

# Digital Behaviours and Generative Music

Dave Burraston  
Andrew Martin

Creativity and Cognition Studios  
University of Technology, Sydney  
andrewm@it.uts.edu.au  
dave@noyzelab.com

## Abstract

The use of computers in the generation of digital art and music has enabled the application of a single data source to the parameters of audiovisual modalities. This paper reports on an investigation within Electronic Arts practice where experimental works have been devised that make use of simulated natural systems. It explores essentially natural systems such as reaction-diffusion systems and the computational simulation method of Cellular Automata (CA). Contemporary artists' practice is continually informed by scientific thought and understanding as new discoveries or conjectures are published. These are examined and presented in a non mathematical format in the context of music composition.

## Introduction

Artists and composers have commonly placed an ideal of nature within their practice. Artists' concept of Nature have been influenced by the scientific knowledge and understanding of the time. For example, Iannis Xenakis has described an "historical parallel between European music and the successive attempts to explain the world by reason" [1]. He links the deterministic nature of European music to the Platonic ideal of causality, and describes how nineteenth century statistical theories in Physics influenced and changed our understanding of causality and reason. "It is only recently that knowledge has been able to penetrate chance and has discovered how to separate its degrees" [1]. John Cage frequently used the I Ching and produced "Indeterminate Music" based on chance operations [2]. Cage believed that the function of art was to imitate Nature in her manner of operation. In the last fifty years the field of nonlinear dynamic systems has become an important subject in physics, and therefore to the conceptual meaning of chance and randomness in nature.

"Since the 1960s, though, with developments in the theory of dynamical systems and computer experimental methods, rapid progress has been made in the study of these systems, and as a result many of nature's processes have become newly understood" [3].

Cellular Automata (CA) were originally conceived by Stanislaw Ulam and John von Neumann to study the process of reproduction and growths of form [4]. Konrad Zuse later proposed a concept of the universe as a type of CA computer that he termed “Calculating Space” [5]. Here Zuse poses the controversial question : “Is nature digital, analog or hybrid?”. Ed Fredkin, a long standing CA scientist, is convinced that the universe is digital (grainy) and has developed his own “Digital Philosophy” termed Finite Nature [6]. Fredkin believes that the digital mechanics of the universe is much like a CA, deterministic in nature but computed with unknowable determinism. Space and time in this view are discrete quantities, everything is assumed to be grainy. Our question is: can this unknowable determinism be made tangible and contribute to artistic ends?

## Cellular Automata

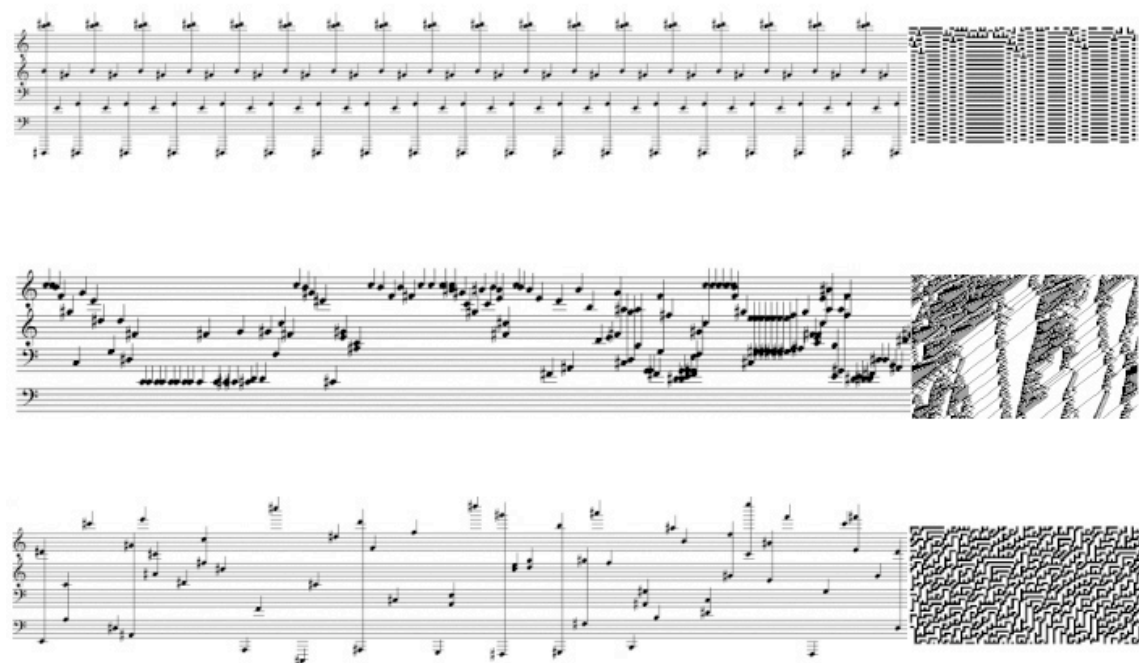


Figure 1. Musical visualisations of ordered, complex and chaotic CA behaviour.

