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An Analysis of "nyx" (2017), a Computer Music Work by Kerry Hagan

Abstract: Kerry Hagan composed "nyx," a real-time computer music work, in 2017. The key inspiration of "nyx" is noise, which Hagan achieves through chaos theory. In Greek mythology, Nyx was born from Chaos, and she is the deity of the night. In the same way, two key materials of the work are chaotic synthesis and, at a higher level, the use of several random algorithms. To analyze "nyx," I apply a specific methodology that considers both the sound and the computer code. In fact, I consider code as a medium through which Hagan has realized her musical ideas, that is to say, seeing code as a support for musical ideas, and not only as a computing object.

This article has two main sections: The first describes Hagan's techniques through Pure Data code, and in the second the music is analyzed in its canonical form, describing the structure of the work. Finally, I argue that "nyx" involves many levels of noise, from the sound design, to the use of random algorithms, and lastly to the inspiration from Greek mythology to structure the work.

Kerry Hagan's computer music work "nyx" (2017) has been publicly presented in well-known music venues including BEAST FEaST (at the University of Birmingham in the UK), the Cube (at the School of Performing Arts, Virginia Tech), and in other facilities with advanced spatialization systems. The work is shared by Hagan on her website, kerrylhagan.net, where one can find a stereophonic audio file as well as the Pure Data patch that permits us to see the computations and hear the work.

The work "nyx" is part of a series of computer works by Hagan that were inspired by noise: "Morphons and Bions" (2011), ". . .of pulses and times. . ." (2012), "s/d" (2015), and finally "nyx." The pieces in this "noise series" strictly use digital synthesis, without any recorded samples, and are "real-time compositions" in the sense that they contain random algorithms so that each realization of a particular composition is different, at least in part. Hagan has explained her aesthetic inspiration from noise (Hagan 2012) and, for the first work of the series, "Morphons and Bions," she has explained how noise has been used for the material of the work (Hagan 2013). In both papers, Hagan also explains the reason behind this series.

At first, there is a wish to extend musical material with synthesis:

> I always worked with recorded sound for my electroacoustic compositions. The richness and variety of acoustic sounds provided enough sonic data for processing and manipulation. Synthesis sound seemed flat, mundane, and plain by comparison. I decided that working with synthesis would be my next challenge (Hagan 2013).

And then, with a goal to make rich noise synthesis, comes the deep inspiration from noise:

> I decided that it was the noise of acoustic sounds that made them richer. . . I approached synthesis from the basis of noise, using noise as the foundation of every synthesis method (Hagan 2013).

Therefore, the use of noise with synthesis techniques is crucial in the works of the series. With "nyx," Hagan used new material that is coherent with noise, namely, chaotic mathematical functions. Two standard chaotic functions, Gingerbreadman and Ikeda, are used. Moreover, all the sound sources of the work come from those chaotic functions. Even if the sound design level is essential for "nyx," this is not the only level influenced by the notion of noise. I can see two others: one concerning the mesoform (i.e., a middle layer of musical form) and another for the aesthetic. For the mesoform, in each work there is the use of random algorithms to determine, within a section, the behavior of the synthesis techniques. In this way, each realization of the same work will be different, within constraints. As we will see, this noise at the mesoform level poses problems for the

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analysis, as it becomes inappropriate to consider only one realization of the work—this is one good reason for considering the patch in analysis: "nyx" exists not only as an audio signal but also as a patch.

The highest level of noise concerns aesthetics. In relation to the preceding chaotic functions, Hagan finds inspiration in Greek mythology, from which the name of the work comes: Nyx is the name of the Goddess of night and—together with her brother Erebus, the god of darkness—was born from Chaos. They were the first two divinities who gave birth to the Greek gods. I suggest that the structure of the work can be seen in this "creation process," starting from chaos, with the raw noise of the chaotic functions at the beginning, and proceeding to creation, with one last pitch gesture from low to high.

Before discussing the work, I will introduce two points that explain the method used to analyze computer music work.

My first point can be explained if one considers the material objects of computer music. The first obvious material object one can think of is the audio signal of the work. In our digital era, the audio signal is stored in computer files, permitting anyone to hear the music, if the files are publicly accessible. This object is perhaps obvious, because it is a more convenient way to permit people to appreciate the work—as Pierre Schaeffer said, "music is made to be heard" (cf. Chion 2009, p. 35). The second material object of computer music is the code (i.e., the instructions written by the composer in a programming language), which computes the audio signal of the work. My first point is related to the existence of this code in computer music. Following the argument made in Otto Laske's article, "The Computer as the Artist's Alter Ego" (Laske 1990), I see the code as an object with which composers create and think of their music. Therefore, to analyze computer music, the code has to be studied, because it sheds light on the work in a different way than the listening does (cf. Di Scipio 1995; Risset 2001; Battier 2003; Zattra 2015). Nevertheless, there could be a danger in following this route, in which one can be dazzled by the code and can forget to listen to the work. To avoid this, my first point is that to analyze computer music, both code and audio signal have to be considered. They enrich each other (for a deeper viewpoint, cf. Larrieu 2019).

My second point is related to the analysis of computer music works that contain indeterminate elements. In "nyx" we find random processes, so that each computation, each calculation of the audio signal, is different. Another way to explain this is to focus on the relationship between the code and the audio signals: One program can produce many audio signals, and all of them belong to "nyx," between code and audio signals there is a one-to-many relationship. To reveal this relationship, I call the result of one computation an *actualization*, so that the actualizations of one work are the many audio files that the code can produce. This one-to-many relationship impacts the way of analyzing a work. In fact, an analysis focusing only on one actualization, dealing with time and sound morphology, will not be suitable, because it does not account for the production of actual sounds or the level of randomness in their production. One sound present at a specific time in one actualization will not necessarily be present in another actualization. My second point is that the analysis of works containing indeterminate processes has to consider many actualizations, so that the analyst can evaluate the level of randomness in the production. Nick Collins (2008) addresses the same questions in the context of generative computer music.

The analysis presented in this article contains two main sections. The first, Music Modules, concerns those of Hagan's techniques captured inside the Pure Data (Pd) patch, for which I use the concept of *music modules*. Music modules are understood here as the grouping of many elements inside the patch, which a composer uses to realize musical material. In this definition, music modules are not merely technological, they belong to a musical level and result from the subjective understanding of the analyst or composer. I differentiate music modules, which are higher-level constructs by a composer, from lower-level technological modules, like reverberation, which are common to the field of sound engineering (for further discussion, see Larrieu 2018, p. 99). The second main section, Music Analysis, concerns the actualization of the work; there I will analyze the temporal structure and the sounding elements of the work.

