The New GENDYN Program
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The New GENDYN Program

This article gives an account of a research project conducted during 1995–1997 studying the GENDYN program and music. The GENDYN program is the software implementation of dynamic stochastic synthesis, a rigorous algorithmic composition procedure conceived by Iannis Xenakis (1992). The original program was written in BASIC by the composer himself at CEMAMu, Paris, with the assistance of Marie-Hélène Serra (Serra 1992). In 1991, a single run of this program, called GENDY301, generated *GENDY3*, a piece of about 20 min duration. It was later released on compact disc (Xenakis 1994). Following this, Xenakis tried to extend the program to include additional time-variant effects by making some parameter settings of GENDYN's stochastic processes time-dependent. This resulted in a second piece, *S709*, which premiered in 1994.

The Xenakis algorithm is an original example of nonstandard synthesis. It uses the mathematical concept of random walks to produce both duration structure and timbral fluctuations in computer-generated sound. This means that the probabilistic movement of random walks is used for wave-shaping sound synthesis as well as for controlling aspects of musical form (i.e., composing a "score"). The composer conceives of a sound-producing automaton creating a complete composition "out of nothing," purely through the structure-generating power of probabilities. From a technical point of view, this is true indeed: Xenakis's *GENDY3* is entirely the output of the program; it does not depend on any other information input than that coded into the program lines. (Xenakis did parameterize some variables in his algorithm, but he did so by hard-coding their values into an auxiliary program called PARAG, read by GENDYN on startup. So, to be precise, the statement is true for the two programs GENDYN and PARAG taken together as a whole.)

Computer Music Journal, 24:2, pp. 31–38, Summer 2000

From an artistic point of view, however, the question is how far Xenakis, working with the program, was actually able to realize his artistic intents in his composition in spite of its sound and structure being entirely generated by probabilities. Trying to understand this, I decided to study the architecture of his program and also to operate it myself in order to practically experience the material conditions of Xenakis's creative work with the program. The idea was not to be confined to analyzing the final acoustic product only, but to simulate the "genesis" of an algorithmic composition. In order to achieve this, I created a new version of the GENDYN program as my working tool that I call the New GENDYN Program. It is a reimplementation of dynamic stochastic synthesis in a graphical, interactive, real-time environment. It creates the same music, but is much easier to work with and understand. It displays aspects of the algorithmic process with the help of lists, plots, and animated pictures, and thereby makes the synthesis process—which is opaque and mysterious in Xenakis's own programming—transparent to the user. It helps better assess the impact of Xenakis's design decisions and parameter choices on the program's musical output.

This article first describes how dynamic stochastic synthesis works in both theory and—more specifically—in Xenakis's original program. Then, it describes how dynamic stochastic synthesis has been ported to a new computer environment, from procedural programming under MS-DOS to distributed objects under Microsoft Windows. Finally, it discusses some central aspects of the algorithmic action inside GENDYN which are crucial for the quality and unique characteristics of GENDYN sound. A more systematic discussion and analysis of the piece may be found in a forthcoming paper and a dissertation in preparation (Hoffman forthcoming, in preparation).

One of the goals of the research presented is to make a highly idiosyncratic work of algorithmic art more accessible to people interested in computer composition. The New GENDYN Program is a tool to explore dynamic stochastic synthesis in general, and a masterpiece like *GENDY3* in particular. I hope that it contributes to a documentation of Xenakis's achievements in computer music. I also hope that Xenakis's example will encourage other people working with nonstandard methods of sound synthesis and compositional software, much in the spirit of originality espoused by the composer. Xenakis, in his concept of originality, went even so far as not to accept another person's faithful realization of his own compositional ideas. He did not encourage the development of the New GENDYN Program, and he did not use it for the composition of new pieces.

Related Work

Stochastics and probability theory have played a prominent role since the beginnings of computer music (Loy 1989). Xenakis himself used stochastic distributions as early as 1962 for his score-computing program ST (Xenakis 1992). Tutorial articles of how stochastic techniques can be used for automated composition have been provided by a wide variety of authors, including Charles Ames (1991), Denis Lorrain (1980), and Kevin Jones (1981), among others. "Non-standard" synthesis (Holtzmann 1979), also referred to as "abstract algorithms" (Smith 1991), have been explored by pioneers such as Herbert Brün, Berg et al. (1980), and Gottfried Michael Koenig, and are still being investigated by Arun Chandra (1994) and others.