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. Chaotic behaviour dominates rule space, which has serious implications for the serendipitous use of these systems in artistic endeavour. An example visualisation of ordered, complex and chaotic behaviour converted to music is shown in Figure 1. Example spacetime plots are shown to the right of each music extract. The spacetime plots represent the cellular space horizontally and time evolving in discrete stages downwards. The different classes of behaviour produced, whether ordered, complex or chaotic, make them interesting to artists and scientists alike. They are fascinating objects,

producing more pattern than a single human is capable of observing within their own lifetime.

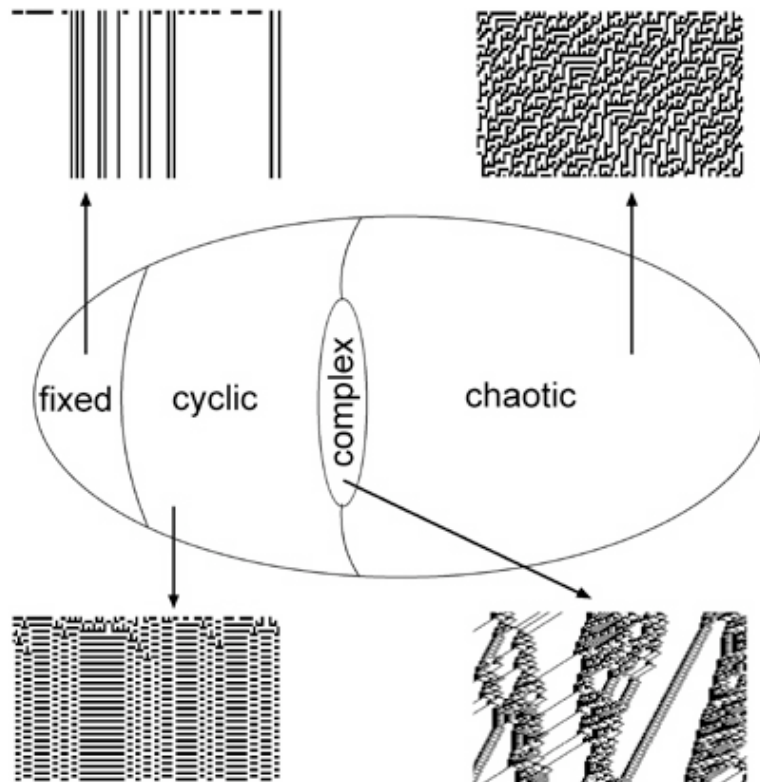


Figure 2. Langton's schematic of CA rule space and example spacetime plots of their behaviour.

CA are dynamic systems in which space and time are discrete. They may have a number of dimensions, single linear arrays or two dimensional arrays of cells being the most common forms. The algorithm is a parallel process operating on this array of cells. Each cell can have one of a number of possible states. The simultaneous change of state of each cell is specified by a local transition rule, applied to a specified neighbourhood around each cell. Patterns produced by these systems were classed by Stephen Wolfram with one of four qualitative behaviours [7].

**Class 1** : Patterns disappear with time or become fixed.

**Class 2** : Patterns evolve to a fixed size with periodic structures cycling through a fixed number of states.

**Class 3** : Patterns become chaotic.

**Class 4** : Patterns grow into complex forms, exhibiting localized structures moving both spatially and temporally.

Other methods of behaviour classification have been devised, an example of six categories is given in [8], although it is undecidable to assign a CA to a Wolfram class [9]. The relatively rare complex behaviour of class 4 was suggested to occur at a "phase transition" between order (class 1 and 2) and chaos (class 3), termed the "edge of chaos" [10]. The concept of the "edge of chaos" and efficacy of Langton's "Lambda" prediction parameter has also

been critically re-examined in [11]. Langton produced an example schematic illustrating his view of rule space shown in Figure 2. We have included spacetime plots of example 1D CA evolutions for each class. It is important to note on this diagram that the boundary between order and chaos contains complex behaviour within it. This implies that the transition from order to chaos may occur either in a discontinuous jump, or may pass through a region of complex behaviour. Langton also supported and promoted work on the global dynamics of CA [12], which offers a new perspective based on the topology of attractor basins, rule symmetry categories and rule clustering. Here one can compare basin topologies and measures between rules to gain insight into different rule behaviours. Attractor basin topology reflects the dynamics of a CA rule and can be used as a method of identifying ordered, complex and chaotic behaviour. These are important concepts and more importantly not as esoteric or difficult to understand in our experience, when compared to much other CA literature.