Finally, because "nyx" has been played on important multichannel systems with highly specific configurations—for example, at the Cube in the School of Performing Arts at Virginia Tech, the spatialization was on 124 channels (cf. Lyon 2016)—there are several versions of the work. In fact, when Hagan is invited to play the work on such a system, she rewrites the spatialization, thus composing a new, ad hoc version. In this analysis, rather than considering multichannel spatialization, I will focus on the stereophonic version of "nyx."

The Pd patch has been made publicly available by Hagan on a scientific repository (https://doi.org/10.5281/zenodo.3971610) using a Creative Commons license, so that now anyone can download, share, and cite the patch; thanks to the persistent identifier, people can be sure of referring to the same version. The patch runs on Vanilla Pd, the version distributed by Miller Puckette, as opposed to versions from other developers, who build on and extend Puckette's version.

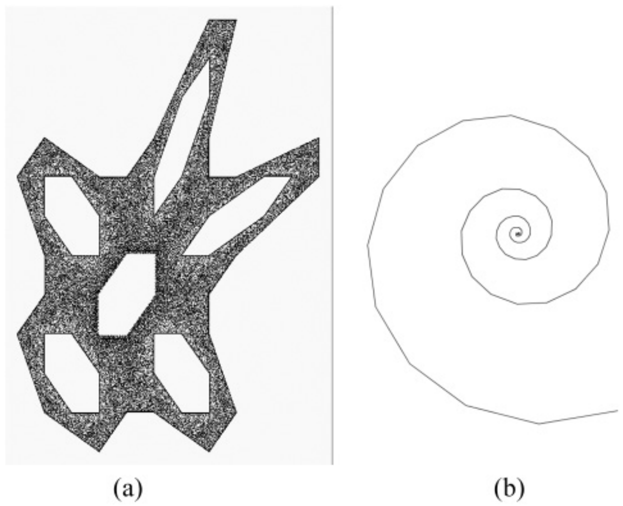
Music Modules

One can differentiate three music modules in "nyx." The first is a chaotic synthesis module, generating noise with chaotic functions; the second is a phase vocoder module, which applies time-scaling and pitch-shifting to the previous signals; and the last is a spatialization module.

Chaotic Synthesis

Using chaotic functions as synthesis techniques is not new in computer music. For example, in the 1990s one can find an article (Slater 1998) where the author combines a chaotic function (named "Ueda attractor") with frequency modulation techniques. With "nyx," the use of chaotic functions is different: The idea is not to combine chaotic functions with synthesis techniques but to directly use these functions to produce sound signals—and moreover to use them as musical material. Hagan used two standard functions, named Gingerbreadman and Ikeda, both discrete and in two dimensions.

Figure 1. Sample representations of two chaotic functions: Gingerbreadman function with $x_0 = -0.1$ *and* $y_0 = 0.2$ *(a); Ikeda function with* $x_0 = 1$, $y_0 = 0.3$, *and* $u = 0.94$ *(b).*



Gingerbreadman and Ikeda Functions

To use these chaotic functions, the two corresponding equations must be implemented. Gingerbreadman:

$$x_{n+1} = 1 - y_n + |x_n|,$$
$$y_{n+1} = x_n.$$

and Ikeda:

$$x_{n+1} = 1 + u(x_n \cos(t_n) - y_n \sin(t_n)),$$
$$y_{n+1} = u(x_n \sin(t_n) + y_n \cos(t_n)),$$

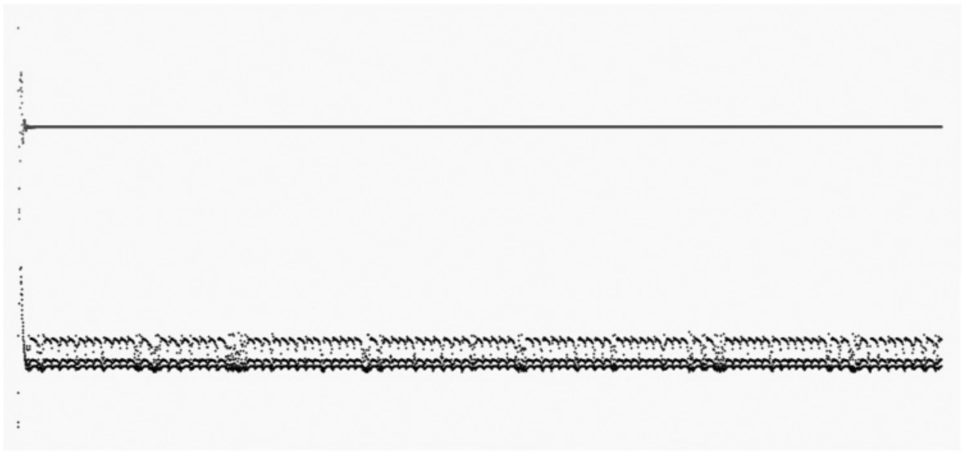
where u is a parameter and t_n is defined as

$$t_n = 0.4 - \frac{6}{1 + x_n^2 + y_n^2}.$$

As one can easily see, the Gingerbreadman function is computationally quite simple, with only an absolute value function and simple arithmetic. The Ikeda function is more complex, with layered trigonometric functions, as well as a specific parameter called u.

Because these functions are discrete with two dimensions (x and y), it is appropriate to represent them in a two-dimensional space. In Figure 1a,

Figure 2. Waveform of Ikeda × signal: with the original function (a) and the modified function (b). The time span is nearly 135 msec.



the Gingerbreadman function is represented with 100,000 iterations, with each of the outcomes (x_n, y_n) as coordinates of one point.

The shape of a gingerbread man can be better recognized if one rotates the figure 135 degrees clockwise.

Figure 1b represents the Ikeda function. It was obtained with 10,000 iterations and by connecting each successive point, (x_n, y_n) to (x_{n+1}, y_{n+1}).

The Ikeda function looks like a spiral, and as the value of u increases, the tighter the resulting spiral—a value of 0.2 will give something like a line, and a value of 0.99 will give many spiral loops.

Sound Synthesis with Chaotic Functions

Hagan's idea is not to combine the chaotic functions with oscillators, but to listen directly to the chaotic functions–as it were, "to plunge into the chaos." To realize this, the outputs of the functions are directly used as sample values. The functions are, therefore, computed near the sample rate (44.1 kHz in "nyx"). This is done with one peculiarity of Pd, where one can set a metronome measured by samples. Finally, to avoid artifacts such as clicks, an audio ramp is used when the function runs slower than the sample rate.

