Stochastic synthesis: An overview

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In the late 1960s, composer, architect and theoretician Iannis Xenakis (1922-2001) began his research on stochastic synthesis: an approach to microsound synthesis that uses probability distributions to manipulate individual digital samples, as if they were indivisible elementary particles. Xenakis continued with this research for most of the 1970s and from the late 1980s until the end of his career. This paper gives an overview of the aesthetic origins and of the development of this non-standard synthesis technique, including a straightforward description of the dynamic stochastic synthesis algorithms (from 1977 and 1991). In addition, a new extension of these techniques is put forward: the stochastic concatenation of dynamic stochastic synthesis.

In the mid 1950s, Iannis Xenakis introduced the use of stochastic functions in musical composition. In the 1960s, he started using computers to accelerate and automate the numerous operations that these methods require. At the very same time, Xenakis was speculating about the possibility of using stochastic techniques to synthesize sounds:

> Although this program gives a satisfactory solution to the minimal structure, it is, however, necessary to jump to the stage of pure composition by coupling a digital-to-analogue converter to the computer. The numerical calculations would then be changed into sound, whose internal organization had been conceived beforehand. (Xenakis 1992, 144)

Composing sound with musical procedures

Since the appearance of computers with digital to analog converters in the late 1950s, some composers have been interested in synthesizing sound through the manipulation of individual digital samples. In this process, amplitude and duration values are obtained through musical procedures and not based on any acoustical model. This approach, often referred to as *non-standard synthesis* (Holtzman 1978), reflects a willingness to explore the sound synthesis possibilities unique to computers.

Three non-standard synthesis strategies that appeared during the 1970s are: "New Proposals in Microsound Structure" by Iannis Xenakis, SAWDUST by Herbert Brün and SSP by Gottfried Michael Koenig. These approaches have the following goals in common: to unify the macrostructure and the microstructure of compositions, to use synthesis techniques idiomatic to computers and to open an experimental field in sound synthesis.

New Proposals in Microsound Structure

It was during his tenure at Indiana University in Bloomington, from 1967 to 1972, that Xenakis first used a computer for stochastic sound synthesis. In 1972, he continued these experiments at the Centre d'Etudes de Mathématique et Automatique Musicales (CEMAMu) in Paris. However, in 1977, with the advent of the Unité Polyagogique Informatique du CEMAMu (UPIC) system, Xenakis postponed his stochastic synthesis research until the late 1980s (Barthel-Calvet 2001).

Xenakis's first concrete ideas about stochastic synthesis were published in *Formalized Music* (Xenakis 1971), in the manifesto-like chapter "New Proposals in Microsound Structure."

In it, he starts by rejecting:

- Fourier analysis as the basis for sound synthesis.

> Now, the more the music moves toward complex sonorities close to "noise", the more numerous and complicated the transients become, and the more their synthesis from trigonometric functions becomes a mountain of difficulties, even more unacceptable to a computer than the permanent

states. It is as though we wanted to express a sinuous mountain silhouette by using portions of circles (Xenakis 1992, 244).

- "pure" electronic sounds: "Any electronic music based on such sounds only, is marked by their simplistic sonority" (Xenakis 1992, 243).
- serialism in electronic music: "The serial system, which has been used so much by electronic music composers, could not by any means improve the result, since it itself is too elementary" (Xenakis 1992, 243).

Instead, he advocates:

- mixing "pure" electronic sounds with "concrete" sounds: Only then "could electronic music become really powerful" (Xenakis 1992, 243-244).
- the use of stochastic processes to efficiently produce sonorities with "numerous and complicated" transients: "It seems that the transient part of the sound is far more important than the permanent part in timbre recognition and in music in general" (Xenakis 1992, 244).
- an approach in which sound synthesis is performed only in the time domain; starting directly from the sound pressure curves, defining them by means of stochastic variations: "we can start from a disorder concept and then introduce means that would increase or reduce it (Xenakis 1992, 246).