Few composers, however, have applied stochastic processes directly to the sound signal, as Xenakis kept trying since his first experiments in "microsound structure" in the 1970s (Xenakis 1992). One of the most interesting aspects of dynamic stochastic synthesis is that it reduces aspects of score composition to sound synthesis, bypassing any preexistent musical theory. Sometimes it seems that sound produced with GENDYN is nothing more than a sonfication of abstract algorithmic action, while at its best it can convey the impression of being pure music. This is one of the mysteries of GENDYN.

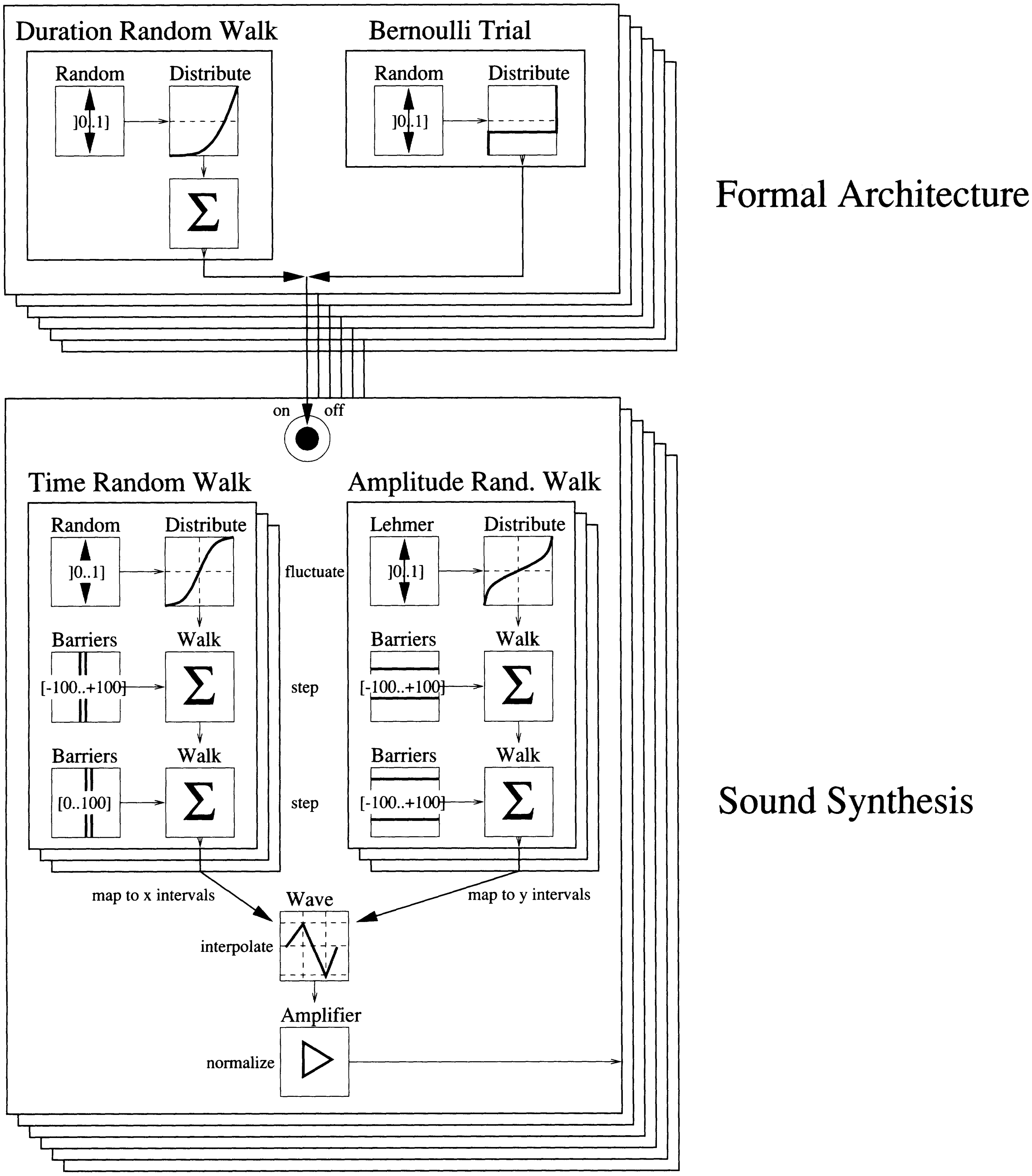
Analysis of the Original Program

The logical structure of the Xenakis algorithm, as realized in his original GENDYN program, is depicted in Figure 1. Let us discuss the figure from bottom to top. The waveform at the bottom of the chart is constructed out of a series of breakpoints. These breakpoints are linked, sample by sample, by linear interpolation. Each breakpoint is defined by a time offset to the preceding breakpoint (i.e., the number of sample values to be interpolated in between them) and an amplitude value. These time-offset and amplitude values are taken from the momentary positions in two associated random walks. They are represented on top of the waveform by the sigma addition operator, because a random walk is the summation of random steps (sometimes depicted as the path of a drunken sailor).

