Xenos

Xenharmonic Stochastic Synthesizer

User Manual

Version 1.0.1

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1 Introduction

Xenos is a virtual instrument plug-in that implements and extends the Dynamic Stochastic Synthesis (DSS) algorithm invented by Iannis Xenakis. Programmed in C++ with the JUCE framework, Xenos is open-source, cross-platform, and can be built in a number of plug-in formats. Key features include:

- Authentic DSS engine
- Xenharmonic pitch quantizer
- Custom scale import in the Scala format
- Ten stochastic distributions with up to two parameters each
- First- and second-order random walks
- Variable number of segments per wave cycle
- Variable amplitude envelope
- Polyphonic (128 voices by default)
- MIDI implementation (notes, sustain, pitch bend)
- External MIDI controller assignment
- Parameter automation
- Simple and streamlined interface
- Free and open source

Xenos retains the fundamental character of DSS, but adapts it for use in contemporary computer-based composition environments. It makes DSS easier to understand and apply creatively by reducing and simplifying its parameters, and by presenting intuitive interfaces; as a plug-in, it leverages host software features, such as MIDI input and parameter automation, to increase the applicability of DSS to a broad range of digital music composition and performance contexts.

Xenos also introduces a novel pitch quantization feature to DSS. While a traditional DSS voice produces continuous pitch, Xenos can optionally be tuned to an arbitrary scale. Several scale presets are provided, and it is also possible to load custom scales in the Scala file format: a popular inter-application exchange standard for musical scale specification. By imposing a layer of determinism onto the chaotic output of DSS, Xenos enhances its suitability to compositional styles that emphasize pitch organization, including xenharmonic practices.

In Greek, *xenos* means "foreigner" or "stranger." It is one root of the term "xenharmonic," which refers to "foreign harmony:" any pitch system comprised of intervals that deviate substantially from those of the equal-tempered chromatic scale. "Xenos" was chosen as the name of this instrument as commentary on the marginal position of direct digital methods within the domain of sound synthesis as a whole; in reference to its xenharmonic quantization capabilities; and in homage to Xenakis.

Xenos was first presented to the Meta–Xenakis Global Symposium (Radna 2022a), and is the subject of a master's degree from the Media Arts and Technology (MAT) program at UC Santa Barbara (Radna 2022b).

1.1 Theory

In DSS, the cyclical portion of a periodic wave is defined by a number of points in amplitude-time space. The wave is produced by linear interpolation between adjacent points. When a wave cycle ends, it undergoes a process of stochastic perturbation in which the breakpoints are displaced by random values. Each point thus represents two random walks: one each in the horizontal (pitch) and vertical (amplitude) dimensions. A random walk is a type of stateful random number generator in which the next value is equal to the previous plus or minus some stochastic "step." The mature form of DSS uses second-order random walks: two random walks in series, in which the output of the first determines the step size of the second. This process produces a new wave cycle that is a variation of the last one, resulting in an evolution of pitch, amplitude, and timbre over time.

The DSS algorithm is influenced by several parameters that affect the nature and extent of the variation between wave cycles. These are the probability functions that produce random walk steps, such as uniform, Cauchy, Logistic, and Exponential; the step size, which is the maximum allowable difference between successive values of a random walk; and what Xenakis called "elastic barriers" that reflect excessive random walk values back within a specified range.

An advantage of DSS is that its parameter space enables interpolation between pitch and noise, and exploration of intervening timbres. Its economy lies in the way that its few interrelated parameters afford considerable diversity of musical behavior. If only slight variation of the wave cycle is allowed, tones of stable pitch and timbre are produced. Conversely, the more that the parameter state allows profound dissimilarities between wave cycles, the more the resultant tone loses its periodicity and tends towards noise.

For formal definitions of the mathematics underlying DSS, see Xenakis (1992) and Serra (1993). For additional low-level descriptions of DSS, see Hoffmann (1996) or Luque (2006).

1.2 Installation Notes

Xenos has been tested on macOS 10.14.6 and Windows 10 (64-bit).

