Analogique B

A COMPUTER MODEL OF THE COMPOSITIONAL PROCESS

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ABSTRACT

In this paper we propose a software reconstruction of Xenakis' composition *Analogique B* - namely, the electronically-generated tape for the mixed work *Analogique A et B* (1958-59). We briefly illustrate both Xenakis' "mechanism" (the compositional algorithm) and the sound synthesis method he implemented and explored, and some music-analytical evidence concerning the *Analogique B* tape. We then illustrate our digital implementation (using C++ and Csound as the sound-synthesis engine), and discuss questions as to the rendering of the original analog process in the digital domain.

1. ANALYTICAL REMARKS ON THE ANALOGIQUE B COMPOSITIONAL PROCESS

Analogique A et B resulted from the superposition of two works, initially composed as separate: *Analogique A* for nine string instruments, and *Analogique B* for electronically generated sounds (realized partly at GRM in Paris and partly in Hermann Scherchen's studio in Gravesano). As he was working, Xenakis also described his compositional process in a paper later published (1963) as Chapitre 2 of Musique formelles (Xenakis, 1963, pag. 23-24). Chapitre 2 describes the theory of Markovian stochastic music, as explored in both *Analogique A* and *Analogique B*. Papers (Di Scipio, «*An analysis of Analogique B*») and (Di Scipio, 2005) clarify many aspects of these works. We will only point out, here, the main concepts as related to what is needed for a digital implementation.

Both *Analogique A* and *Analogique B* are generated from one and the same the statistical process, resulting into sequences of instances of 8 items, called "screens" (in the terminology of *Formalized Music(Xenakis, 1963)*), labelled A to H. The time sequence of screens is conditioned by a specific selection process, namely a 8x8 state transition matrix (MPT, matrice de probabilitè de transition).

	A	B	C	D	E	F	G	H
A	0.021	0.357	0.084	0.189	0.165	0.204	0.408	0.096
B	0.084	0.089	0.076	0.126	0.15	0.136	0.072	0.144
C	0.084	0.323	0.021	0.126	0.15	0.036	0.272	0.144
D	0.336	0.081	0.019	0.084	0.135	0.024	0.048	0.216
E	0.019	0.063	0.336	0.171	0.11	0.306	0.102	0.064
F	0.076	0.016	0.304	0.114	0.1	0.204	0.018	0.096
G	0.076	0.057	0.084	0.114	0.1	0.054	0.068	0.096
H	0.304	0.014	0.076	0.076	0.09	0.036	0.012	0.144

Figure 1. MPT used by Xenakis for Analogique A and Analogique B

For example the probability that screen A will be followed by screen B is 35.7 % whereas the probability that screen A will be followed by screen C is 8.4 %.

Each screen is a function of three variables: a density value **d**, an amplitude interval **g** and a frequency interval **f**. As a particular screen is selected, the next step is to get random amplitude and frequency values from given intervals (described below). Thus, we can view each screen as an infinite set of parameter values.

We will focus, here, on the process as designed and utilized for *Analogique B* particularly. The sound synthesis is based on the theory of acoustical quanta put forth by Dennis Gabor*(Xenakis, 1963*), (Gabor, 1947). *Analogique B* is considered the first musical work based what is known, today, as "granular synthesis" (Roads 1996).

Xenakis' screens are defined as follows:

1) the full frequency range is partitioned in 16 "regions" (Xenakis' term). The ranges for the 16 frequency regions are:

f-region 1: 42-63 Hz, f-region 2: 63-84,
f-region 3: 84-131, f-region 4: 131-178
f-region 5: 178-267, f-region 6: 267-355
f-region 7: 355-532, f-region 8: 532-710
f-region 9: 710-1065, f-region 10: 1065-1420
f-region 11: 1420-2130, f-region 12: 2130-2850
f-region 13: 2850-4275, f-region 14: 4275-5700
f-region 15: 5700-8550, f-region 16: 8550-11400

Two frequency sets are defined as regions linked among themselves in this way:

f0=(1; 2; 3; 5; 7; 10; 13; 14; 15; 16)
f1=(4; 6, 6; 8; 9, 9; 11, 11; 12, 12)