Wuensche's Discrete Dynamics Lab (DDLab) software allows for the exploration of global dynamics [13], as well as many other important aspects of CA and related discrete networks. Wuensche has importantly shown that as the neighbourhood size is increased, the proportion of chaotic rules rises very sharply in a random sampling of rules [14]. The magnitude of the numbers of rules is extremely large, Wentian Li [15] has commented on the 5 neighbour rules :

“Even if we can produce a spatial-temporal pattern from each rule in 1 second, it is going to take about 138 years to run through all the rules. Considering the redundancy due to equivalence between rules upon 0-to-1 transformations, which cut the time by half, it still requires a solid 69 years.”

Rule type	Total number of rules
2 neighbour	16
3 neighbour	256 (the elementary rules)
5 neighbour	4294967296
7 neighbour	3.402823669209385e+38

Table 1 - Total number of CA rules with binary cells for small neighbourhood sizes.

The total number of CA rules is a function of the number of states and the size of the neighbourhood. The three neighbour rules amount to a total of 256, and are known as the elementary rules [16]. Table 1. shows a summary of the total number of rules for 1D binary CA with small neighbourhoods. As the neighbourhood is increased there is astronomic increase in the total number of rules. A popular method of reducing the number of rules for a chosen neighbourhood size is to simply take the sum of these cells [16]. Rules computed in this manner are termed “totalistic” and are a very small subset of each rule type.

