Research > COMPOSING WITH PROCESS: PERSPECTIVES ON GENERATIVE AND SYSTEMS MUSIC

**Generative music is a term used to describe music which has been composed using a set of rules or system. This series of nine episodes explores generative approaches (including algorithmic, system-based, formalised and procedural) to composition and performance primarily in the context of experimental technologies and music practices of the latter part of the twentieth century and examines the use of determinacy and indeterminacy in music and how these relate to issues around control, automation and artistic intention.**

**Each episode in the series is accompanied by an additional programme featuring exclusive or unpublished sound pieces by leading sound artists and composers working in the field.**

PDF Contents:



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# COMPOSING WITH PROCESS: PERSPECTIVES ON GENERATIVE AND SYSTEMS MUSIC #8.1

**Models of Change**

Episode eight in the series continues to look at how composers working with generative systems implement change in their works. This episode focuses on models of change using mathematical structures derived from complex dynamic systems observed in nature. Through advances in mathematics, physics and biology, the programme looks at how composers have utilised the central findings of chaos theory and emergent systems – such as cellular automata, Lindenmeyer Systems and fractal geometry – to generate automated dynamic patterns of change.

## 01. Transcript

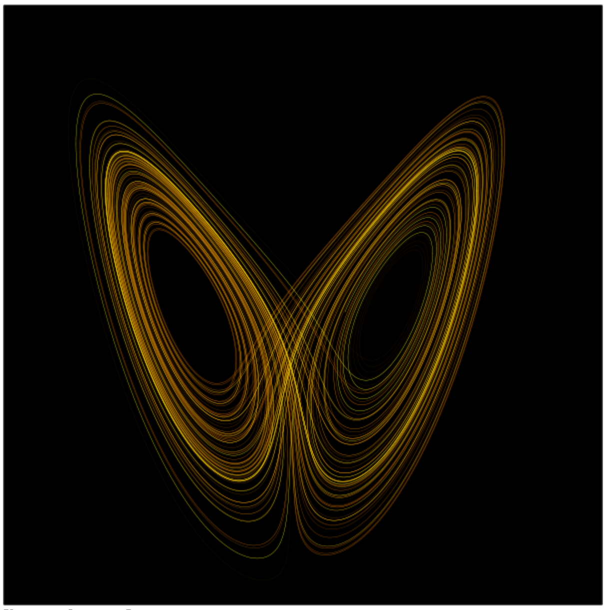
Welcome to the eighth episode of COMPOSING WITH PROCESS. In the previous episode we looked at the role change plays in music and how composers working with generative systems, conceive of, control, and implement change in their works. The sound we have just listened to is the sonification of a mathematical object known as a Hénon map, realised by Emmanuel Deruty. The Hénon map is a discrete-time dynamical system that exhibits chaotic behaviour. In this episode we will look at similar models and systems and discuss how they are used to generate automated dynamic patterns of change. These systems are all modelled on forms of change observed in nature, for example, the movement of air or water. The rules which underlie these systems define how complex structures – with defined conditions – change and evolve over time. Their behaviour can be used to define musical criteria in composition or sound synthesis.

In 1990, whilst sick with a virus, American composer Laurie Spiegel, decided to 'map the complete genetic base sequence of a viroid into the musical pitch domain'. In order to map the virus, Spiegel substituted the letters A, G, C and U which comprise the nucleic acid of the virus' RNA, with the notes A, E, G and C. This sequence was then entered manually into sequencing software and played back as MIDI data.

This process of composing music seems counter to Spiegel's usual way of working, where she 'builds systems to automate carefully selected aspects of musical decision-making in order to increase the number of musical dimensions' which she can control in real-time performance. Change in this piece is both constrained (by the note selection) and regular (due to unchanging tempo). Similarly, the sequence of notes from one to the next does not change over the duration of the work.

In the sixties, advances in various fields of study, including mathematics, physics, engineering, economics and biology paved the way for new understandings of the natural processes underlying change and organisation in complex, dynamic systems. The study of the complex behaviour of planets in motion and weather systems led to the formulation of Dynamical Chaos, or what later became known as Chaos theory. Chaos theory is the study of nonlinear dynamics, where seemingly random events are actually predictable from simple deterministic equations. Studies in mathematics and the laws governing the evolution of natural, self-organising systems, led to the development of other dynamic systems such as Cellular Automata, L-Systems and Fractal Geometry. Many artists have utilised these findings in order to implement rule-based change into their work. For the artist or composer working with generative systems, these algorithms provide interesting and novel ways to implement and deal with change. We will now look at these.

Firstly, Chaos theory… The roots of Chaos theory lie in astronomical experiments carried out by Henri Poincaré in 1887. Poincaré was attempting to solve the three-body problem, a problem that had eluded mathematicians since Newton.