2) Similarly, there are 4 amplitude regions, measured in phones[1] . Phone ranges are:

g-region 1: 50-60 phones
g-region 2: 60-70
g-region 3: 70-80
g-region 4: 80-90

Phone regions are combined together as follows, making up two phone sets:

g0 = (1, 1, 1, 1; 2, 2; 3, 3; 4, 4)
g1 = (1, 1, 1; 2, 2, 2; 3, 3; 4, 4)

3) Finally, there are 7 density regions, with density values measured in grains per second (gps):

d-region 1 = 1.3 gps
d-region 2 = 3.9
d-region 3 = 11.7
d-region 4 = 35.1
d-region 5 = 105.4
d-region 6 = 315.9
d-region 7 = 957.7

Here are the two density sets:

d0 = (1, 1, 1; 2; 3, 3; 4; 5; 6, 6)
d1= (1; 2, 2, 2; 4, 4; 5, 5; 6, 6)

Observe that the highest density range (d-region 7) is not comprised in the density sets actually utilized in the composition, probably due to the restrictions of the technological means available to Xenakis. A discussion on issues related to technological restrictions, in the making of this work, is sketched later on in the paper.

The 8 "screens" (A, B, … H) are thus defined by the combinatorics of 23 variables:

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[1] The phon is a non-standard sound unit that is designed to reflect perceived loudness, and is based on psychoacoustic experiments in which volunteers were asked to adjust the decibel level of a reference tone of 1 kHz until it was the same loudness as the signal being measured. So for example, if a sound is 70 phons, that means it sounds as loud as a 70-dB, 1-kHz tone.

A = f0, g0, d0	B = f0, g0, d1
C = f0, g1, d0	D = f0, g1, d1
E = f1, g0, d0	F = f1, g0, d1
G = f1, g1, d0	H = f1, g1, d1

As the MPT is looped (i.e. iteratively applied), a sequence of screens is generated, that Xenakis calls a "protocol". Each subsequent screen in a protocol sets the statistical musical content in a fixed time window of 0.5". Grain amplitudes and grain frequencies are thus selected from within the regions included in the current screen, and the number of sound grains in the time window is fixed, also based on the density range included. The entire piece is made with several protocols, i.e. several sequences of combinations of the 8 screens available.

2. TIME-FREQUENCY ANALYSIS OF THE TAPE SOUND

The tape sounds of *Analogique B* consist in 0.5"-long "clouds" (Xenakis' term), each made of the statistical content of one screen. There are two kinds of protocols: "equilibrium" protocols and "pertubation" protocols. "Equilibrium" means "statistical balance", i.e. protocols generated by iterating the 8x8 matrix illustrated above (Figure 1). "Perturbation" protocols are generated independent of the matrix (perturbated protocols are, in turn, of two possible types, as illustrated below). In other words, "perturbated" protocols are contradictory to the matrix process itself: they are to manifest, according to Xenakis, the logics of the algorithmic process by negating the process' own functioning *(Xenakis, 1963*): the normal (statistical) behavior of the process (protocols generated with the matrix) is alternated with behaviors which are not reducible to the matrix functioning (protocols generated with other means, not less formalizable, but not belonging to the fundamental matrix).

For our purposes, it is useful to analyze the frequency content of a sample segment[2]. We focus here on the first tape segment (0'00"-0'20"), consisting in two protocols (0'00"-0'15" and 0'15"-0'20"). Figure 2 shows a frequency analysis of the initial 6" of sound.

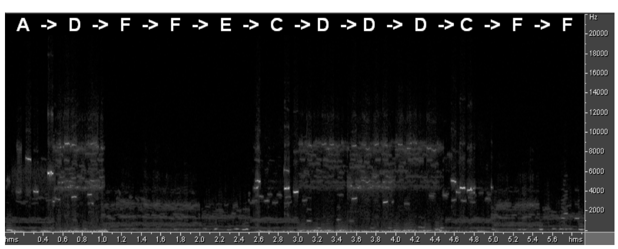

Figure 2. *Frequency analysis of the initial 6'' second of sound*

This segment is clearly in "equilibrium", that is, the sequence of 12 screens correctly reflects the MTP statistical behaviour. The next sonogram (figure 3) shows the next 5", with the subsequent 10 screens:

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2 The source sound for our sonogram analysis is a digital copy available from Salabert (Xenakis' publisher), and kindly provided by Prof. Makis Solomos and Agostino Di Scipio.

