PHINGEN: A PHYSICALLY INFORMED STOCHASTIC SYNTHESIS GENERATOR

Luc Döbereiner

University of Music and Performing Arts Graz
Artistic Doctoral School, Graz, Austria
luc.doebereiner@gmail.com

ABSTRACT

This paper describes a method for the synthesis of sound that we have termed Physically Informed Stochastic Synthesis. The starting point of the investigation which has led to the development of this method was Iannis Xenakis's Dynamic Stochastic Synthesis. Xenakis's method is based on the idea of constructing waveforms by linearly interpolating breakpoints. The method described in this paper is an attempt to move beyond Dynamic Stochastic Synthesis by replacing the linear interpolation with a physical model. The system can be seen as a dynamic wavetable and is general enough to form the basis for a variety of possible synthesis methods. Although the method is not based on psychophysical insights, it has many similarities to Scanned Synthesis. This paper describes the method's workings and how it relates to Xenakis's method and Scanned Synthesis. The parameters and some results will be described.

1. INTRODUCTION

1.1. Xenakis's Stochastic Synthesis

The composer, architect, and music theorist Iannis Xenakis worked on the development of microsound synthesis from the 1960s until the 1990s. In the mid 1950s, Xenakis started using stochastic principles for the composition of instrumental music and he first proposed applying these prinicples to the digital synthesis of sound in the context of his Stochastic Music Program (ST Program), which he started to develop in the early 1960s [6]. In the 1970s, he first developed implementations of Dynamic Stochastic Synthesis, which he used in the pieces *Polytope de Cluny* (1972) and *La Légende d'Eer* (1977). Here, however, it was used in conjunction with instrumental and other recorded sound. The method used *La Légende d'Eer* is described in the text "Dynamic Stochastic Synthesis" [11, Chapter 13]. In the 1990s, Xenakis developed the GENDY program, which extended Dynamic Stochastic Synthesis by second-order random walks [11, Chapter 14].

Xenakis considered Fourier analysis to be the wrong starting point for digital sound synthesis. Rather than starting from a unit element, Xenakis proposed to start from a "disorder concept and then introduce means that would increase or reduce it." [11, p. 246] He proceeded to use stochastic procedures directly for the construction of wave forms. Xenakis used random walks to vary a probabilistic wave form in amplitude and time. He was searching for a general method which could produce "all possible forms from a square wave to white noise." [11, p. 289] It is indeed possible to generate a continuous transition from noise to a static periodic sound with Xenakis's model.

We cannot go into details about Xenakis's models here[1], but we understand them as experimental starting points for the method discussed here. For Xenakis himself, Dynamic Stochastic Synthesis was only a beginning.

> This approach can be compared to current research on dynamic systems, deterministic chaoses or fractals. Therefore, we can say it bears the seed of future exploration. [11, p. 293]

1.2. Physically Informed Non-Standard Synthesis

There is an underlying assumption in Xenakis's models, which receives relatively little attention, but which nevertheless severely conditions it: the linear interpolation between the breakpoints. Xenakis's models share this feature with other "non-standard"[2] synthesis methods such as Gottfried Michael Koenig's SSP, although Koenig initially planned to use a half-cosine interpolation.

In his text "New Proposals in Microsound Structure" [11, Chapter 9], Iannis Xenakis proposes seven methods for stochastic microsound synthesis. All of the methods, however, are based on the idea of constructing wave forms from straight lines. This does not only impose a strong limitation on the possible sound output, but it is also far removed from sound as a physical phenomenon. Xenakis's "stochastic polygonal wave forms" [11, p. 296] are essentially based on a visual and geometric thinking, not on one concerned with pressures and forces.

The "non-standard" synthesis methods developed by Xenakis, Koenig and others opened up a new path for composing sound. We propose a new continuation of this path, which we term Physically Informed Non-Standard Synthesis. The goal is to preserve the radically explorative

[1] See [4] and [6] for detailed descriptions of Xenakis's models.

[2] The term was introduced by Steven R. Holtzman [5]. For more recent discussions on "non-standard" synthesis see [8] and [1].

and compositionally motivated approach to sound synthesis of the „non-standard" systems and combine it with ideas of sound from physics and digital signal processing. The method described in this paper is a first attempt in this direction. We are trying to go beyond Dynamic Stochastic Synthesis by replacing the linear interpolation with a physical model.

2. PHYSICALLY INFORMED STOCHASTIC SYNTHESIS

Instead of a series of interpolated breakpoints, the method presented in this paper is based on a circular sequence of masses connected to adjecent masses by springs. This can be seen as a model of a circular string. The circularity (the last and the first mass are connected) avoids problems of discontinuity.

The masses can be deflected according to any signal input. The implementation is open and general enough to allow for various different types of synthesis and control possibilities. In this context, we will concentrate on two stochastic methods to control the positions of the masses: second-order random walks and random impulses. By second-order random walks, we mean that the successive positions of a random walk are the step sizes of a second random walk whose successive positions are the output values.