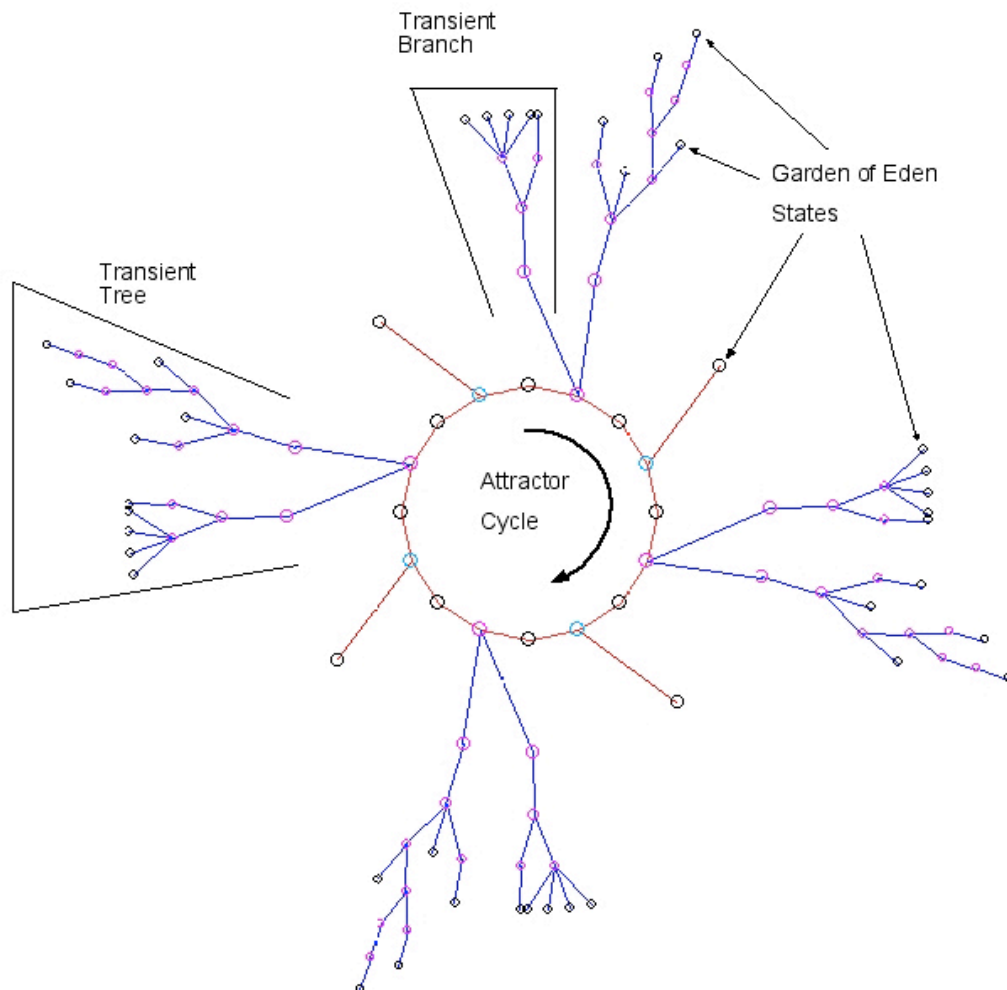


Figure 3 - Basin of attraction

A CA state space consists of all possible global states. In a finite deterministic CA all state transitions must eventually repeat with period 1 or more. States are either part of an attractor cycle or lie on a transient leading to the attractor cycle. If a transient exists there will be states unreachable by any other states at the extremity. These extremities are called garden of Eden (**goE**) states. All transients leading to an attractor, and the attractor cycle, is termed the basin of attraction (**boa**) of that individual attractor. An example basin of attraction is shown in Figure 3. State space for a particular CA rule and size is populated by one or more basins of attraction, termed the basin of attraction field. For a deeper understanding of these concepts the reader is strongly advised to study the referenced literature, in particular Wuensche and Lesser's book, now freely available on the internet [12].

## Reaction-Diffusion Systems

Reaction-diffusion systems were first proposed by Alan Turing [17] in a work aimed at proving that growth and form in embryology was the result of physical and chemical processes rather than Design. Reaction-diffusion systems were later further developed in the form of non-linear equations to

show realistic biological patterning and development [18]. Hans Meinhardt and Alfred Gierer formulated ‘activator-inhibitor systems’ that led to plausible simulations of the patterning of seashells [19].

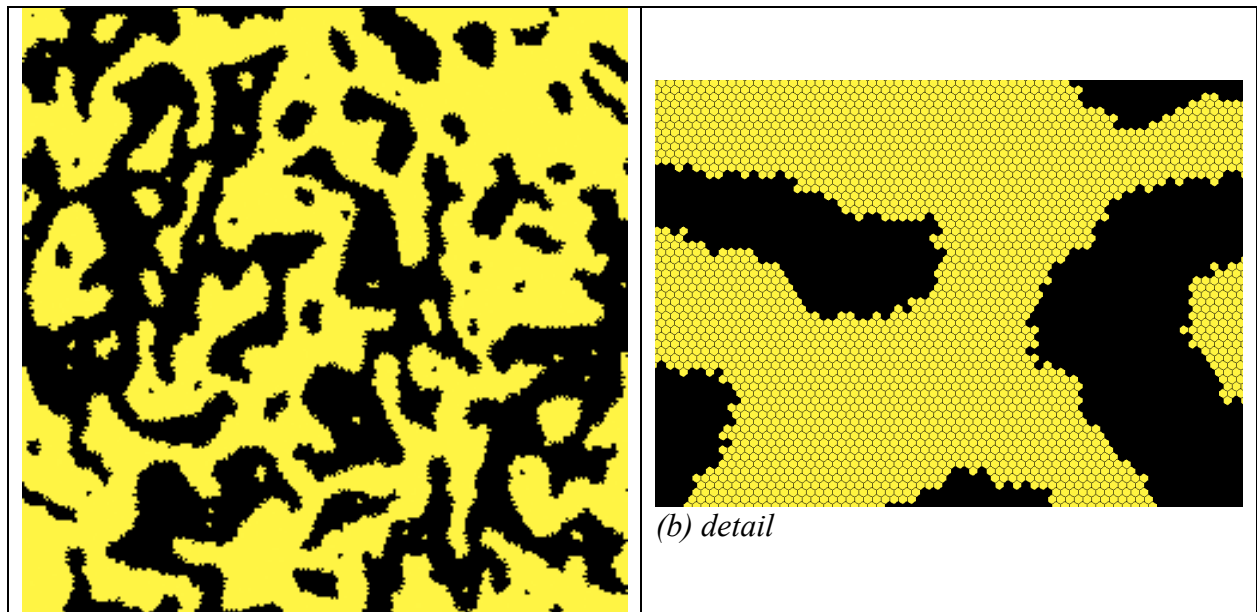


Figure 4(a). A two dimensional Reaction-Diffusion (RD) process, complete system of 256x256 cells (left). Figure 4(b) shows detail of the hexagonal cell structure (right).