In the case of GENDYN, random walks occur in one dimension only. In other words, at every step of a random walk, the direction (forward or backward, up or down) and the width of the step to be taken are chosen at random. In Figure 1, there are three breakpoints to the waveform (the first and the last in the figure are taken to be the same, for the waveform is "wrapped around" and cycled through in time). Consequently, there must be three random walks to generate time-offset values, and three random walks to generate the associated amplitude values. (Note that a random walk does not produce the positions of successive breakpoints, but rather the successive positions of one breakpoint as the waveform is cycled through in time.) In other words, there are as many pairs of time and amplitude random walks as there are breakpoints in the waveform, and they evolve independently and in parallel. The result is a nonlinear stochastic distortion of the shape of the waveform over time.

The successive step widths of the time and amplitude random walks are controlled by yet another pair of random walks, shown on top of the aforementioned random walks. (The "patch connection" between the random walks in Figure 1 means that the output of each upper random walk, i.e., its momentary position, is taken by the lower one as its current step input.) Let us call the upper

Figure 1. Chart diagram of dynamic stochastic synthesis as realized in GENDY301.



ones *primary*, and the lower ones *secondary*. The step widths of the primary random walks follow a certain probability distribution around and including zero (depicted in the figure by a distribution graph for each). All random walks are confined by pairs of barriers that reflect excessive values back into the value range between themselves. The random walks for the time offsets are constrained to stay within a range of positive values, because time cannot flow backwards.

There are 6 tracks of sound drawn in Figure 1, each represented as a card in a stack of cards, but there are 16 of them in GENDY301. (Conceptually, there is no fixed limit to their number.) These sound tracks are played simultaneously, and mixed by a "mixer" in the lower right part of the diagram. This concludes the description of the sound-synthesis aspect of GENDYN (called *microcomposition* by Xenakis).

The next aspect of the New GENDYN Program is the score structure, which is restricted in GENDYN to computing durations. In GENDYN, pitch and timbre are not part of "macrocomposition," but rather are the immediate outcome of stochastic sound synthesis. In GENDYN, sounds are broken into patches of sounds and silences (called *fields* by Xenakis) by a control depicted on top of the synthesis module in Figure 1 (and called *duration random walk* in the figure). Each track is controlled by an independent-duration random walk. At each positive random step, sound generation is switched on and off by a probabilistic yes/no decision (a Bernoulli trial). All fields, whether sounding or silent, have random different durations, from fractions of a second to up to 30 sec or more. This creates a kind of stochastic rhythmic counterpoint between the tracks. The sum of the durations of the fields defines the duration of a whole track.

The superposition of a number of tracks so generated is called a *sequence* by Xenakis. A sequence has a typical duration of between several seconds and several minutes. It is as long as the longest of its tracks. An arbitrary succession of such sequences structured in this way (eleven in the case of *GENDY3*) forms a GENDYN piece. For the composition of *GENDY3*, Xenakis assigned different sets of random-walk parameters to each sequence. This created different sounds and different field densities, and hence, sections of different sonic character within the composition. Different probability values, barrier positions, and choices of distribution formulae also strongly affect the timbre and pitch evolution of the generated sound. In this article, the impact of these parameters onto the sound characteristics is discussed in general; for a more complete description, the reader is referred to Hoffmann (in preparation).

There are a few peculiarities in Xenakis's design of the algorithm. For one, even though the random walks define a quantized digital waveform, they run in a continuous space of real numbers. Therefore, their movement is much more delicate than it could be if random-walk space had also been quantized. This allows for a much more sophisticated dynamic behavior, and consequently results in richer sound. Second, that the random walks forming the wave are of second order (i.e., they are driven by another set of random walks) makes their dynamic behavior much more interesting (see Figure 2).

