because usual computation units, namely the 20 available subdivisions of the measure, would lead to a deadlock due to overlapping probabilities. In other words, it is impossible to have a second distribution of events up on an already existing one using the same units. By "already existing distribution" we mean the distribution of timely events that require primary computation, such as the taps on the body of the instruments and the pitch durations. Once these events have definitely taken their place on the time axis, no other distribution can be realized using the same parameters. Therefore, $P_i = P_{(30\cdot 1)}$. New linear density $\delta = n/l = 18/30 \rightarrow \delta = 0.6$ provides the following series of occurrence of the classes mentioned above: 10-5-3-2-1 **(Fig. 11)**:

x	δx	$e^{-\delta x}$	$\delta \cdot e^{-\delta x}$	**$P_i \cdot 30$**	
1	0.6	0.548812	0.329287	9.878609	**10**
2	1.2	0.301194	0.180717	5.421496	**5**
3	1.8	0.165299	0.099179	2.97538	**3**
4	2.4	0.090718	0.054431	1.632923	**2**
5	3.0	0.049787	0.029872	0.896167	**1**
6	3.6	0.027324	0.016394	0.491827	–
7	4.2	0.014996	0.008997	0.26992	–
8	4.8	0.00823	0.004938	0.148135	–
9	5.4	0.004517	0.00271	0.081298	–
10	6.0	0.002479	0.001487	0.044618	–
				Σ :	**21**

Figure 11. Probabilistic distribution of rests in *Pithoprakta*, meas. 15-44

Effective series 10-5-3 is then a subset of the theoretical series 10-5-3-2-1, as amongst 21 probable "empties" only 18 have been used. So, although he makes no mention of this process at all, Xenakis has indeed distributed silence according to a stochastic process.

IV. Formal impact and stylistic significance of silence distribution

However, there is a crucial issue pending: why did Xenakis bring in such an intricate technique? Is there any pre-existing criterion dictating rest positioning? This question applies also to the striking massive silence affecting the whole orchestra in the middle of meas. 44 **(Fig. 5c)**. Taking into account that meas. 44 is an important formal point, after which a new section (meas.45-51) together with a new sonority[22] begins, we might wonder again if rests are scheduled following a pre-established plan.

A very interesting hand note at the left bottom of graph paper fol. 20 in File 1/13 already mentioned **(Fig. 5b)** gives a hint, in Greek, about the use of the golden mean[23]. This notice is neither further commented by the author nor any sign of calculation relative to that matter is present in his manuscripts. Our investigation, however, revealed that the form of the first part of *Pithoprakta*, meas. 0-51, is entirely governed by the Golden Mean[24] with bilateral expansion from the starting point meas. 43.5. Using half-note unit,

First segmentation level divides the first part of the work, meas. O-51, in three sections: meas. 0.0-15.0 – meas. 15.5-43.5 – meas. 44.0-51.0.

Secondary segmentation splits the second section, meas. 15.5-43.5, into three segments: meas. 15.5-20.0 – meas. 20.5-30.0 – meas. 30.5-43.5.

Tertiary segmentation divides a) the first section meas. 0.0-15.0 in two segments: meas. 0.0-13.5 – meas. 14.0-15.0, b) the second level segment meas. 30.5-43.5 into three sub-segments: meas. 30.5-34.0 – meas. 34.5-37.0 – meas. 37.5-43.5 and c) the third section meas. 44.0-51.0 in two segments meas. 44.0-47.5 – meas. 48.0-51.0 **(Fig. 12)**.