**[Lorenz Attactor]**

The three-body problem (later known as the n-body problem) is a problem of predicting the motion of more than three celestial bodies which interact with each other gravitationally. Poincaré found that tiny errors in initial measurements when amplified would yield enormous unpredictability. His solution to the three-body problem resulted in chaotic motion with no obvious sign of repetition.

In 1961, the MIT meteorologist and mathematician Edward Lorenz constructed a mathematical computer model to simulate a weather system. Using a set of differential equations, Lorenz's model attempted to represent changes in temperature, air pressure and wind velocity. Lorenz expected the system to be completely deterministic but found to his surprise that insignificant variations in initial conditions gave rise to increasingly chaotic results. Lorenz was able to derive richness, diversity, unpredictability and chaos through a simple, deterministic system. To visualise the data, numbers generated by the three equations are plotted as coordinates in three dimensional space. We can create a record of the system's behaviour by tracing its path of change through space. The resultant model, known as a Lorenz attractor, displays infinite complexity, staying within bounds but never repeating itself.

Data from the Lorenz Attractor can also be used in the same way to generate or control parameters of sound. 'Lorenz', composed in 2005, is a collaboration between James Crutchfield and American composer and sound artist David Dunn. The piece is a real-time sonification of two Lorenz attractors, using UNIX-based software called Mode, written by Crutchfield. According to the composers, 'Lorenz' is 'a real-time sonification of [a] classic chaotic attractor occurring as both a pitch-based articulation of the phase space and as a slicing through a corresponding spectral domain. The attractor has also been carefully placed into the stereo field such that a path along its spatial trajectory occurs with the dominant lobes roughly corresponding to the two loudspeakers.'

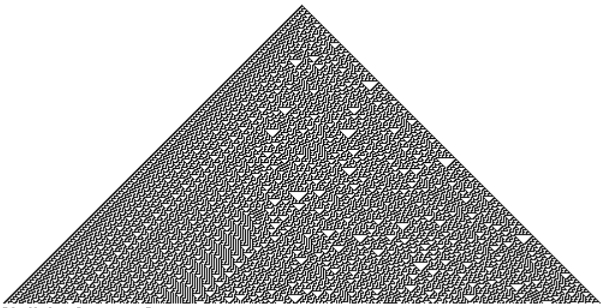
The behaviour of a dynamic system over time is highly sensitive to initial conditions. In chaotic attractors initial conditions converge toward a particular set of trajectories. Change is therefore continuous in three dimensions and allows for the generation of an infinite amount of distinct yet structurally similar musical material. The composer Mike Winters has translated several different chaotic attractors into sound using the software Mathematica 7. Winters mapped the dimensions of Lorenz, Rossler and Chua attractors to frequency, amplitude and origin of the sound. The following example is a Lorenz attractor with x, y and z dimensions mapped to spatial position, frequency and amplitude respectively.

The following example is a Rossler attractor with x, y and z dimensions mapped to amplitude, spatial position and frequency, respectively. The trajectory of the Rossler attractor is very simple compared to the Lorenz attractor, and this is evident in the recording.

The following example is a Chua attractor with x, y and z dimensions mapped to spatial position, amplitude and frequency, respectively. The Chua attractor has two attracting equilibrium like the Lorenz attractor but the change in frequency between the two basins is not as distinct.

Another mathematical model of a dynamic system, often used in generative works, are Cellular Automata. Cellular Automata (or 'CA') were conceived by Stanislaw Ulam and John von Neumann in the forties at the Los Alamos National Laboratory whilst studying crystal growth and self-replicating systems.

A typical two-dimensional Cellular Automaton consists of a grid of cells, each with two possible finite states, for example, 1 and 0, or on and off. The grid can have multiple dimensions, but the most common is two. The Cellular Automaton algorithm is a parallel process operating across this grid of cells, determining the state of each cell simultaneously. Each cell is defined in relation to its adjacent neighbourhood of cells. For example, the neighbourhood of a cell could be defined as the set of cells within a distance of two cells. The value of each cell at a specific time is determined as a function of its adjacent cells at the previous point in time. According to Dave Burraston and Andrew Martin: 'complex systems such as logic-based CA produce global behaviour based on the interactions of simple units. Their evolution is specified by local interaction rules that generate some form of ordered, complex or chaotic behaviour. This wide variety of behaviour represents an important generative tool for the artist.'


**[Cellular Automata]**

Several composers have used Cellular Automata to compose music. Iannis Xenakis read about Cellular Automata in a scientific journal and used it to combine scales of durations and pitch in order to create complex temporal evolutions of orchestra clusters in his work 'Horos' in 1981. The musical score for 'Horos' consists of a grid of cells with pitch on the vertical axis and time on the horizontal. Taking a cell as a starting point Xenakis then derived a rule to work out the progression of change over time.

Xenakis describes his use of Cellular Automata as '… simple rules which can create structures on very large surfaces. It's related to the nature of fluids, for instance. For me sound is a kind of fluid in time – that's what gave me the idea to transfer one area to the other. I was also attracted by the simplicity of it: it's a repetitious, a dynamic procedure which can create a very rich output.'