As we have seen, the functions have two dimensions, x and y, which is suitable for image rendering. To adapt these functions to the audio domain, each dimension is used as a separate audio signal: The output values from the x dimension produce one audio signal and those for the y dimension another. Thus, each chaos function implemented produces two independent audio signals, referred to as x and y.

Before going further, I must note a mathematical error in the patch that occurs in the implementation of the Ikeda function. One principle of the Ikeda function is that, as the iteration progresses, the difference between results diminishes (i.e., the more they tend towards an attractor). Therefore, because we are concerned with audio samples, it is apparent that after 1 second of sound (iteration 44,101) the sample values would be almost static, thus producing no sounds. However, the implementation made by Hagan does produce sounds. This comes from a small error inside the calculation of t_n, where one can read $t_n = 0.4 - 6/(1 + 2 \times y_n^2)$ instead of $t_n = 0.4 - 6/(1 + x_n^2 + y_n^2)$. Figure 2 compares results of 6,000 iterations for the original function and the function as actually implemented. As is apparent, the waveform of Ikeda's original function is quickly null, whereas the one with the error in the t_n calculation produces sound.

Describing the resulting sound is not an easy task because it is unrelated to perceptible components, such as sine waves, formants, or spectral distribution. Indeed those "perceptible components" cannot shed light on signals produced by chaotic functions. Unlike the visualization in Figure 1, the

Figure 3. Waveform (a) and spectrogram (b) of Gingerbreadman × signal for 2 seconds. (All spectral analyses are made with a Hann window: size 1,024 samples, threshold −43 dB.)

Figure 4. Waveform (a) and spectrogram (b) of Ikeda x *signal for 2 seconds.*

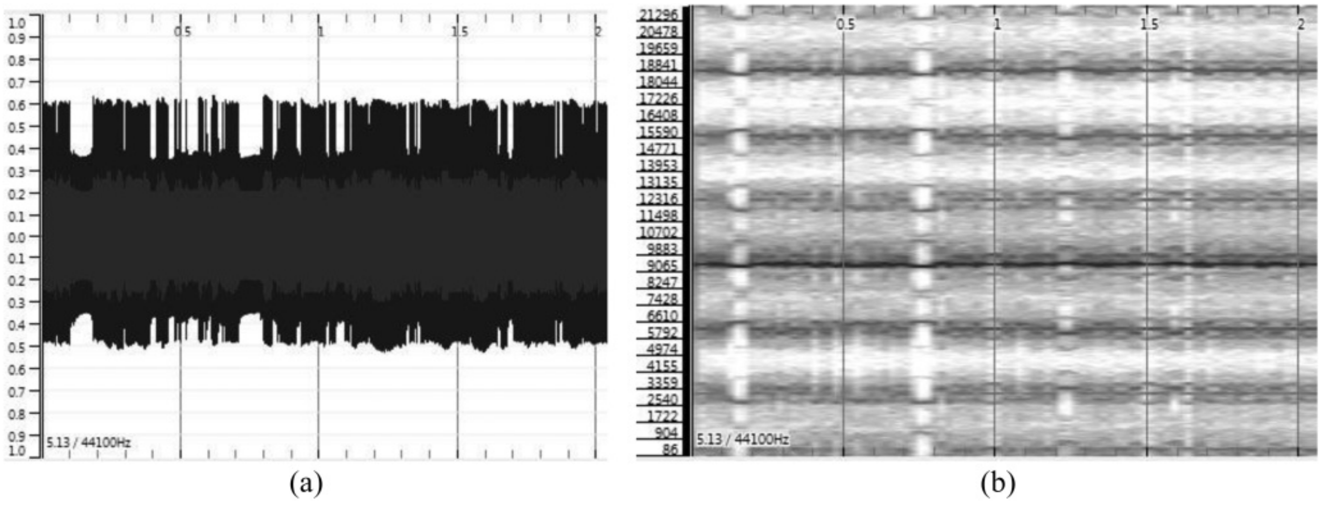


Figure 3

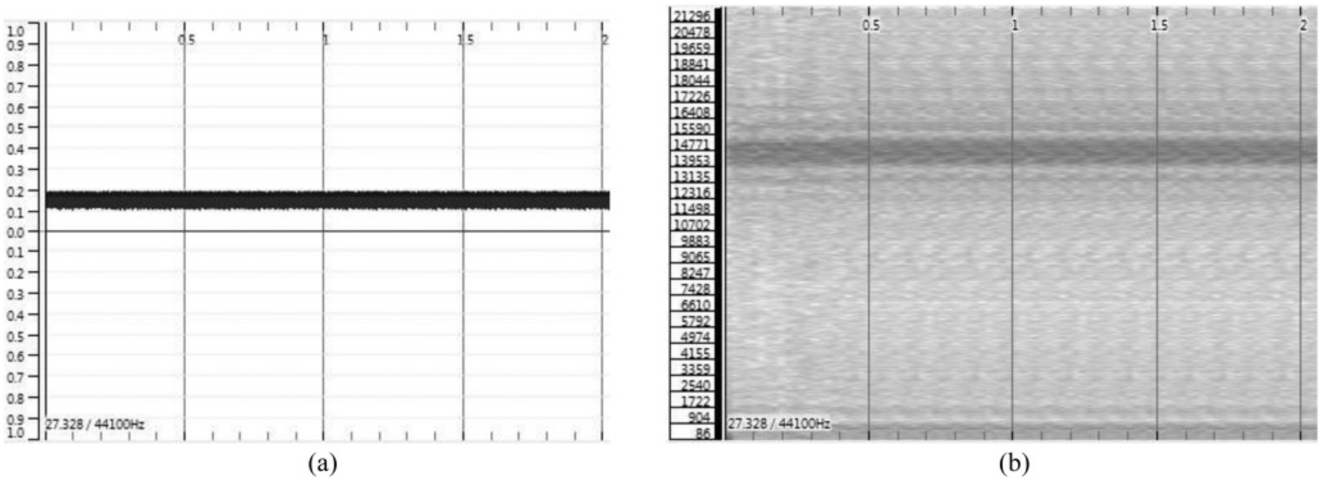


Figure 4

sound produced does not have a familiar pattern. Here, what is produced is fundamentally noise: We cannot immediately hear any spectral or temporal organization.