There are masses that can be controlled by external processes and masses whose positions cannot be controlled parametrically. Dynamic Stochastic Synthesis's idea of having a number of stochastic processes control breakpoints of a periodic waveform is still at the heart of PhinGen. The difference is that the waveform is not a polygon constructed of straight lines between the breakpoints, but that a series of masses connected by springs are forming the interjacent shapes. The masses whose positions can be controlled correspond to the breakpoints in Dynamic Stochastic Synthesis. This is the reason why some masses are controllable and others are not and it is also one of the main differences to Scanned Synthesis.

The number of masses whose positions can be controlled and the number of masses in between the controllable masses together determine the total number of masses. The total number of masses is therefore the number of equally spaced controllable masses (determined by the parameter `nMasses`) multiplied by the number of masses in between (determined by the parameter `distance`) two controllable masses.

The vertical positions of all masses are periodically read at a given frequency and used to construct the wave form. The method thus has strong similarities to Scanned Synthesis and dynamic wavetables.

Figure 1 depicts the circular string. The darker cubes represent the masses whose positions can be parametrically controlled. There are two controllable masses and the parameter `distance` is four.

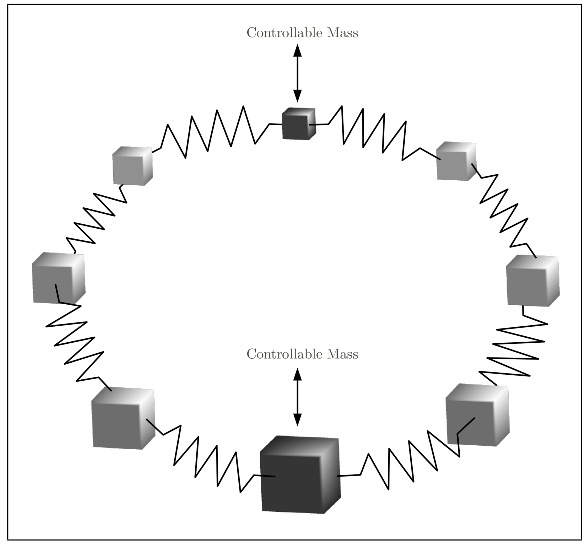

Figure 1. A circular string with two controllable masses.

2.1. Relations to Scanned Synthesis

Generally, the method presented here can be seen as a special case of Scanned Synthesis. There are, however, a number of differences. Scanned Synthesis, as described by Verplank et al. is based on motor control abilities and is designed to be "directly manipulated by motions of the performer." [10] The scanned dynamic system therefore moves at "haptic" frequencies below 15 Hz. However, the method described here is controlled by stochastic processes, not by the motions of a performer. Moreover, the frequencies at which the underlying system fluctuates are not limited to a specific range. An audible signal might still be produced if the scanning frequency is below audio rate, if the fluctuation speed of the connected masses is high enough. The separation of timbre and pitch is thus not as strict as in the case of Scanned Synthesis.

Boulanger et al. [2] have shown how Scanned Synthesis can be extended by using higher dimensional structures and different connection schemes for the masses. This allowed for the design of different scanning trajectories. The Physically Informed Stochastic Synthesis generator described here is limited to a circular string-like model and a circular scanning trajectory, because it is still understood as an extension of Xenakis's Dynamic Stochastic Synthesis.

2.2. Implementation

The method is implemented as a plug-in unit generator[3] (UGen) for SuperCollider [7] and is written in the programming language C++. SuperCollider was chosen, because it supports real-time synthesis and because of the variety of already existing UGens with which the UGen can be combined. The implementation follows Cyrille Henry's physical modeling library for pure data (pmpd) [3].

[3]The source code is release under the GNU GPL and can be downloaded from `http://www.doebereiner.org`.

3. PARAMETERS

Figure 2 shows the parameters of PhinGen. We will describe each of these parameters in turn.

```
PhinGen(frequency,
        stiffness,
        viscosity,
        damping,
        mass,
        nMasses,
        distance,
        updateFrequency,
        signalArray)
```

Figure 2. The parameters of the UGen

The first parameter is the frequency which controls the speed at which the vertical positions of the masses are read, similarly to a wavetable oscillator. The positions are interpolated using a cubic interpolation.

The next four parameters determine the physical properties of the masses and the springs which connect them. These parameters can be changed in real-time, but should be modulated with caution. The second parameter controls the stiffness or rigidity of the springs connecting the masses. The third parameter is viscosity, it is a damping factor related to the difference of velocities of the two connected masses. The fourth parameter is a second damping factor that relates to the velocity of each mass individually, it is thus not a symmetric factor. The fifth parameter determines the weight of each mass.

The sixth parameter controls the number of masses (and springs) that constitute the circular string. This parameter can also be modulated in real-time and has a significant influence on the resulting sound, a greater number of masses results in a sound with more high frequency content. The seventh parameter controls the distance of two controllable masses, i.e. the number of interjacent masses. This parameter controls the 'granularity' of the model. The eighth parameter determines the frequency at which the model will be updated, i.e. the rate at which the forces and positions are calculated. In order to avoid any discontinuities, the generator interpolates between the states of the system. If this frequency is equal to the `frequency` parameter, the model will updated after each period.