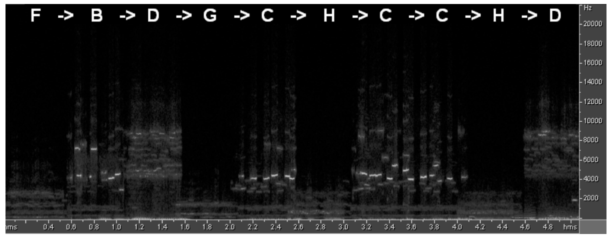

Figure 3. *Frequency analysis of the the next 5"*

Following is the sonogram of the next 4 seconds:

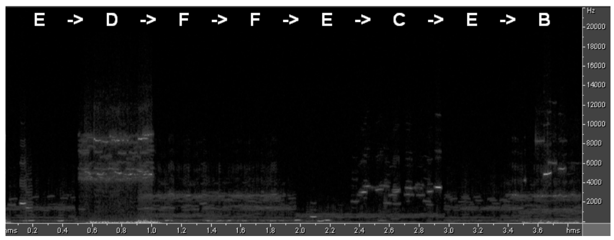

Figure 4. *Frequency analysis of the the next 4"*

From these sonograms, we can tentatively reconstruct the protocol unfolded in these initial 15", comprising 30 *screens* in total:

Y=A--> D--> F--> F--> E-->C-->D-->D-->D-->
C-->F-->F-->-->F-->B-->D-->G-->C-->H-->C-->
C-->H-->D-->-->E-->D-->F-->F-->E-->C-->E-->B

This sequence, therefore, fully represents a possible state vector of the MPT stochastic process.

After the first 15", the tape has a completely different screen protocol, consisting of screen A repeated 10 times (figure 5). This is not to say that the sound signal repeats itself for 10 times, but that the statistical configuration is repeated, while the precise frequency content statistically reflects the prescribed (repeated) ranges. Overall, this is not anything possibly achieved with the Xenakis' MPT: this is a "perturbated" protocol, not at all reflecting the stochastic process.

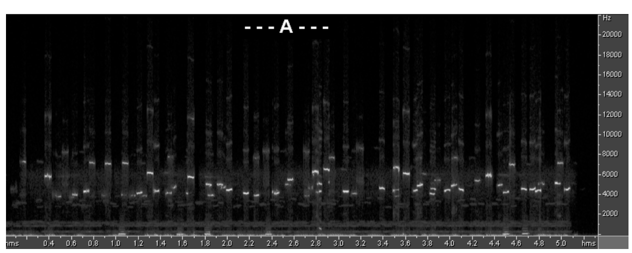

Figure 5. P*erturbated protocol*

This is a very simple perturbation (or variation) of the given MTP: P (A | A) = 1 (the transition from A to A is certain, no other transitions are possible). There is a second type of "perturbation", a simple statistical distribution. We won't go into further details on the issue, here, as we will only be concerned, in our digital implementation, with the normal use of Xenakis' MTP, in "equilibrium" mode. In actuality, the two types of perturbations are still normalizable as two different MTPs. In further work, we will accordingly implement the whole process with three different MTPs.

3. XENAKIS' GRAINS: THEORY AND PRACTICE

Let's take the opportunity here for a short detour on the sound grain description. Xenakis wrote that his grains were 40 ms in durations, and mentioned no grain envelope. That is not confirmed by the scrutiny of the tape signals, which evidences grain envelopes of different shapes. In Figure 6, a single grain is illustrated, isolated from the sound sequence analysed in Figure 5:

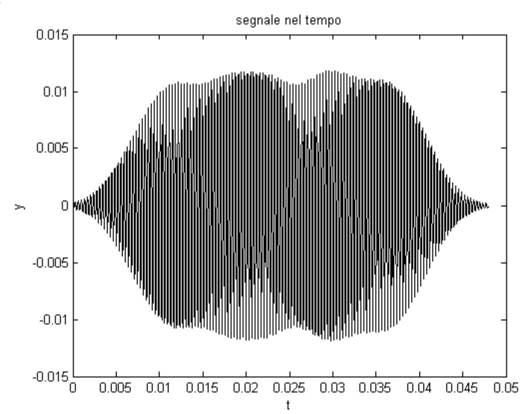

Figure 6. *Single grain*

In Xenakis' theory, the grain should have been a rectangle window[3]:

$$rect(t) = u\left(t+\frac{1}{2}\right) - u\left(t-\frac{1}{2}\right)$$

Actual envelopes are smoothed, as we clearly see in Figure 6. That can be due to several factors, especially relating to the studio technologies available to the composer at the time. Among the several hypothesis, it has been also noted (Di Scipio, «*An analysis of Analogique B*») that Xenakis mentioned the use of "filters" in the making of this work, not going into any details. Use of band-pass filters could clearly explain envelope shapes such as the one illustrated in Figure 6[4].

4. XENAKIS IN THE STUDIO

But how Xenakis did achieve his granular textures and how did he practically arrange the sonic values according to his Markovian process (or the negation, "perturbation" of it)? Following Di Scipio (Di Scipio,

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3 that already represents a significant deviation from Gabor's theory of acoustical quanta [6]

4 As we know from theory of signals, every filter that cuts high frequencies in the frequency domain also modifies the temporal shape of the signal that results more smoothed.

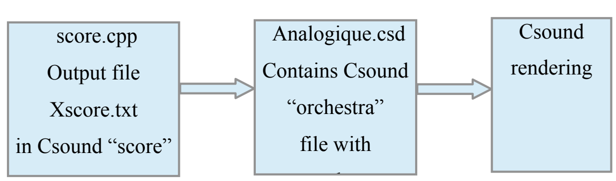
«*An analysis of Analogique B*»), we know that Xenakis created several separate tapes, each with granular materials corresponding to the frequency/amplitude/density regions. His basic grains were short sine-wave signals, approximately lasting 0.04" (empirical evidence contradicts this datum, as grain durations seem to span over durations longer than that). Because grain densities prescribed by the composer go up to such a relevant figure of 300 gps, Xenakis should have undergone an incredible, huge amount of mechanical cut-and-past work to achieve that. It is reasonable to agree with (Di Scipio, «*An analysis of Analogique B*»), where the hypothesis is made that he devised a much more economic procedure, simplifying his task in the studio. In short, we can summarize the process as follows:

- 16 longer grain sequences were created, corresponding to the 16 frequency regions, all having normalized peak amplitude and minimal density (1.3 gps);
- tape segments were extracted and mixed together to create higher grain density sequences, as prescribed by the selected screens;
- the mix thus obtained was scaled to achieve the amplitude value as prescribed by the selected screen.

This out-of-time, additive procedure, which is anyway rather cumbersome and time-consuming, allowed Xenakis to get fractional density values (see the density regions, listed above). That represents a problematic point for our digital implementation (to be discussed later). This elaborate studio procedure is of little import for our software implementation; however, it suggested us a possible modeling strategy, maybe closer to the actual decision making process Xenakis had to deal with. Other implementations are indeed possible and may reveal more effective (in fact, one of the authors followed a different path in an independent work (Silvestri, «*Studio e implementazione della macchina stocastica in Analogique A+B*»*)*; another attempt is described in (Hagan 1995*),* but our goal here is to stay as close as possible to the path designed by Xenakis for himself. This is like leaning more on the analysis of the compositional process than on the analysis of the compositional results (Laske 1991).

5. SOFTWARE IMPLEMENTATION OF *ANALOGIQUE B* COMPOSITIONAL ENGINE

Our software implementation factors the whole problem in two: it splits into two software modules; the first written in C++ language[5] generates the screen sequence (i.e. It creates the "protocols"), based on the Xenakis MPT (see Figure 1). The second module is written in Csound[6] and implements the granular synthesis process, driven by the screen values:



[5] Standard c++ language. We have used open source Dev-C++ IDE with mingw compiler (http://www.bloodshed.net/dev/)

[6] Csound v 5.15 http://www.csounds.com/

Figure 7. Single grain

The algorithm engine

The C++ program outputs a text file with the Csound "score" format. The main part of the C++ code is a loop iterating the MPT for as many times as specified by the program user. When launching the program, the user can set the first screen to start with, and the protocol length (number of MPT iterations).