As can be seen, the Gingerbreadman signal (see Figure 3) is complex, with a pattern that repeats itself vertically in the spectrogram. It is impossible, however, to hear any patterns. The sound we hear is high (cf. the black line near 9.5 kHz) and made of infinitesimal movements dispersed across the spectrum scale. The Ikeda function is also high and clearly evinces a fast cyclic pattern (see Figure 4).

I describe these signals here only for an analytical purpose, however; one cannot hear them independently in "nyx." In fact, to add complexity, Hagan implemented three distinct Gingerbreadman and two distinct Ikeda functions, which can be run at different rates. Thus, the chaotic synthesis module produces no fewer than ten signals: Five chaotic functions are implemented (three Gingerbreadman and two Ikeda) with each producing two signals (x and y).

Control

At this point in the analysis, it would be fruitful to focus on the controls present in the chaotic synthesis. First, because Hagan deals with mathematical functions, there is a series of low-level parameters that must be noted. Each x_0 and y_0 of the Gingerbreadman functions and each x_0, y_0, and u of the Ikeda functions must be defined at the start of the computation. This is done during initialization, when the patch is open or reset. Even if these values are at a low level, it is important to note them, because it is through these values that the module produces different signals. The last low-level parameters are the ones that modify the amplitude of the signals. There is one on each signal, with variables 1gingXfl and 1ikedXfl. The variable naming convention is: instance number, function name, x or y signal, "f" for a fader, and "l" for line object generating a ramp. They are worth noting because, as we will see, random processes are applied to them.

The next control is at a higher level of abstraction and is more closely linked to the perception of the sound: the computational rate of the functions. There are five variables for controlling the rates of the five instances, named 1gingratel, 2gingratel, 3gingratel, 1ikedratel and 2ikedratel. Again the ending "l" stands for line, meaning a ramp function is used. Functions with changing rates are significantly more perceptible to the listener than are the low-level parameters noted above. The standard rate is the sampling rate, 44.1 kHz, and one key action Hagan executes is to slow down these particular rates, which will decrease the perceived pitch of both the x and the y signals.

Algorithms

Two simple algorithms with the same behaviors are present in the module. The first affects signal amplitude, the second affects the computational rates of the chaotic functions. Both algorithms simply generate a pairs of points (x, y) where x is a destination value and y a time in seconds to achieve that destination. Also, once the point x has been achieved in the desired time y, a new pair of values is generated. Thus, once activated—with Boolean variables randlevelsorig and randrate for amplitudes and rates, respectively—the algorithm will continuously generate new values. Each chaos function changes independently in amplitude and rate with these variables.

For amplitude, time y is selected randomly in each implementation in the interval [1, 5] seconds with a step of one, and amplitude values are selected randomly in an interval that changes according to instances. Table 1 describes the amplitude calculation.

For the rate algorithm, the time is selected randomly in interval [10, 29] seconds and the destination point x is selected randomly with the distribution shown in Table 2.

Table 3 describes the meaning of chaotic module controls.

Table 1. Scales of Random Amplitude Algorithm

Variables	*Minimum Value*	*Maximum Value*
1gingxfl, 1gingyfl	50	74
2gingxfl, 2gingyfl	70	94
3gingxfl, 3gingyfl	46	70
1ikedaxfl, 1ikedayfl	80	104
2ikedaxfl, 2ikedayfl	70	94

Values are in decibels, with 100 corresponding to unity gain, following Pure Data conventions.

Table 2. Scales of Random Rate Algorithms

Variables	*Minimum Value*	*Maximum Value*
1gingrate	5	9
2gingrate	45	55
3gingrate	1	5
1ikedarate	60	100
2ikedarate	1	10

Table 3. Meanings of Chaotic Synthesis Controls

Variable	*Type*	*Meaning*
1gingratel 2gingratel 3gingratel	float or list	Change the rate of one Gingerbreadman instance
1ikedratel 2ikedratel	float or list	Change the rate of one Ikeda instance
1gingXfll 2gingXfll 3gingXfll	float or list	Change the amplitude of the *x* signal from one Gingerbreadman instance
1gingYfl 2gingYfl 3gingYfl	float or list	Change the amplitude of the *y* signal from one Gingerbreadman instance
1ikedXfl 2ikedXfl	float or list	Change the amplitude of the *x* signal from one Ikeda instance
1ikedYfl 2ikedYfl	float or list	Change the amplitude of the *y* signal from one Ikeda instance
randlevelsorig	Boolean	Activate random amplitude algorithm
randrate	Boolean	Activate random rate algorithm

Phase Vocoder

The second module is a phase vocoder, which is applied to the chaotic synthesis signals. It permits one to change, independently and in real time, the duration and tuning of an incoming signal via time stretching and pitch shifting, respectively. The implementation is taken from the description given by Miller Puckette (2006, p. 292) in his seminal publication *The Theory and Technique of Electronic Music*, and is also present as an example in the Pd library (see the patch named I07.phase.vocoder.pd). In this analysis I will not describe Miller Puckette's implementation. A higher level of mathematics would be needed (complex numbers, fast Fourier transform) and, more importantly, it is not something developed by Hagan for "nyx." I will therefore focus on how she has used this technology in her work.

Usage

The phase vocoder is applied independently to each of the ten signals produced by chaotic synthesis. It is used to change both speed and tuning (see Table 4 to view all phase vocoder controls). Speed, once set, remains static throughout, whereas tuning changes all through the work. Concerning the speed, each signal of the chaotic module is slowed down to one fifth of its original speed. Slowing down all noise signals is valuable, because the raw signals are made up of infinitesimal movements. The goal, however, is not to produce something identifiable. Indeed, these new slowed-down signals do not replace the "raw" signal but are distributed simultaneously instead.

Concurrently, the tuning parameter is used to add short gestures in pitch. It will basically change the perceived pitch of noise signals. All the transformations lower the pitch, transposing the

Table 4. Phase Vocoder Controls

Variable	*Type*	*Meaning*
1speedl 2speedl . . . 10speedl	float or list	Changes the speed of incoming signal (stretching)
1gpvXfl 2gpvXfl 3gpvXfl	float or list	Changes the amplitude of the *x* signal from one Gingerbreadman instance
1gpvYfl 2gpvYfl 3gpvYfl	float or list	Changes the amplitude of the *y* signal from one Gingerbreadman instance
1ikedXfl 2ikedXfl	float or list	Changes the amplitude of the *x* signal from one Ikeda instance
1ikedYfl 2ikedYfl	float or list	Changes the amplitude of the *y* signal from one Ikeda instance
randlevelspvoc	Boolean	Activates random detuning algorithm
decreasedetune	Boolean	Activates a sequence to continuously reduce detunes range

signals downward between 0 and 8,000 cents (almost seven octaves). Therefore, the phase vocoder, with its speed reduction and lowering of pitch, is used to add another layer of noise, intensely enriching the noise of the chaotic synthesis.