The Belgian composer Peter Beyls was one of the first to explore the use of Cellular Automata with both interactive and MIDI systems in the eighties. He experimented with Cellular Automata in a variety of ways: using both one and two dimensions; using time-based rule changes during Cellular Automata evolution; and applying two dimensional rules to one-dimensional Cellular Automata. Beyls remarks that he is more interested in models of evolution and change than in theories of structural design. For Beyls, experimentation is central to composing with dynamic systems. According to him, complex dynamic systems are 'an alternative to the constructivist approach in composition, i.e. the critical assembly of architectures of time according to some explicit scenario.' What is more interesting to him is the 'design of tools that allow the topology of the composer to interact with the system's internal activity.' The following piece, 'Drake Circus', by Peter Beyls, is described by the composer as 'a virtual guitarist playing a Cellular Automaton. A computer program runs the automaton and communicates to an algorithm specialised in harmonic articulation.'

Beyls says: 'Randomness or determinism, and chance or necessity seem at the heart of creativity and happen to be central to the music of our time. Emergent properties from initial random configurations can be viewed as a subtle alternative for both constraint-based reductionist handling of randomness as well as rule-based composition by way of some generative grammar. Complex dynamics can be viewed as a creative, generative principle and a channel for higher levels of human-machine interaction.'

Cellular Automata evolve through a number of discrete time steps according to the rules based on the states of neighbouring cells. Change is therefore parallel and continuous across the grid at any given moment in time. Typically, Cellular Automata activity is characterised by cells in the grid clustering together and forming pockets of activity.

In 1968, Aristid Lindenmayer, a Hungarian theoretical biologist, developed a system for modelling the behaviour of plant cells. Lindenmeyer studied the growth patterns of yeast, fungi and algae in order to conceive a mathematical theory of plant topology.

According to Lindenmeyer, 'the development of an organism may […] be considered as the execution of a "developmental program" present in the fertilised egg. The cellularity of higher organisms and their common DNA components force us to consider developing organisms as dynamic collections of appropriately programmed finite automata. A central task of developmental biology is to discover the underlying algorithm for the course of development.' [Lindenmayer, Rozenberg, 1975]

A Lindenmeyer System (or L-system) can be described as a formal language, that is, it is a string of symbols that are arranged into strings using rules. L-systems consist of two fundamental elements: an axiom, which is a kind of seed, and a set of rules for generating production. By applying the rules to the axiom repeatedly, an infinite variety of branching, plant-like geometric structures can be generated. In L-Systems the same set of rules can be used to generate different results with different seeds. Like nonlinear equations and Cellular Automata, the L-system is a temporal structure where change unfolds in time. The L-system's output can be interpreted in a variety of ways to produce temporal structures which evolve in time such as geometric forms, architectures or music. Musically,


[Nick Collins]

the most straightforward interpretation of the L-system is to convert strings of symbols to notation.

The evolution of an L-system when graphically represented resembles the growth of a plant, with branches at various angles and lengths. Lindemeyer introduced brackets into L-systems in order to achieve more tree-like structures. In the following three examples, the Greek composer Stelios Manousakis uses an L-system directly for sound synthesis using simple wavetable playback. The first example uses a bracketed L-system mapped stochastically to twelve branch groups.

The second example uses a bracketed L-system using a tree method and a sinewave as a seed.

The third example uses heirarchical sample-level sound synthesis where the Cellular Automata are controlled by a non-bracketed L-system.

L-systems often result in recursive structures and self-similarity. In objects which are self-similar, parts of the object are similar to the whole. Self-similar forms can be observed in nature – for example, in fern leaves and Romanesco Broccoli. In mathematics, self-similarity is a property of fractals, which are often exactly the same at every scale. In the following example, Stelios Manousakis uses a fractal interpretation of an L-system in the sample-, micro- and meso-levels to create granular synthesis. The L-system is active in three dimensions and generates in real-time the waveform and the parameters for granular synthesis processing. Each branch of the system is mapped to grain length, pitch and reading speed.

The following example from a fractal music research project by Hazard, Kimport and Johnson also explores self-similarity with L-systems. In it, the L-system axiom is A B and the production rules are: A = ABC; B = CAD; C = DC; and D = BDB. Starting with the axiom 'A B', after one iteration, the string becomes 'A B C C A D'. The same production rules are then applied with this new string, which then becomes 'A B C, C A D, D C, D C, A B C, B D B'. Further iterations of this string clearly give rise to self-similar, fractal like structures.

In his paper 'Errant Sound Synthesis', the researcher Nick Collins says: 'indirect control via the parameters of equations can be a liberating experience; it may enable the alternative expression of inspiring spectral transitions, of a type unencountered at the normal timescale and physics of airbourne acoustics.'

## 02. Acknowledgements

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## 03. Copyright note