Xenakis designed a special random generator for the amplitude pro babilities after the Lehmer formula, with a much more periodic time behavior (see Figure 1). Xenakis gives this formula (Xenakis 1996, p. 154) as

$$x_i = (x_{i-1}a + c) \bmod M \quad (1)$$

where x_i represents the amplitude of the ith sample, and a, c, and M are all parameters to the formula. This equation can be recognized (albeit not easily) in the GENDYN program (compare the listing in *Formalized Music* [Xenakis 1992, p. 319]).

Another design peculiarity is that the random-walk spaces are arbitrarily restricted to the abstract numeric interval [–100..100]. This is adequate for the time offsets between breakpoints, which should not get too large. (They are measured in sample ticks, where the sampling rate can be chosen at will; Xenakis chose 44.1 kHz for both *GENDY3* and *S709*.) But for the amplitude values, this means that when they are later normalized by a constant factor to 16-bit integers (i.e., to the interval [–32,768..+32,767]), they take on only 200 different values.

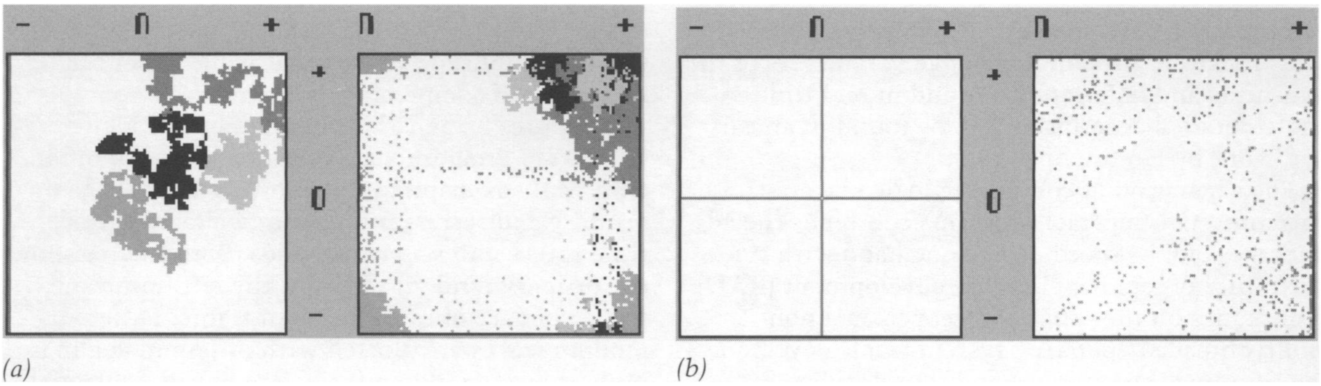


Figure 2. Trajectories of four parallel primary (left frame) and secondary (right frame) random walks (a and b). The primary ones are driven by the hyperbolic cosine distribution. Figure 2b is the same as Figure 2a, but the primary random walks (left frame) are restricted to a minimal interval of [−1.0..1.0] by a pair of barriers in both the amplitude (horizontal bar) and the time increment (vertical bar).

A final design peculiarity is that the interpolation between the amplitude breakpoints is also done within the same interval [−100..100]. (Note that in Figure 1, the sound signal is normalized to 16-bit integers only after interpolation.) Therefore, GENDYN sound has a fidelity less than that of 6-bit sound. The resulting quantization noise, however, gives GENDYN sound its specific brilliance.

In addition, there are peculiarities in Xenakis's implementation of the GENDY301 program that have nothing to do with the realization of the algorithm itself, but add additional features to its operation. Owing to a program bug (undeclared variables), the finite impulse response (FIR) filter acting on successive time-offset values has a delay line of length 0 (instead of length 3). If this filter is active, all time-increment values are simply reduced by a constant weighting factor of one-third. Since time increments are integer values, this reduction increases the coarseness of the waveform's time structure. If applied to noise, the result is a sizzling modulation of the noise that is impossible to obtain by other means.

Owing to an intricate interaction between cascades of "if-then-else" statements, control flow (with BASIC's GOTO operand), and variable state transformation, soundfields are one sample value longer than muted ones, making it more difficult to retrace the history of the successive random-number drawings. Simulation of the original composition procedure is further complicated because the original implementation uses alternating arrays to store the current random-walk positions. Therefore, when a new active soundfield is started, all random walks resume with positions stored in the first of the two arrays, regardless of which array was assigned the position computed by the last preceding soundfield.