Algorithms

There are also two random algorithms inside the phase vocoder. The first is the same as that used in the chaotic synthesis, which changes the amplitude of the *x* and *y* signal pairs. The second permits modification of the tuning signals. This modification also uses randomness, but in a new way.

The random detuning algorithm generates a pair of values (*x*, *y*), with *x* being the transposition value and *y* the time. The transposition value is reached directly, without a duration value. The second value, *y*, is a time lapse before a new transposition value *x* is calculated. Therefore, this random detuning algorithm does not generate a ramp of values, but an instantaneous change.

The time lapse is selected randomly in the interval [10, 19] seconds, and the transposition is also selected randomly in the interval [−8000, −1] cents. The values are generated once the algorithm is activated, with a variable named detune.

Finally, there is a second input inside this algorithm that, once activated, progressively reduces the range of detuning values. At first, the range will ramp continuously from [−8000, −1] to [−7000, −1] in 60 seconds, then to [−6000, −1] in 36 seconds, and so forth, creating a sequence of 3:30 minutes with this key correlation. The more time progresses, the smaller the range of random detuning. Indeed, at the end of the main section (duration of 3:30 min), detuning values are zero, and there is no more transposition.

Spatialization

The last module of "nyx" to discuss is that of spatialization. It allows the placement of a signal in

Figure 5. Pseudocode illustrating the spatialization algorithm.

Figure 6. Pd patches for the spatialization model (a) and the expon abstraction (b).

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Run randomDur() and spat() functions, wait for duration and start them again, etc.

randomDur() function is
    d = random(0.001, 1) with a step of 0.001
    duration = -log(d) / 0.0009

spat() function is
    x = random(0.001, 0.999) with step of 0.001
    smoothx = line(x, duration)
// line() outputs a floating point value that ramps
// continuously to x within the specified time duration.
// Once x is reached, the output stops ramping.