The synthesis engine

he Csound "orchestra" file contains the sound synthesis code. This opcode takes as input the following parameters:

a) the function that defines the waveform of the grain (the sine function) and the function that defines the windowing envelope:

```
itmp        ftgen 1, 0, 4096, 10, 1            ;genera tabella seno
gifnum   = 1 ;grain waveform (seno) richiamata in grain
itemp2  ftgen 2, 0, 8192, 20, 9  ;genera tabella sync
giwfn    = 2              ;sync waveform - richiamata in grain
```

b) the grain duration, which in our case is constant and is 0.04"

c) the frequency range from which the actual frequency value is randomly selected for each grain. The range is specified as a base frequency value (offset) and a range width. Here is an example for the first two regions:

```
; Definizione delle f-region (16 in totale)
gifreg1=42
gifinter1= 63-42 ; width is 11
gifreg2=63
gifinter2= 84-63 ; width is 21
```

d) the range from which the amplitude value is randomly selected for each grain. Here is an example for the first two regions:

```
; Definizione delle g-region (4 in totale)
gigain1=2000
gigain_inter1=2000
gigain2=4000
gigain_inter2=4000
```

e) the density values:

```
; Definizione delle d-region
gidens0 = 1.3
gidens1 = 3.9
gidens2 = 11.7
gidens3 = 35.1
gidens4 = 105.4
gidens5 = 315.9
```

We define 8 syntehsis "instruments", one for each of the 8 screens, A to H. Each instrument has 10 overlapping grain generators. Each generator has a fixed frequency range (related to the f0 set and f1 set). Here is an example for the screen B instrument:

```
instr 2                                    ; B screen
aenv    linseg 0, 0.001, 1, 0.498, 1, 0.001, 0
a1      grain   gigain1, gifreg1, gidens3, gigain_inter1, gifinter1, 0.04, gifnum, giwfn,0.04
a2      grain   gigain2, gifreg2, gidens1, gigain_inter2, gifinter2, 0.04, gifnum, giwfn,0.04
a3      grain   gigain4, gifreg3, gidens4, gigain_inter4, gifinter3, 0.04, gifnum, giwfn,0.04
a4      grain   gigain3, gifreg5, gidens3, gigain_inter3, gifinter5, 0.04, gifnum, giwfn,0.04
a5      grain   gigain1, gifreg7, gidens1, gigain_inter1, gifinter7, 0.04, gifnum, giwfn,0.04
a6      grain   gigain1, gifreg10, gidens0, gigain_inter1, gifinter10, 0.04, gifnum, giwfn,0.04
a7      grain   gigain2, gifreg13, gidens1, gigain_inter2, gifinter13, 0.04, gifnum, giwfn,0.04
a8      grain   gigain1, gifreg14, gidens5, gigain_inter1, gifinter14, 0.04, gifnum, giwfn,0.04
a9      grain   gigain3, gifreg15, gnidens4, gigain_inter3, gifinter15, 0.04, gifnum, giwfn,0.04
a10     grain   gigain4, gifreg16, gidens5, gigain_inter4, gifinter16, 0.04, gifnum, giwfn,0.04
out aenv*(a1/10+a2/10+a3/10+a4/10+a5/10+a6/10+a7/10+a8/10+a9/10+a10/10)
endin
```

6. CONCLUSION

The digital rendering of Analogique B could be done in two different ways:

1) as described in this paper

2) creating a digital version of Xenakis' tapes with a series of audio files corresponding to the screens' montage made with analog tapes, then writing a Csound orchestra that implements a sampler adressing those files.

Variants of the first approach would be required for realtime versions (Hagan, 2005)

The second method would be closer to the way of work adopted by Xenakis with analog technology, but it would involve a smaller amount of automation and more handiwork. Our choice followed not merely from the available technology, but from a design strategy making full advantage of the digital domain. Tools and technologies used to produce a musical work are not neutral but incorporate knowledge that influence the choices of the composer.

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