Software Engineering Issues

The GENDYN re-engineering project mirrors in some ways the evolution of software engineering from the 1960s to the 1990s. Xenakis is of course more regarded as a composer than a software engineer, and his programming constructs have not changed much from the times of his pioneering ST program, written in Fortran on an IBM mainframe in 1962 (Xenakis 1992). Control flow in his GENDYN program jumps along GOTO statements. The calculations are overloaded with a number of state transitions on a large variable set. Large subroutines work with side effects. This programming style is very hazardous indeed! However, the algorithm is more or less correctly implemented (with the minor deviations mentioned above). The fact that Xenakis produced such a rich variety of sounds out of this extremely complicated program makes the composer's achievement even more impressive.

The New GENDYN Program is divided into two parts: a C++ sound-server engine and a graphical user-interface client written in a 4GL language (currently Visual Basic). Client and server are coupled with the help of distributed objects (currently using Microsoft's OLE library). Sound computation has been sped up by a factor of about 60. This makes it possible to change parameters of the synthesis and listen to the sound in real time. A more detailed description can be found in an earlier work by Hoffmann (1996).

The separation of computing logic and control logic into two separate programs combines the advantages of C++ speed on the one hand with the flexibility of rapid application development (RAD) techniques on the other. (Moreover, in a non-multi-threaded operating system, such as Windows 3.x, running the interface and sound engine as two separate tasks is the only possibility to realize a fair balance between user interaction and computation.) The distributed design allows for independent development of the purely algorithmic and interactive parts of the program. For example, it would make it easy to reintroduce the idea of time-variant parameters that Xenakis tried in his own program. It could easily be done by automating the graphical control interface with a script, without further complicating the sound engine itself.

The Dynamic Behavior of Stochastic Synthesis

The key idea of stochastic synthesis is its nonlinear waveshaping, where the waveshaping function changes stochastically from period to period. Consequently, it is not the waveform as such that defines the aural result (although its jaggedness and quantization may contribute to a special sonority), but rather the dynamic behavior of its deformation over time. It is this change that makes up the specific quality of GENDYN sound by continually transforming its spectrum.

This differential aspect links stochastic synthesis to the study of dynamic systems and to notions such as *phase space* and *attractors*. A phase space is spanned by the set of degrees of freedom of the system under consideration. An attractor is a subset of that phase space which geometrically characterizes the long-term dynamic behavior of the system. Is the long-term behavior of stochastic sounds governed by attractors? If so, their shape will look different from the fractal images of deterministic systems, because probabilities are involved. A look at the trace of a random-walk particle in the phase space of amplitude value versus time offset can help to clarify some of its dynamics.

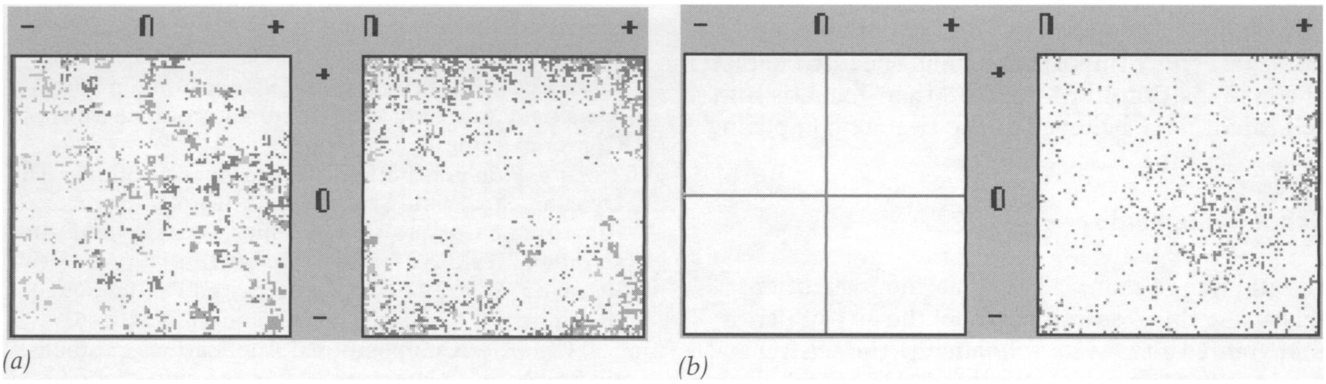
In Figures 2a and 2b (generated by the New GENDYN Program), the dynamic behavior of random walks is displayed by plotting GENDYN's primary and secondary random walks during a time interval of several seconds. Both figures show the primary random walks in the left frame and the secondary ones in the right frame. Different random walks are plotted with different shadings. Note that the random walks are one dimensional: the amplitude random walk is plotted on the *y*-axis, and the time random walk is on the *x*-axis. A point in the plot of a secondary random walk, therefore, denotes a current time offset of a breakpoint to its preceding breakpoint as well as its current amplitude. A point in the plot of a primary random walk denotes the difference between the current time and amplitude values and those of the previous sample, taken as the step-width input for the associated secondary random walk.