    leftChannel = cos(smoothx * PI/2)
    rightChannel = sin(smoothx * PI/2)
```

Figure 5

stereophonic space. It is applied each time a signal is diffused, so on the ten signals coming from the chaotic synthesis module and the ten signals coming from the phase vocoder module. Consequently, one can see that spatialization is not made "by hand" but with the use of small random algorithms. These algorithms have the same behavior as those previously discussed. They generate a pair of values (x, y) where x is a position in the stereophonic space and y a duration. What is new here, however, is that duration is calculated with an exponential function. Figures 5, 6, and 7 describe calculations made by the algorithm.

As shown in Figure 7, the use of the exponential function allows Hagan to incorporate noncyclic behavior (Hagan 2018, p. 119). The mean of outcomes is nearly 770 milliseconds (mean = 0.69315 / 0.0009) but because of the exponential function it will vary widely. Therefore, the spatial movement occurs at the scale of a "note": near to one second. Because movements are not going from full left to full right, however, and because the listener will hear at least ten spatial movements at the same time, it should be hard to hear precisely one "spatial movement." We should, however, hear a whole series of movements. In fact, the spatialization module is a way for Hagan to add, one more time, additional noise within the stereophonic space.

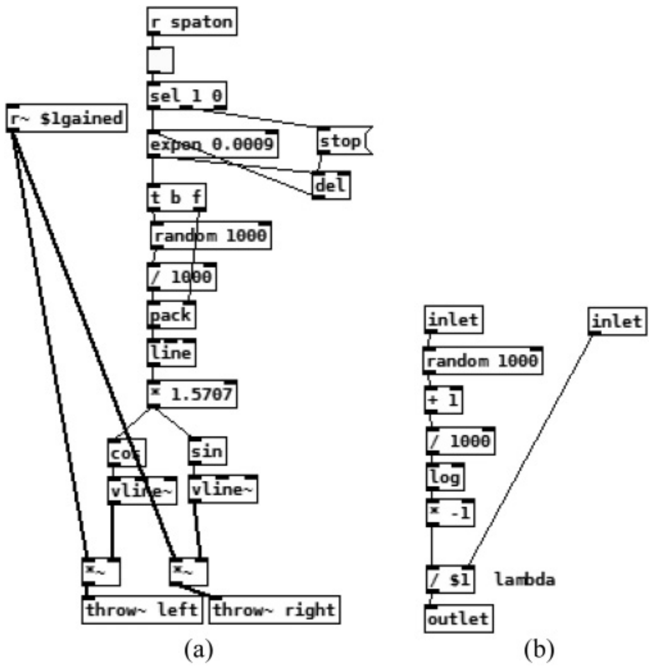


Figure 6

Routing

Routing—that is to say, connections between modules—is fixed throughout the work. I suggest

Figure 7. Outputs of the randomDur() function during one actualization for one instance of spat (471 outputs).

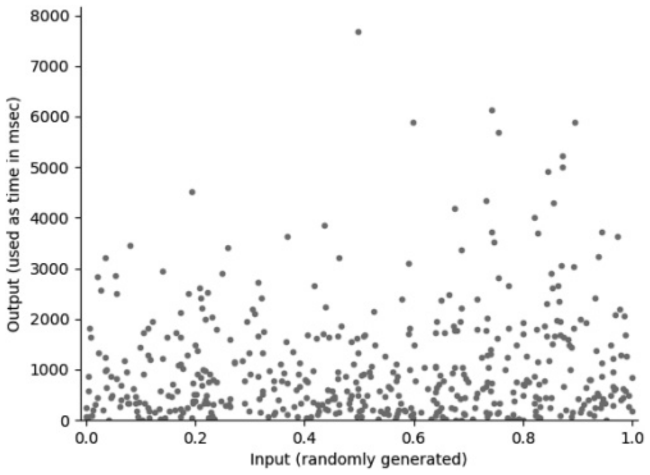
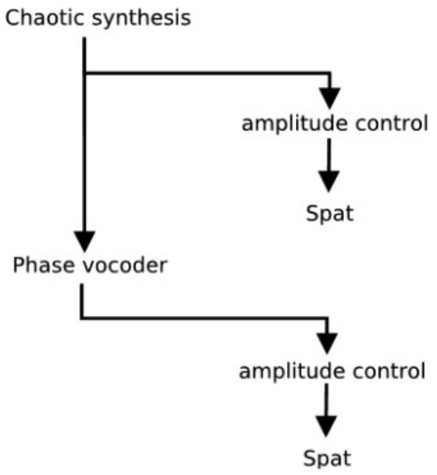


Figure 8. Audio flow chart for one of the ten voices from the Pd Patch. Each voice produces two audio signals, one coming directly from chaotic synthesis and the other after the output from the chaotic synthesis has been processed by a phase vocoder module.



therefore describing the patch as a set of voices. Each voice is basically made of one signal from one chaos function, one phase vocoder instance, and two spatializer instances. The first spatialization is applied to the chaotic synthesis output and the second to the phase vocoder output. Figure 8 represents one voice.

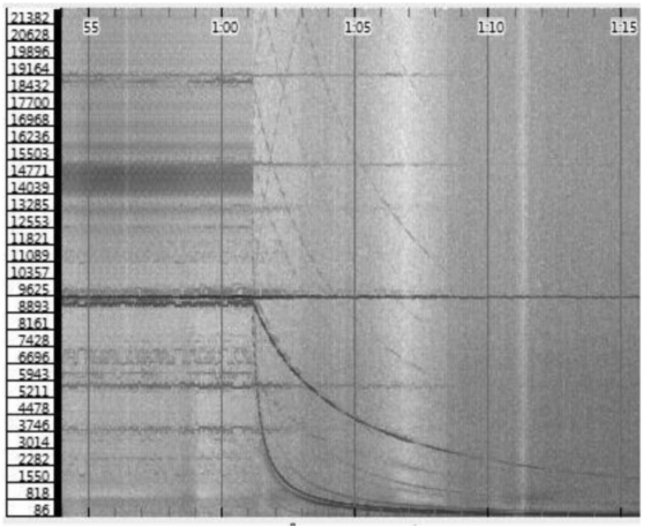
The patch contains ten voices; therefore, the composition is made with 20 different signals.

Musical Analysis

Even if "nyx" is largely based on noise, this does not imply that there is a lack of organization. One can easily perceive structure when listening to this work lasting 8:15 min. This structure is largely gestural, with a prominent gesture going from low to high pitch, or from high to low, at significant points in the work. This gesture is implemented via one of the most important controls yet to be addressed: the rate of chaotic synthesis. Hagan decreases or increases the five chaotic rates that produce an important sliding in pitch. The first gesture appears near the beginning at 1:00 and the last one at 7:30. These two gestures encapsulate the main section of the work. The two resulting short fragments at the opening and closing are essentially introductory and closing materials. Consequently, the structure of "nyx" approximates an ABA′ structure, with the central section constituting the largest and most developmental.

Before explaining these three sections it is important to note precisely how the composition is realized in time. There is a sequencer, made of messages boxes and connected through delay objects, that contains all the changes over time of all variables described. Thus, there is one way to compose with time that is determinate: Each time "nyx" is computed, the same sounding elements appear at the same times (e.g., the two prominent gestures in pitch noted above). However, as we have seen with the many random algorithms, there is another way to compose with time that is indeterminate, in which we cannot know exactly what will happen each time the work is computed (for interesting questions related to indeterminacy and real time in computer music, see Hagan 2016). The structure of "nyx" reflects this fundamental opposition: The opening and closing are determinate and do not contain random algorithms, whereas the main section is partially indeterminate and contains all the random algorithms. Analyzing determinate computer music does not present new problems, because the audio signal is fixed. Problems arise with the analysis of indeterminate computer music, however, when the audible elements can be different in another actualization. To accommodate this challenge, I have chosen a methodology outlined immediately following the discussion of the opening section.

Figure 9. Spectrogram of the first prominent gesture. At 1:00 min Hagan decreases the rates of the chaotic functions, which produce an important glissando from high to low pitch. This gesture marks the end of the opening of the piece.



Opening