Polytope de Cluny

Xenakis first used the results of his experiments in stochastic synthesis in *Polytope de Cluny* (1972); he was proud to be the first in France to use digitally synthesized sounds (Harley 2004, 70). Decorrelated stochastic synthesis opens the work (just after a brief introduction in the third channel, intended for when the audience entered the performance space), and it is present for about 6 minutes, sometimes in the foreground and sometimes receding to the background, as it is inhabited by the other sounds: ceramic windchimes, thumb pianos, low stringed instruments bowed with extreme overpressure and other sounds sources that are hard to identify. All the sonorities have a very rich spectrum and are full of buzzes, rattles and distortion.

Random walks in instrumental music

Xenakis used the plotted graphs of stochastic synthesis in his instrumental music. In *Mikka* (1971), *N'Shima* (1975) and *Mikka "S"* (1975), he read the horizontal axis of the graphs as time and mapped the vertical axis onto a grid of quarter-tone pitch values (Xenakis 1976).

Dynamic stochastic synthesis (1977): *La Légende d'Eer*

In 1977, Xenakis composed *La Légende d'Eer*, which was the musical component of *Le Diatope*. Most of the sound materials used in this piece are very similar to the ones used in *Polytope de Cluny*, although a greater prominence is given to synthetic sounds: analog and digital (stochastic).

In this piece, Xenakis started using a new technique for stochastic synthesis that he named Dynamic Stochastic Synthesis. This technique had its origin in the methods presented in "New Proposals in Microsound Structure," and introduced an important conceptual development: the waveform as the basic unit to be varied stochastically at each iteration.

In this model, waveforms are constructed by linearly interpolating a set of breakpoints (Fig. 1). Each breakpoint is defined by a pair of duration and amplitude values. At every repetition of the waveform, these values are varied stochastically using random walks: Any probability distribution can be employed to determine the size and direction of the steps. There are as many pairs of duration and amplitude random walks as there are breakpoints in the waveform (Xenakis 1992, 289-293).

The fluctuation speed of a parameter is directly proportional to the step size of its random walks: the smaller the steps, the slower the rate of change in that parameter. Depending on their speed, the perception of these fluctuations in duration and amplitude can be located on a continuum ranging from slow glissandi and subtle variations in timbre to noise.

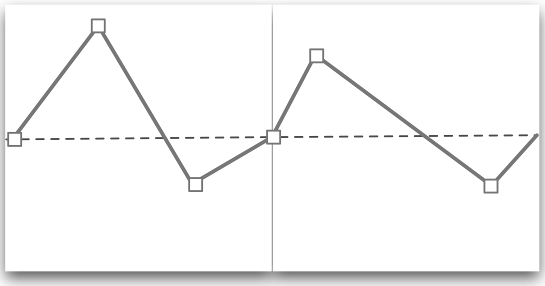

Figure 1. Breakpoints linked by linear interpolation.

Each random walk is forced to remain within a predefined space by means of two elastic barriers that reflect excessive values back into the barrier range (Xenakis 1992, 289-293). These barriers provide control over the frequency and amplitude of the waveform: the larger the space between a pair of barriers, the larger the variation that is possible in that parameter (i.e. the bigger the potential size of glissandi and the amplitude of the waveform); if the two elastic barriers of the duration random walks are set to the same value and the amplitude values fluctuate slowly, then gradual and independent variations in the amplitude of the overtones of a fixed pitch are heard.

Previously, Xenakis worked with individual duration and amplitude values that were either independent or dependent on the preceding value (e.g. random walks) (Xenakis 1992, 246-249; Serra 1993, 240). The new approach evidences Xenakis's interest in having a finer control over the periodicities (duration) and symmetries (amplitude) of stochastic waveforms.

This technique is described in the chapter "Dynamic Stochastic Synthesis" of *Formalized Music* (Xenakis 1992, 289-293) and is often mistaken to be the explanation for the dynamic stochastic synthesis algorithm implemented in the early 1990s as part of the GENDY program.

Also, it is important to remember that, for Xenakis, this method was just an arbitrary starting point that he used in *La Légende d'Eer* (Xenakis 1992, 293).