1.2.1 Build from Source (Mac or Windows)

1. Download JUCE
2. Clone or download Xenos from GitHub
3. Open Xenos.jucer in the Projucer
4. Export the project for your IDE and platform, e.g., Xcode (macOS) or Visual Studio 2019 (Windows)[1]
5. Compile Xenos using your IDE
6. Move the plug-in binary, e.g., Xenos.component or Xenos.vst3, to the proper location according to your platform, host software, and plug-in format
   - e.g., `/Macintosh HD/Library/Audio/Plug-Ins/Components` (MacOS)
   - e.g., `C:\Program Files\Common Files\VST3` (Windows)
7. Open a suitable plug-in host application and add Xenos on a software instrument track

1.2.2 Build from Source (Linux)

0. Install JUCE dependencies:

```
sudo apt install libasound2-dev libjack-jackd2-dev ladspa-sdk \
    libcurl4-openssl-dev libfreetype6-dev libx11-dev \
    libxcomposite-dev libxcursor-dev libxext-dev libxinerama-dev \
    libxrandr-dev libxrender-dev libwebkit2gtk-4.0-dev
```

1. Clone Xenos: `git clone https://github.com/raphaelradna/xenos.git`
2. Navigate into the Xenos folder: `cd xenos`
3. Clone JUCE: `git clone https://github.com/juce-framework/JUCE.git`
4. Configure the build:

```
mkdir -p build/Release && cd build/Release && cmake -D \
CMAKE_BUILD_TYPE=Release -G "Unix Makefiles" ../..
```

1. See here for more information.

5. Build Xenos: `cmake --build ./ --config Release`

Once built, Xenos VST3 and LV2 plugins will be in:

`xenos/build/Release/Xenos_artefacts/Release.`

However, they should have already been automatically copied to the default location for such plugins on your computer (probably `~/.vst3` and `~/.lv2`).

1.2.3 Pre-Built Binaries

1. Download the latest Xenos release for your platform from GitHub

2. Extract the plug-in binary, i.e., Xenos.component or Xenos.vst3, and move it to the proper location according to your platform, host software, and plug-in format

   - e.g., `/Macintosh HD/Library/Audio/Plug-Ins/Components` (MacOS)
   - e.g., `C:\Program Files\Common Files\VST3` (Windows)
   - e.g., `~/.vst3` (Linux)