The opening section of "nyx" spans one minute and immediately immerses the listeners in the work's noise, confronted as they are by ten signals from the chaotic synthesis module. Signals are diffused raw, with no phase vocoding, only spatialization. Thus, during the first minute, the listener is totally thrown into a noise environment. Noise is the only element present, without alteration or effect, for one minute. This opening is like an invitation "to go inside the noise" and stop considering it as something undesirable.

The opening finishes with the first prominent gesture from high to low pitch, at one minute. Hagan smoothly decreases rates of chaotic synthesis. She generates a ramp from a frequency of calculation of once per sample to one calculation for every 50 samples. The effect is an important decrease in the perceived pitch, as Figure 9 shows.

After the raw noise, we now have an important familiar gesture in the pitch dimension, the glissando, which encourages anticipation in the listener.

Main Section

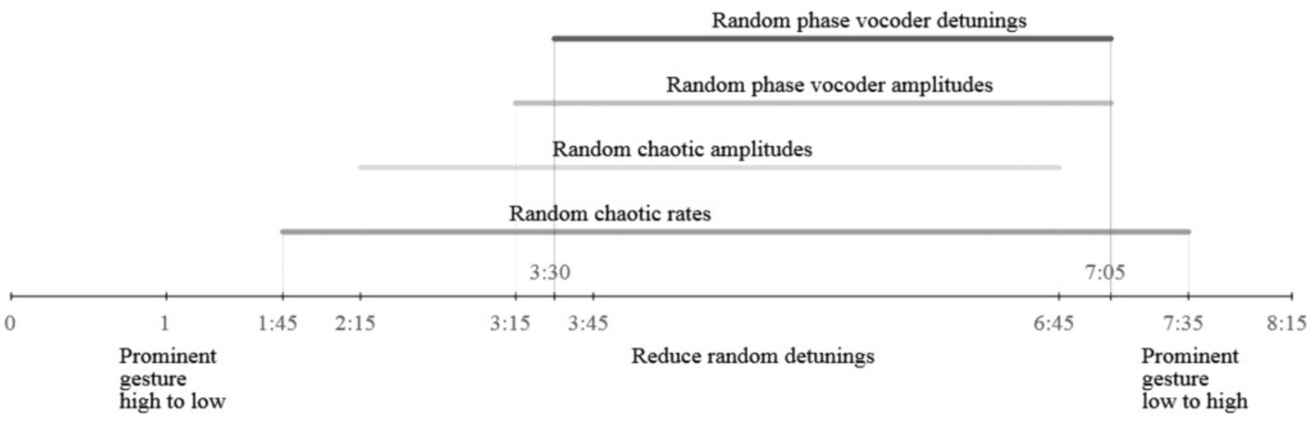
As stated earlier, this main section contains difficulties for musical analysis because there are a host of indeterminate elements produced by algorithms. Concretely, it means that the sounds I am listening to as "the work" can be different (or completely missing) in another actualization. For example, if I hear a harmonic interval at a precise moment, nothing permits me to say that it will present in another actualization. Because "nyx" is real-time computer music, audio files must be understood as one of many possible actualizations: One trap for the analyst would be to over-consider any audio file in particular, and to analyze "nyx" as an acousmatic work. Another danger would be to only consider the algorithms, the computer writings made by Hagan, without considering sound at all in the six minutes of the main section.

Thus, for this section I will consider both what is written and what is heard. First, I will describe what is written, when and how long the algorithms are launched, and then I will, in turn, describe the sound manifestation in the section. To avoid focusing on one actualization, I have realized six actualizations and I will take them all into account.

Analysis of Written Materials

Figure 10 represents all the writing of the algorithms. As one can see, the main section is constructed with an accumulation of algorithms. First, just after the prominent gesture, the random rates algorithm is triggered at 1:45, generating long lines of pitched noise. At the same time, the phase vocoder fades in, doubling the chaotic signals with a deceleration by a factor of five. Then the two random amplitudes algorithms are added at 2:15 and 3:15, respectively. The last algorithm is started at 3:30; it is the random detuning algorithm from the phase vocoder. Until this moment, the phase vocoder was only slowing down the original noise signals. With this last algorithm, the phase vocoder's signals become independent in pitch, randomly detuning each chaotic signal. Near the middle of the section, at 3:45, the sequence to reduce random detuning is launched. The range will decrease progressively from a maximum of −8,000 cents to zero at 6:45. The last part of the section consists of progressively switching off all the algorithms.

Figure 10. Algorithm states (above timeline) and sounding elements (below timeline).



Analysis of Generated Sound

Even if the development is made with random algorithms, one can hear some persistent sonic elements when one listens to a few different actualizations. After the prominent pitch gesture that opens the section, at 1:45 there is a new set of pitch lines. These come from the random rate algorithm, which produces new rate values with longer durations (between 10 and 30 seconds). This element is reminiscent of the prominent structural gesture, but it is considerably more subtle. Rates here are not synchronized: Their directions (up or down) are set randomly. The listener discovers herein yet another compositional idea in the work, whose character is situated between the raw noise of the opening and the prominent pitch gesture.

At 2:00 more new material is introduced, enriching the experience thus far. The material comes from the phase vocoder, which is softly faded in. The deceleration effect adds a deep lower layer of noise. For one minute all the materials of the work find exposition: the raw noise with random rates lines plus random fades, and the last deep noise coming from the phase vocoder.

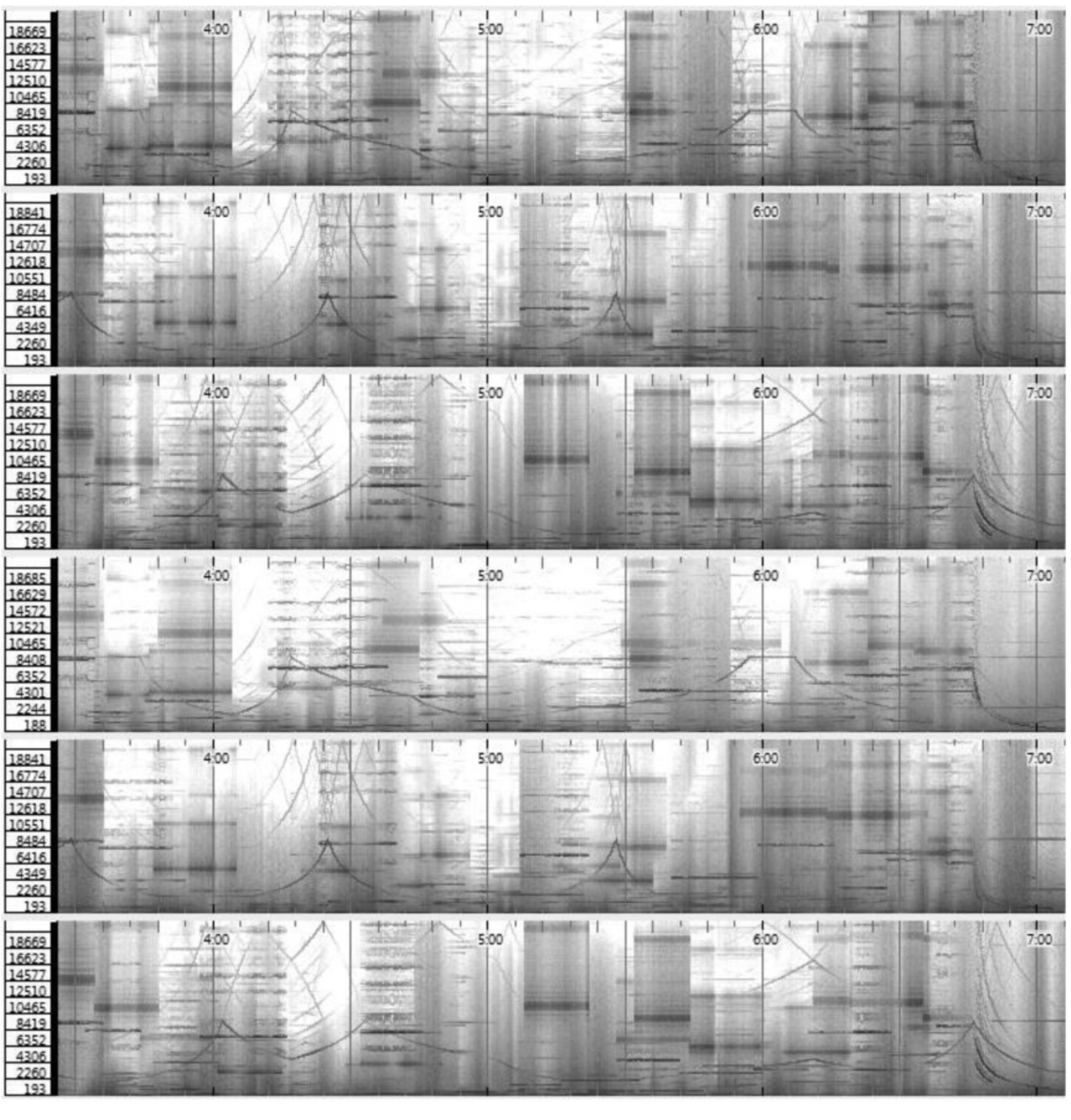
At 3:35 there appears a new movement. The deep noise of the phase vocoder suddenly fades out to give way to a quiet region. The spectrogram of this area contains less energy; low noises are less present and there are untidy short sound events, with different pitches, which appear and disappear after a few seconds. This is visible in Figure 11, which shows the spectrogram of six actualizations.