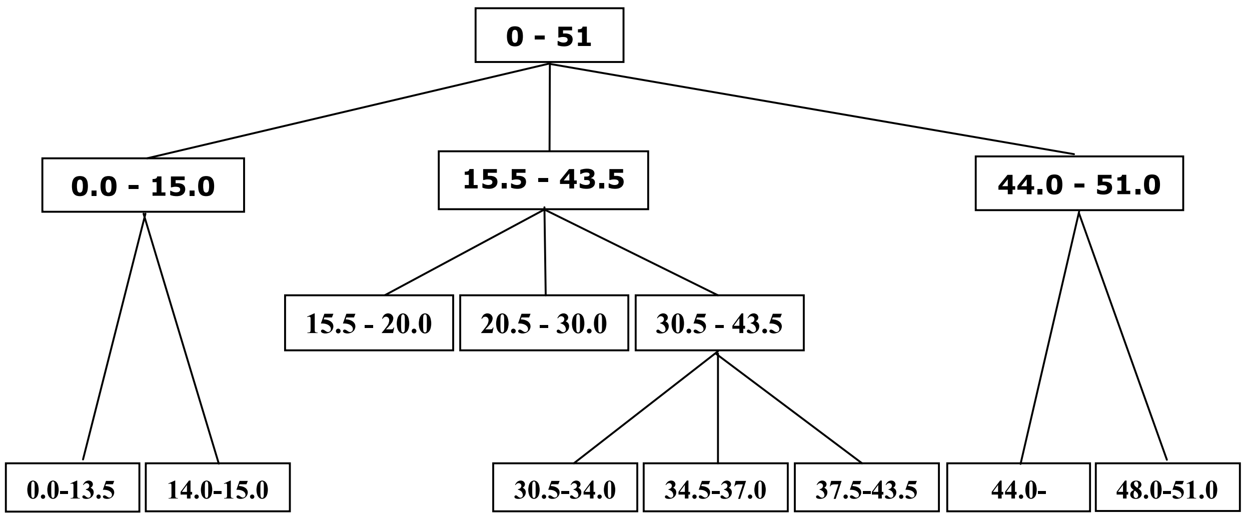

Figure 12. First part of *Pithoprakta*, meas. 0-51: segmentation in harmony with the Golden Mean

Being concerned with silence distribution in the second and the third section of the first part of he work, meas. 15.5-43.5 and meas. 44.0-51.0 respectively, we find out that rest positions are designated by the Golden Mean segmentation **(Fig. 13)** and that silence is used as a kind of separation means between sections and segments. Silence, thus, is elevated to a regulating factor granted with formal functions. Nevertheless, only primary segmentation is clearly understood by the listener, secondary and tertiary being intended rather to the composer, namely for structural purposes.

Under this view point, structural solutions are mingled with style: the first part of the piece is constructed out of evolving sonorities separated by silence. Then, if rests described so far serve as a delimiting formal agent, their aesthetic significance should be assimilated to the stylistic evaluation of sound transformation, the composer's distinctive characteristic. On that ground, silence is a constituent of transformation on equal terms with other ingredients[25].

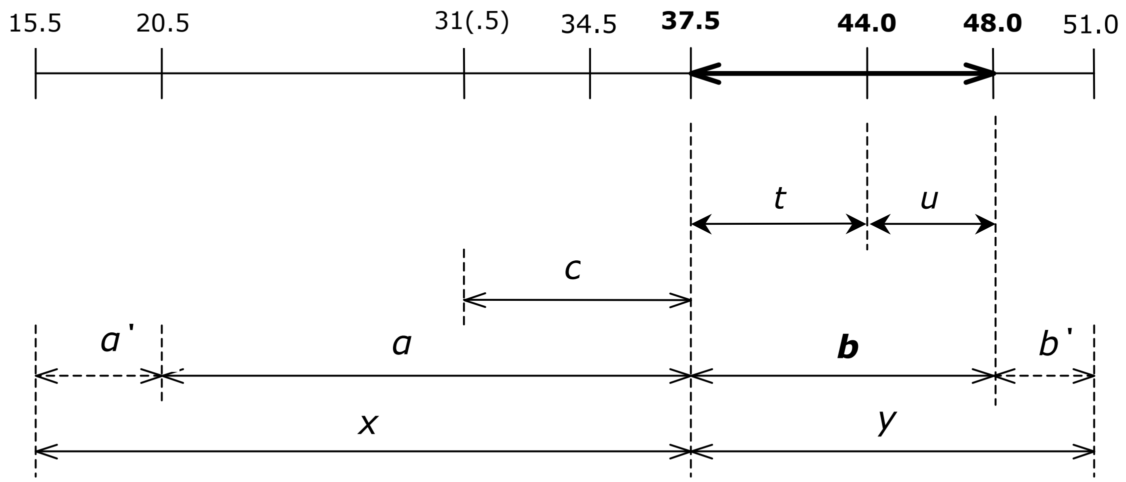

Figure 13. Position of rests in meas. 15.5-51.0 in harmony with the Golden Mean

V. Conclusion

Progression of sonorities is well organized through stochastics and graphics. The stochastic part of compositional procedures relies on indeterminism [Xenakis, 1963, 19] and, therefore, gives rise to sonorities resulting of haphazard motions of pitched and unpitched sounds. The graphic part of the procedures, clearly deterministic, provides formal parameters giving shape and momentum to stochastic data. Given that sound transformation might be continuous as much as non continuous, either progressive or abrupt, sudden silence has to be thought as a sonic entity in the sense of sound refutation, namely, as a form of extreme discontinuity in sonorous evolution. Additionally, as time is linked to event density, the lack of sonic activity is contradictory neither to theoretical principles nor to formal planning and graphic design. What comes out of this fact is that part separating rests might be rigorously computed as much as not computed. In the first case, part separating rests are either graphically assigned to the entire orchestra with no specific computation proper to that purpose, as in meas. 45-51, either they derive from previous event formalization and after being gathered together in specific sets they are brought in among existing pitched and unpitched events according to a new probabilistic process, as in meas. 16-41. In the second case, long rests might have arbitrarily taken their place between two consecutive sections or segments just for formal reasons, a possibility that needs to be thoroughly scrutinized. In both instances no impact has to be encountered to stylistic and aesthetic aspect of the composition. Since the return of musicological research to formalization questions confirms that silence is a regulating factor of the course of the composition, in *Pithoprakta* at least, analysis of other works of Xenakis's stochastic period (1956-62) should be undertaken.