3. Open a suitable plug-in host application and add Xenos on a software instrument track

1.3 Version History

1.0.1

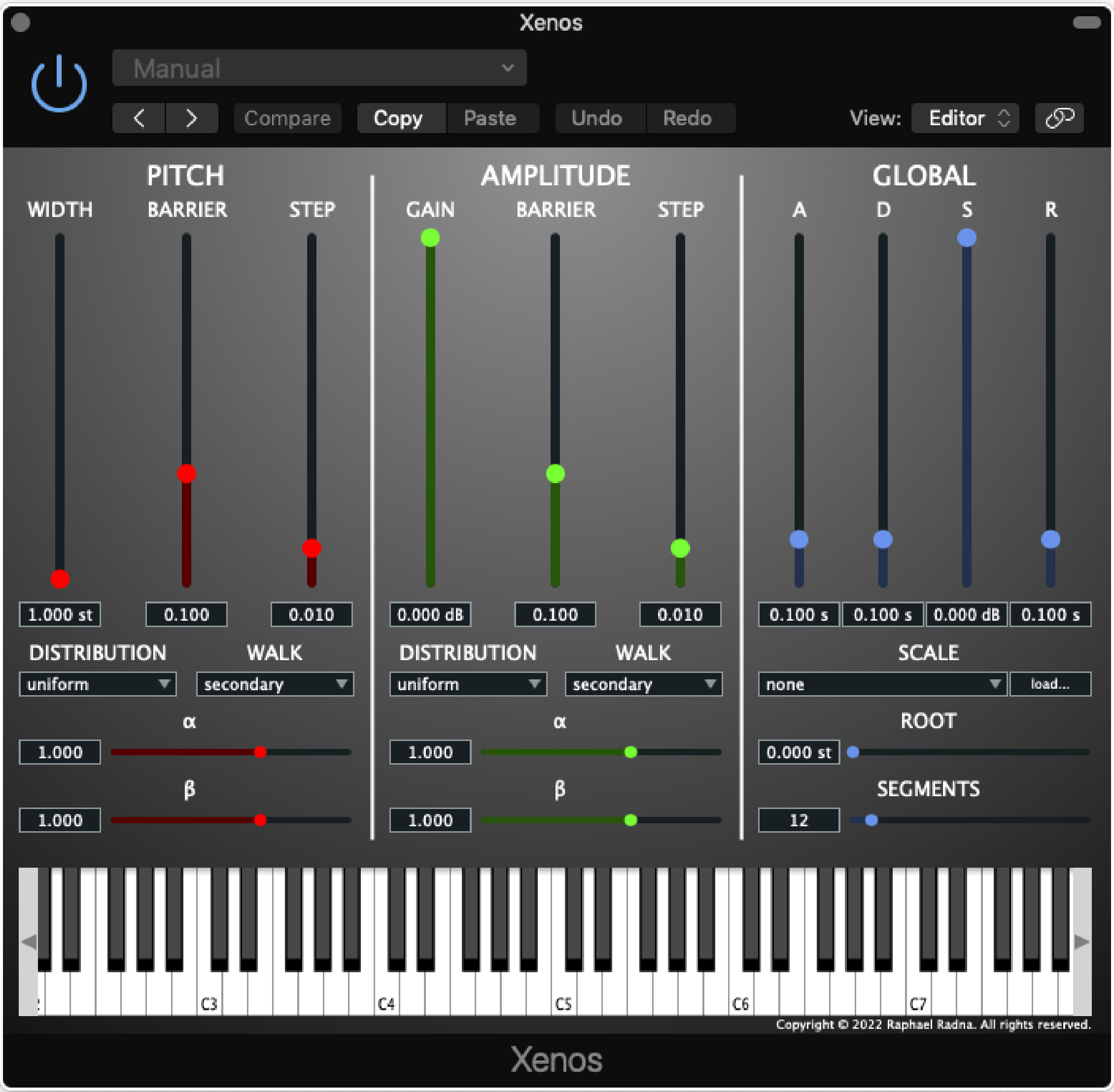
- Initial Linux release
- Increase default polyphony to 128 voices
- New voices begin with the current pitch bend value
- Properly clear inactive voices
- Fix bug affecting pitch at sampling rates other than 44.1 kHz

1.0.0

- Initial public release

2 Interface

The Xenos Graphical User Interface (GUI), shown below, is divided in three color-coded panels that group related controls: the pitch panel (left) contains the pitch random walk parameters; the amplitude panel (center) contains the amplitude random walk parameters; and the global panel (right) contains the parameters affecting the envelope, quantizer, and number of linear segments. At the bottom of the window is an interactive keyboard interface that triggers notes when clicked and that also displays incoming MIDI note data.



Xenos plug-in interface.

Clicking and dragging a slider changes its value. Each slider is associated with a number box that displays its corresponding parameter value. Clicking in the number box prompts keyboard input, facilitating precise value entry. Where applicable, the number box also displays the parameter unit, e.g., “st” (semitone), “dB” (decibels), or “s” (seconds). Furthermore, each slider is configured with an appropriate range and taper (linear or logarithmic.) A logarithmic taper assigns a greater proportion of the slider length to the end of the parameter range where increased resolution is desired.

The plug-in host handles external controller mapping and automation of Xenos parameters. In addition to MIDI note-on and note-off events, Xenos responds to pitch bend messages, enabling pitch transposition up to one octave above or below voice pitch; and sustain pedal messages.

3 Parameters

The following section describes the Xenos parameter set. The range of each parameter is given in square brackets. The pitch and amplitude controls are largely analogous.

3.1 Pitch

- **Width** [0, 96]

  Bipolar range in semitones about a center pitch within which the pitch of a voice may wander. At a value of 12, the voice fluctuates up to 6 semitones above or below the MIDI note played; for C4, the pitch range would be F♯3–F♯4. A value of 0 produces a precise, unchanging pitch.

- **Barrier** [0, 1]

  Position of the upper and lower reflective barriers as a ratio of the total pitch range. Low values constrain pitch movement within a limited interval, while high ones increase the effective pitch range; a value of 1 uses the full pitch range defined by the "Width" parameter.