In Figure 2a, the mirrors are set to maximum position (+100 and −100), and are therefore not visible in the plot. The primary random walks follow fractal curves, which are typical attractors of Brownian movement (Mandelbrot 1983). Their diffusion in space is isotropic, and spreads all over phase space (an ergodic process).

In contrast, the movements of the secondary random walks, taking the current locations of the primary ones as their input, are extremely anisotropic. When the current position of a primary random walk is close to zero (i.e., a small step width value), the secondary one is driven to one of the four corners of the phase space, depending on the sign of the step input. Locations in between are not stable; note the thin trajectories connecting the corners. They are passed through when the primary random walk crosses the border between positive and negative values. For the time offset, this behavior results in capricious pitch curves, typical for the *GENDY3* "solo voices," which remain fixed for a comparably long time and then suddenly jump into high or low registers.

When the primary random walks reach for greater values, the momentum for the movements

Figure 3. Trajectories of four parallel primary (left frame) and secondary (right frame) random walks (a and b). The primary ones are driven by the Cauchy distribution. Figure 3b is the same as Figure 3a, but the primary random walks (left frame) are restricted to a minimal interval of [–1.0..1.0] by a pair of barriers in both the amplitude (horizontal bar) and the time increment (vertical bar).



of the secondary random walks increases. If the momentum becomes significantly greater than the distance from the confining barrier, the secondary random walk jumps between two centers of "attraction" (see the pairs of spots of equal shade in the upper right corner of Figure 2a, in the right frame). This oscillating behavior (a dynamic equilibrium of period two) contributes to a supplementary richness of the sound.

In Figure 2b, in contrast to Figure 2a, the mirrors of the primary random walks are set to their minimum positions: –1 and +1. They constrain the random walks to values within the narrow interval of [–1.0..+1.0] (represented by the cross-hairs in the left frame of Figure 2b). Therefore, the sign of the step-width input for the secondary random walks always changes as the primary ones are constantly thrown across the zero border by the barriers. Consequently, the secondary random walks always change direction—there is no chance for stable attractors. The result is a chaotic fluctuation in pitch and amplitude, a "buzzy" and "noisy" sound very typical of some of the background voices in GENDY301.

The positions of the barriers for the secondary random walks also play an important role. Applied to the time random walks, they bind sounds to pitch registers. Applied to amplitude random walks, they "fractalize" the shape of the waveform by reflecting the amplitude values back and forth. If the space of the time random walks is reduced to zero, a phenomenon like "overtone music" can be perceived as the amplitude fluctuations cause transient inner symmetries within the otherwise stabilized waveform period.

The choice of the stochastic distribution functions that govern the primary random walks also has a strong influence on the sound dynamics. Figure 3 is the same as Figure 2, except that the distribution function is changed from hyperbolic cosine to Cauchy. In Figure 3, the primary random walks seem more dispersed in random-walk space, because the Cauchy distribution yields extreme values. The secondary random walks, in contrast, show a concentration toward the borders. This is the effect of the barriers reflecting excesses back toward the inside. This picture corresponds to the music: the hyperbolic cosine distribution is responsible for the delicate slow and smooth glissandi curves in *GENDY3*. The Cauchy distribution, in contrast, generates a pitch movement in steps, jumping from one pitch to another with a little portamento.

Conclusion

In his 1991 ICMC paper, reprinted in *Formalized Music* (Xenakis 1992), Xenakis pointed out that his GENDYN compositions are created "out of the void" by probabilities only, comparable to a "big bang." Our closer look at the dynamics of the sound-creation process reveals that the specific constraints by which these blindly raging probabilities are "tamed"—both by the specific design of the computing algorithm and the choice of its parameters—are influential on the acoustic quality of the result. It seems that the "few premises," as Xenakis humbly called them in his paper, i.e., the algorithmic "boundary conditions" and parameters he chose, are more important for the specific character of a composition like *GENDY3* than Xenakis himself might have believed at the time of composing.

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