Dynamic stochastic synthesis (1991): *GENDY3*

It was not until the late 1980s that Xenakis continued with his research on stochastic synthesis (Harley 2004, 215). He wrote a program that implemented an extended version of the dynamic stochastic synthesis algorithm used in *La Légende d'Eer* (Xenakis 1992, 296). This program was written in the BASIC programming language, with the assistance of Marie-Hélène Serra, and was called GENDY (a portmanteau constructed from the French words *génération* and *dynamique*) (Serra 1993, 239).

The only difference between the new implementation of the algorithm and the previous one is the use of second-order random walks. A second-order random walk consists of three elements: a probability distribution and two random walks. The probability distribution generates the step sizes of the *primary random walk*; the successive positions of the *primary random walk* are the step sizes of the *secondary random walk*. The successive positions of the *secondary random walk* are the values of the second-order random walk (Xenakis 1992, 304).

This technique is described in the chapter "More Thorough Stochastic Music" of *Formalized Music* (Xenakis 1992, 295-322) and is the one used by Xenakis in *GENDY3* (1991).

S.709 (1994)

Three years later, Xenakis modified the program used for *GENDY3,* adding the possibility of modulating the parameters of the dynamic stochastic synthesis algorithm. With this version of the program, Xenakis created *S.709* (1994) (Hoffmann 2000, 31).

Stochastic concatenation of dynamic stochastic synthesis

> [A]ny theory or solution given on one level can be assigned to the solution of problems of another level. Thus the solutions in macrocomposition (programmed stochastic mechanisms) can engender simpler and more powerful new perspectives in the shaping of microsounds (Xenakis 1992, vii).

After writing an implementation of Xenakis's 1991 dynamic stochastic synthesis algorithm in the C programming language, as a plugin for SuperCollider, I have been looking for ways of extending this model. The stochastic concatenation of GENDYs (i.e. the dynamic algorithm from 1991) is a procedure that almost immediately started to yield very promising results. In this technique, a signal is constructed by concatenating the waveforms of a set of GENDYs, one iteration at a time. For example, Fig. 2 shows a sequential concatenation of two GENDYs.

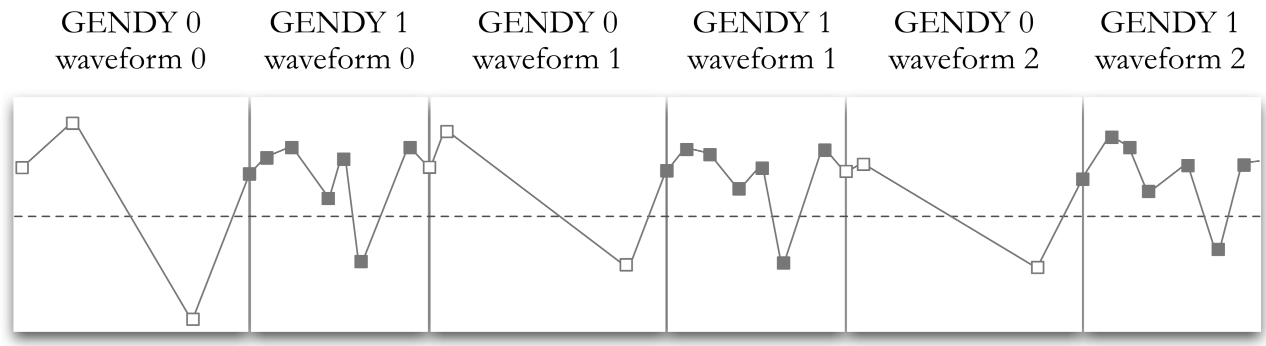

Figure 2. A sequential concatenation of two GENDYs.

Conceptually, there is no limit to the number of GENDYs in a set, but I have found that 72 is a reasonable limit.

Any stochastic procedure can be used for selecting GENDYs from a set; the most fruitful ones that I have used so far are: tendency masks, sequences of second-order random walks, Markov chains and probability distributions. Each of these procedures gives its own character to the resulting sounds, which range from continuous textures to differentiated arrangements of microsounds to timbres that exhibit interesting behaviors over time.

This approach is very close to SSP's use of *Selection Principles* for the creation of *Permutation*s (Berg 2009, 83-85).

A more detailed explanation of the techniques mentioned in this paper can be found in Luque (2006, 2009).

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