- **Step** [0, 1]

  Step size of the random walk as a ratio of the total pitch range. Low values produce incremental pitch movement, while high values result in discontinuous fluctuation (noise).

- **Distribution** [Uniform, Gaussian, Poisson, Cauchy, Logistic, Hyberbolic Cosine, Arcsine, Exponential, Triangular, Sinus]

  Choice of stochastic distribution affecting the pitch random walk. Their differing probabilities produce various behaviors; see Apprendix B for a description of the available options.

- **Walk** [Primary, Secondary]

  The order of the pitch random walk. A primary walk produces a more uniform probability, while a secondary walk tends towards the minimum or maximum of the pitch range.

- α [-100, 100]

  The first parameter affecting the response of the pitch stochastic distribution.

- β [-100, 100]

  The second parameter affecting the response of the pitch stochastic distribution. Not all distributions respond to a second parameter.

3.2 Amplitude

- **Gain** [-inf, ±0]

  Bipolar range in decibels within which the amplitude of a voice may wander. At the maximum value of ±0, the voice fluctuates within the full amplitude range [-1, 1]; lower values constrain and reduce the amplitude overall.

- **Barrier** [0, 1]

  Position of the upper and lower reflective barriers as a ratio of the total amplitude range. Low values constrain amplitude movement within a limited interval, while high ones increase the effective amplitude range; a value of 1 uses the full amplitude range defined by the "Gain" parameter.

- **Step** [0, 1]

  Step size of the random walk as a ratio of the total amplitude range. Low values produce incremental amplitude movement, while high values result in discontinuous fluctuation (noise).

- **Distribution** [Uniform, Gaussian, Poisson, Cauchy, Logistic, Hyberbolic Cosine, Arcsine, Exponential, Triangular, Sinus]

  Choice of stochastic distribution affecting the amplitude random walk. Their differing probabilities produce various behaviors; see Apprendix B for a description of the available options.

- **Walk** [Primary, Secondary]

  The order of the amplitude random walk. A primary walk produces a more uniform probability, while a secondary walk tends towards the minimum or maximum of the amplitude range.

- α [-100, 100]

  The first parameter affecting the response of the amplitude stochastic distribution.

- β [-100, 100]

  The second parameter affecting the response of the amplitude stochastic distribution. Not all distributions respond to a second parameter.

3.3 Global

- **A** [0.001, 100]

  The amplitude envelope attack time in seconds.

- **D** [0.001, 100]

  The amplitude envelope decay time in seconds.

- **S** [-inf, ±0]

  The amplitude envelope sustain level in decibels.

- **R** [0.001, 100]

  The amplitude envelope release time in seconds.

- **Scale** [None, Pentatonic, Pentatonic (Pythagorean), Blues, Blues (7-limit), Whole-tone, Major, Major (5-limit), Minor, Minor (5-limit), Octatonic, Overtone, Chromatic, Bohlen–Pierce, Quarter-tone, Custom]

  Activate quantization and select the scale to be used. "None," the default value, deactivates quantization, resulting in continuous pitch. "Custom" implements quantization using a scale loaded in the Scala (.scl) file format. See Appendix A for a description of the included scale presets.

- **Root** [0, 12]

  The tonic pitch class for the quantization scale; 0 is C, 1 is C♯, etc.

- **Segments** [2, 128]

  The number of linear segments per wave cycle. Higher values produce a brighter timbre.

4 Tips

This section compiles some comments, suggestions, and insights about using Xenos.

- Different combinations of the pitch random walk parameters produce fluctuating pitch, glissando, or noise. Larger barrier and step values produce less periodic waves.
- The primary walk produces a more entropic behavior than the secondary walk, and is therefore a good choice when extreme noisiness, i.e., aperiodicity, is desired.
- Conservative settings of the amplitude random walk produce a subtly shifting emphasis among harmonics of the wave period that is effective for drone textures.
- Using a greater number of segments per wave cycle produces a brighter timbre. The perceptual effect of this parameter is similar to that of the modulation index in FM synthesis.
- The choice of stochastic distribution and its parameters has a major effect on the random walks. The distributions tend to fall into one of two categories: symmetrical, i.e., those that generate values around a mean; and asymmetrical, i.e., those that converge on one or the other random walk boundaries. The former produces fluctuation, while the latter produces a directed, more-or-less continuous trajectory. The table below classifies the available distributions according to their tendency. Even within these categories, the distributions produce subtly different effects.