The last parameter has to be an array of audio signals with a length equal to `nMasses` or greater. The positions of the controllable masses will be set by these signals at a frequency determined by `updateFrequency`.

4. RESULTS

We have used the described generator in two setups:

- The positions of the masses are controlled by second-order random walks.
- The positions of the masses are controlled by random impulses.

Both setups can create a great variety of diverse sounds. They range from string-like sounds (plucked string sounds if impulses excite the system) to sonorities similar to the noisy textures of Xenakis's work *S.709* (1994). The physical properties of the system and its stochastic excitation create a complex and inter-depended network of parameters whose effects are less predictable and harder to control than Dynamic Stochastic Synthesis. Furthermore, the physical model adds an internal timbrical dynamic and varying spectrum that is not present in Dynamic Stochastic Synthesis.

Xenakis advocated the application of stochastic process for the synthesis of sounds, because of their ability to render sounds with rich and complex transients. He rejected additive synthesis on the grounds that it was unsuitable for creating such sounds:

> 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. 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, [...]. It is as though we wanted to express a sinuous mountain silhouette by using portions of circles. [11, p. 244]

A characteristic feature of Physically Informed Stochastic Synthesis is that the synthesis parameters also effect the attack and the decay of the sound. The model creates sounds with complex transients whose characteristics can be changed by altering the physical properties of the system.

5. FUTURE EXTENSIONS

The generator is sufficiently general to allow for arbitrary signals to control the movable masses. The experimentation with various stochastic control procedures has already been a fruitful stimulus for this work and should be further pursued.

The underlying model is still uniform. In their paper on Scanned Synthesis, Verplank et al. write:

> In general the most interesting sounds involve nonuniform strings in which the damping, the tension, and the centering springs vary along the string. [10]

Stochastic control should be extended to the properties of the underlying circular string model, and should be varying the damping, weight, and stiffness non-uniformly.

6. CONCLUSION

Our initial motivation was to extend Xenakis's Dynamic Stochastic Synthesis by combining it with a physical model. In doing so, we have developed a synthesis method which is very close to Scanned Synthesis, although it is rooted in very different initial premises. While Scanned Synthesis is based on psychophysical insights and an „understanding of the properties of spectral time variations that [. . .] the brain likes" [10], Dynamic Stochastic Synthesis has rather grown out of compositional principles and experience and does not assume the existence of a scientific truth about what „the brain likes." Nevertheless, the models resemble each other.

Xenakis bemoaned the lack of development in the area of sound synthesis. He said that, "Scientists simply lack imagination in a field [sound synthesis] which lies outside mathematics or physics." [9, p. 76] We hope that this synthesis method can be a step towards overcoming the standard/non-standard divide and a compositionally motivated approach to sound synthesis that can contribute to destabilizing the demarcating border between artistic and scientific discourse.

7. ACKNOWLEDGEMENTS

The author would like to thank Professor Gerhard Eckel of the Institute of Electronic Music and Acoustics of the University of Music and Performing Arts Graz for his suggestions which initiated the development of the described method and Paul Berg of the Institute of Sonology in The Hague for his valuable comments on this paper.

8. REFERENCES

[1] P. Berg, "Composing sound structures with rules," *Contemporary Music Review*, vol. 28, no. 1, 2009.

[2] R. Boulanger, P. Smaragdis, and J. ffitch, "Scanned synthesis: An introduction and demonstration of a new synthesis and signal processing technique," in *Proceedings of the 2000 International Computer Music Conference*, Berlin, 2000.

[3] C. Henry, "Physical modeling for pure data (pmpd) and real time interaction with an audio synthesis," in *Proceedings of SMC Conference 2004*, Paris 2004.

[4] P. Hoffmann, "The new gendyn program," *Computer Music Journal*, vol. 24, no. 2, pp. 31–38, 2000.

[5] S. R. Holtzman, "An automated digital synthesis instrument," *Computer Music Journal*, vol. 3, no. 2, pp. 53–61, 1979.

[6] S. Luque, "The stochastic synthesis of iannis xenakis," *Leonardo Music Journal*, vol. 19, pp. 77–84, 2009.

[7] J. McCartney, "Supercollider: a new real time synthesis language," in *Proceedings of the 1996 International Computer Music Conference*, Hong Kong, 1996.

[8] P. Thomson, "Atoms and errors: towards a history and aesthetics of microsound," *Organised Sound*, vol. 9, no. 2, 2004.

[9] B. A. Varga, *Conversations with Iannis Xenakis.* Faber and Faber, 1996.

[10] B. Verplank, M. Mathews, and R. Shaw, "Scanned synthesis," in *Proceedings of the 2000 International Computer Music Conference*, Berlin, 2000.

[11] I. Xenakis, *Formalized Music.* Pendragon Press, 1992.