In conclusion, Xenakis did not use rests as an uncontrolled void of sound. Instead, he incorporates silence in time flow via probabilistic procedures throughout sonorities using both graphic planning and stochastics.

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Notes

[1] Compositions previous to *Metastasis* (1953-54) are considered as early works.

[2] Mainly *Théorie des probabilités et composition musicale* in Gravesaner Blätter n° 6, 1956. The text reappears in *Musiques formelles* (1963), *Musique. Architecture* (1976) and *Formalized Music* (1992).

[3] The composer's archives, namely all documents relative to his musical and architectural output have posthumously been assigned by Xenakis family to the *Bibliothèque nationale de France (BnF) - Département de la musique - Archives Iannis Xenakis*.

[4] Such as those proposed in [Antonopoulos, 2008]. The present paper is partly based on data appearing in this dissertation.

[5] Xenakis's inside/outside time theory appears in several of his writings, as in [Xenakis, 1976, 57-60, 80], [Xenakis, 1992, 192, 255-267] etc. this theory is thoroughly explored and commented in [Exarchos, 2007, 20-51].

[6] A (finite) stochastic process is a finite sequence of experiments where each experiment has a finite number of outcomes with given probabilities [Lipschutz-Lipson, 2000, 87]. Concerning probabilities, Xenakis in his manuscripts is quite often referring to Emile Borel's *Éléments de la théorie des probabilités* [Borel, 1950].

[7] This phenomenon has been first visualized through Wilson's Chamber. Wilson's Chamber is mentioned in *Archives Iannis Xenakis, Carnet n° 14*, p. 3, 10/12/1956. Although the "formule radium" is of crucial importance, researchers turn mostly towards the presentation of the application of Gauss-Maxwell equation in glissando speeds generation in the historical meas. 52-59, as in [Orcalli, 2000, 39-45] for instance.

[8] Xenakis is using different colors for elements belonging to each rhythm pattern: red for *α*, green for *β* and blue for *γ*.

[9] Among many other examples, see: meas. 15, 17 – CB_2, meas. 20 – CB_6.

[10] Glissandos and multimeasure tied notes should be considered as continuous.

[11] *Col legno frotté* and *col legno frappé* for instance.

[12] Nouritza Matossian in [Matossian, 1981, 124 & 2005, 126] writes that the work is divided into four parts, but does not offer precise locations for the divisions. For James Harley in [Harley, 2004, 14] the work is divided into "three main sections"; he does not precise the locations either. Makis Solomos in [Solomos, 1993, 373] offers a precise division in four parts: meas. 0-51, meas. 52-121, meas. 122-207 and meas. 208-268. A similar division in four parts is adopted by Angelo Orcalli [Orcalli, 2000, 31-35].

[13] [Matossian, 1981, 147 & 2005, 137], [Solomos, 371].

[14] According to Pascal Dusapin, although very elaborate, form in Boulez's and Xenakis's works remains arbitrary: "They are doing what has always been done. […] time in Xenakis's works is never administrated by a basic mathematical concept." [Dusapin, 1988, 74-75]
[15] Meas. 48.5: the second half of meas. 48. Meas 50.0: the first half of meas. 50.
[16] Archives Iannis Xenakis, Pithoprakta, File 1/13, fol. 59v: a probabilistic table with some annotations. The document is not dated, but as it appears on the back of fol. 59 we infer that it has been worked out that same date.
[17] Archives Iannis Xenakis, Pithoprakta, fol. 102-3 in File 1/13.
[18] "In *Pithoprakta*, tiny glissando clouds, pizzicato and col legno powder constitute the macroscopic events." [Varga, 1996, 79]. See also: [Solomos, 1993, 426].
[19] Meas. 51 is left out of consideration as all pitches dispose of no differential durations. Namely, each instrumental line contains only one pitch that occupies the duration of the first quaver, the rest of the measure being just rests.
[20] The differential duration 0.05 is equal to a quintuplet crochet (rhythm pattern *α*).
[21] This technique is used quite often by Xenakis.
[22] *En arraché*
[23] Ταινία αρμονική (χρυσή τομή).
[24] [Matossian, 1981, 124 & 2005, 116]: "Large scale proportions are in harmony with the Golden Section". [da Silva Santana, 1998, 25]: "La section d'or règle les différentes textures musicales.'' But in [Solomos, 1993, 373] we read that "En réalité, seules deux parties –mes. 208-230 et 231-268– présentent un rapport proche du nombre de celle-ci (23 et 27 mesures respectivement, soit un rapport de 0,622)." However, Xenakis himself denies the use of the Golden Section in *Pithoprakta*: "As far as rhythms are concerned, there's no trace of the golden section. I applied probability theory almost exclusively." [Varga, 1996, 75]
[25] James Haley counts 21 sonic entities, the first being *silence*. [Harley, 2004, 15]