Symmetrical	Asymmetrical
Uniform	Arcsine
Gaussian	Exponential
Poisson	Triangular
Cauchy	Sinus
Logistic	
Hyperbolic Cosine	

- Application of an asymmetrical distribution to the pitch random walk produces continuous glissandi. Since these glissandi terminate at an interval defined by the pitch width parameter, they can be applied quite deterministically. The step size affects the glissando rate, with the primary walk providing much slower glissandi. In many cases, the sign of the distribution parameter affects the direction of the glissando.

- Xenos can produce very chaotic sounds, but because it centers a DSS voice on a MIDI pitch, it can also be played like a typical keyboard instrument. By using a narrow pitch width, voices are constrained around their center pitches, even without quantization.

- Automation of the pitch width parameter enables interpolation between deterministic and chaotic pitch. This can be very interesting for musical phrase or gesture design.

- The Xenos quantizer "snaps" the instrument's normally continuous-pitch output to the tones of a user-defined scale. Quantization retunes fixed pitches, turns vibrato into ostinato, transforms glissandi into scalar melodies, and filters noise through specific pitch collections.

- With multiple voices, quantization produces counterpoint. Quantizing the independent and random motion of the voices produces complex linear and simultaneous relationships within the scale chosen.

- Quantization of a glissando produced by an asymmetrical distribution creates an ascending or descending scalar run.

- With certain settings of the amplitude random walk, Xenos can simulate granular synthesis. As the amplitude barrier distance increases, a smooth dynamic contour gives way to an increasingly iterative and chaotic texture, an effect similar to increasing the asynchronicity of a grain stream. Increasing the step size results in a much noisier timbre in a way that is perceptually analogous to reducing grain size. The turbulent Cauchy distribution is well-suited for this application. Combining this technique with quantization produces harmonic quasi-granular textures.

5 Acknowledgments

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6 Disclaimer

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A Scale Presets

Scale	Cardinality	Description
Pentatonic	5	Equal-tempered pentatonic
Pentatonic (Pythagorean)	5	Just-intoned (three-limit) pentatonic
Blues	6	Equal-tempered minor blues
Blues (7-limit)	6	Just-intoned blues with septimal blue notes
Whole-tone	6	Equal-tempered whole steps
Major	7	Equal-tempered diatonic major
Major (5-limit)	7	Just-intoned diatonic major
Minor	7	Equal-tempered diatonic natural minor
Minor (5-limit)	7	Just-intoned diatonic natural minor
Octatonic	8	Alternating equal-tempered whole and half steps
Overtone	8	Thirteen-limit collection using only intervals from the first four octaves of the harmonic series
Chromatic	12	Equal division of the octave into twelve parts
Bohlen–Pierce	13	Equal division of the third overtone into thirteen parts
Quarter-tone	24	Equal division of the octave into twenty-four parts

B Stochastic Distributions

Distribution	Description	α	β
Uniform	Equal probability of all values in range	Scale	N/A
Gaussian	The normal distribution, with characteristic bell shape	Mean value	Standard deviation
Poisson	Represents the number of events occurring in a fixed interval based on a mean rate of occurrence	Mean rate	N/A
Cauchy	A bell-shaped distribution that is steeper than the Gaussian	Scale	N/A
Logistic	A bell-shaped distribution similar to the Gaussian but with heavier tails (increased chance of extreme values)	Inverse scale	Displacement
Hyperbolic Cosine	A relatively flat and smooth bell-shaped distribution	Scale	N/A
Arcsine	An asymmetrical distribution that tends to the extremities; very sensitive to parameter settings	Scale	N/A
Exponential	Similar to the Arcsine, but with a distinct parametric response that causes the inversion of some behaviors	Inverse scale	N/A
Triangular	Nearly identical to the Arcsine, but with a smoother slope	Scale	N/A
Sinus	An asymmetrical distribution with pronounced fluctuation	Scale	Frequency scale