At this point in the work, all materials and algorithms have been exposed; one might say in this movement "the composer lets the algorithms speak." Because of the two random-amplitude algorithms (which generate ramps between 1 and 5 seconds in length), many short sounds appear and disappear, and occasionally moments with less energy, of relative calm, appear. In addition, the random detuning algorithms transpose these short sounds. Thus, sometimes the succession of two sounds forms a clear pitch interval. There is, moreover, a tension building as a result of the detuning algorithms: The more time passes, the smaller the transposition. Indeed, at 6:32 detunings fall within the interval [−1000, 0] and finally at 6:45 there is no more transposition.

With these calm areas, clear pitch intervals, and the aforementioned tension that builds from full to null transposition, this main section is the richest part of the composition. It is the opposite of the raw noise sounds from the opening. There are now sounds of a few seconds, with different pitches, that attract the listener's attention.

The main section finishes with a small gesture at about 6:50, in which pitch goes from high to low. This is produced with the phase vocoder module and in an original manner. Because the detuning is null

Figure 11. *Spectrograms of the main section for six actualizations of "nyx."*

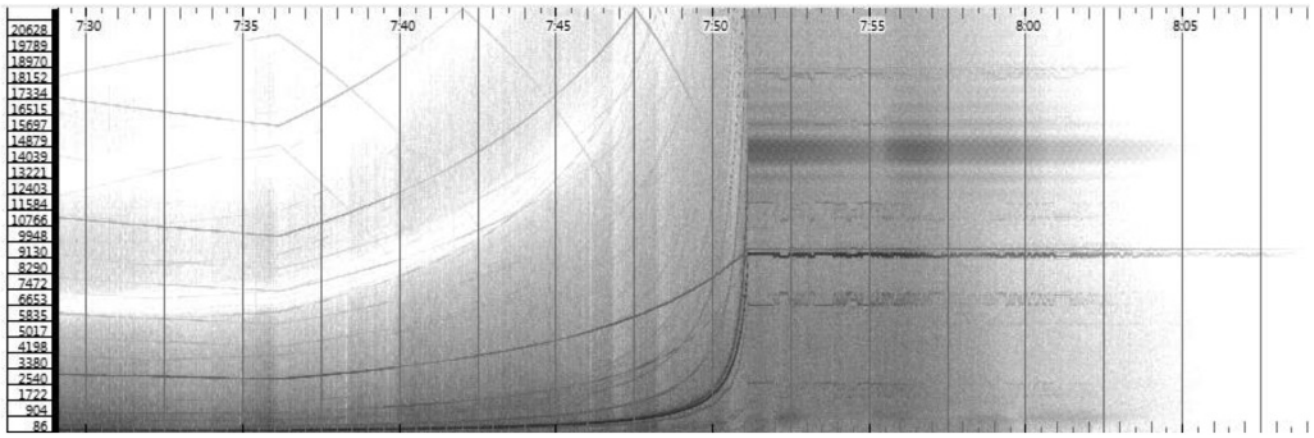


at that time, the pitch should go from low to high; however, the gestures one can hear are going to be low because of aliasing. Signals are indeed going up but the frequencies are over the Nyquist frequency, 22.05 kHz, and because of aliasing they are reflected and essentially mirrored into the audible spectrum.

Closing

The end of the main section is marked by the second prominent gesture at 7:35, from low to high pitch this time (see Figure 12). Again, this is made by increasing the rate of the instances of

Figure 12. Spectrogram of the last gesture.



chaotic synthesis module. Of course, the beginning of this gesture recalls the first gesture and places the listener in a situation of considerable anticipation.

The gesture finishes beautifully: Just after its end, in a very high pitch, the raw noise signals return, much like the opening. Hearing chaotic noise here does not create an impression of chaos, however: The noise signals only last a few seconds and then slowly fade out. Here, noise is used constructively, to finish the last important gesture.

Conclusion

Analyzing a real-time computer music work presents unique challenges, because one must fundamentally question what constitutes the appropriate object for analysis. Do we engage with the sound manifestation or computer music code? Considering Risset (2001), Battier (2003), and Zattra (2015), I have developed an analysis that answers that question: Both the sound manifestation and the computer music code must be taken into account. Therefore, the purpose of the research was explaining both what is contained with the patch and how it is used, as well as providing a sonic analysis of the music via listening.

In the Music Modules section, I described the patch and its contents: three music modules including chaotic synthesis that produces raw noise, a phase vocoder that is used for time-stretching and transposition, and finally a spatialization module that spatializes these signals within a stereophonic space. The key controls of these modules are the rate of chaotic synthesis, the detune of the phase vocoder, and, to a lesser extent, amplitude for both chaotic synthesis and phase vocoder. Lastly, all these modules include random algorithms that are applied to the aforementioned key controls for the chaotic and phase vocoder modules, as well as to the spatialization, resulting in random rates, random detuning, random amplitudes, and random spatial positions. Another way to shed light on the "nyx" artifact (the patch) is to see four successive levels of noise: (1) the use of chaotic functions to produce sound, (2) the use of phase vocoder for noise signals, (3) the realization of a map of 20 noise signals, and (4) the use of random algorithms to produce music.

In the Musical Analysis section I engaged with the work in terms of duration. Even if "nyx" is realized with chaos, the work nonetheless contains an ABA′ structure. Moreover, during the work there is a clear direction: It begins with raw noises for one minute and finishes with an important expressive gesture. This direction is clearly one of organization and corresponds nicely with a narration of mythology: "Verily at the first Chaos came to be, but next wide-bosomed Earth, the ever-sure foundations of all" (from Hesiod's *Theogony*). The important gesture at the very end of the work, from low pitch to high, easily corresponds with something like this creation.

Finally, three main areas of note in "nyx," the most obvious being the use of chaotic functions to produce noise and to use that noise as music material. The second point to note is the implementation of random algorithms, so that the work contains significant indeterminate elements that vary across realizations. Third, there is the use of the meaning of chaos in Greek mythology to structure the musical work. These three areas can be understood as three facets of the totality of noise, which make "nyx" a captivating computer music work.

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