Tamayo and Hartman have proposed a model for the reaction-diffusion of clay particles in which the synthesis of inorganic molecules takes place, producing the necessary combination of elements for the origin of life to occur [20]. Tamayo and Hartman’s approach was to utilise CA for the simulation of reaction-diffusion systems. DDLab software uses three-state CA within a totalistic rule set to demonstrate Reaction-Diffusion dynamics. An example of a two-dimensional RD system from a binary CA is shown in Figure 4(a), modeled with DDLab software. The system contains 256x256 hexagonal cells, which can be seen in detail in Figure 4(b). The visualisation shows a single time frame in the systems evolution. The temporal history of part of the system is shown in Figure 5, where striking patterns are seen.



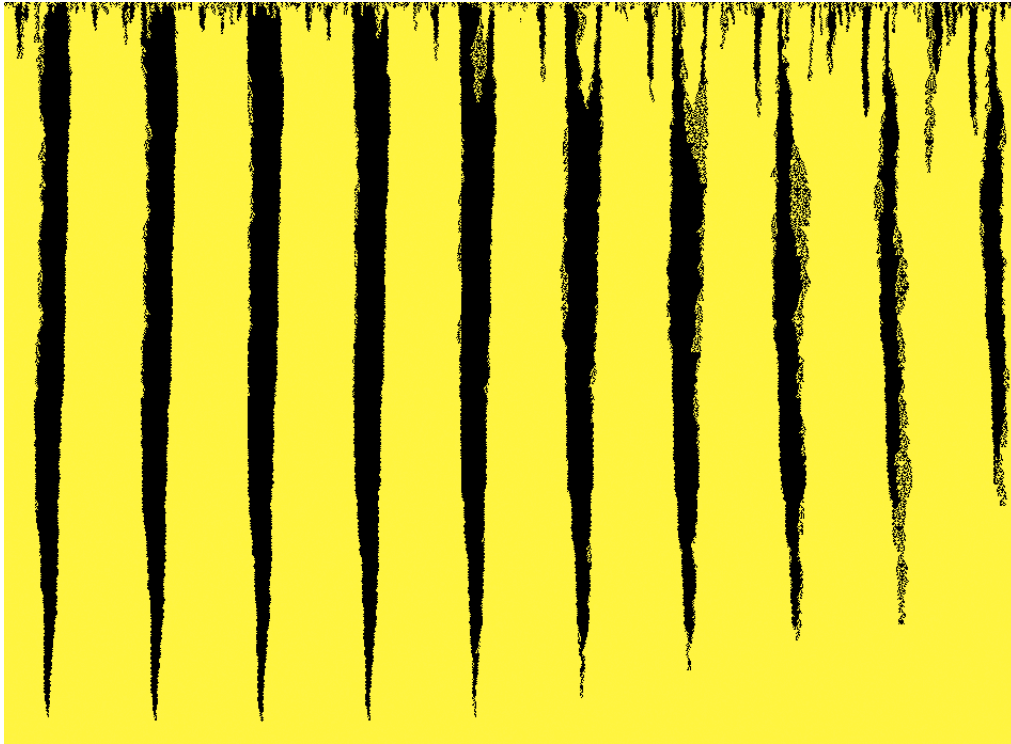


Figure 5. Slice of a two dimensional RD system, the system is stretched out horizontally showing time evolving vertically downwards.

## Composition at the Edge of Chaos

Within the domain of generative music access to a variety of behaviour is essential. CA have played a key part in generative music for many years [21] [22]. The reflective practice method of research has also been utilised to investigate and describe generative music with CA of all types of behaviour [23][24, 25]. CA behaviour is often described based on a subjective assessment of its spacetime images. A thorough account of all behaviour, automatic classification by various parameters and example rules is given in [14, 26]. Complex behaviour arouses particular interest when studying these systems. According to Wuensche complex behaviour emerges (self-organises) in spacetime from random initial conditions to form gliders, particles or self-sustaining patterns existing over a uniform or periodic background. A glider can be seen as a dislocation or defect of this background. At least 150 cells in a 1D system, and more cells for larger neighbourhood sizes, are required before complex behaviour can emerge. Attractor basin topology will typically consist of long transients of complex behaviour leading to small attractor cycles. An example of this attractor basin topology is shown in Figure 6. The left shows a subtree section entering the attractor cycle and the right image shows 8 transient levels of a subtree from a randomly generated seed.

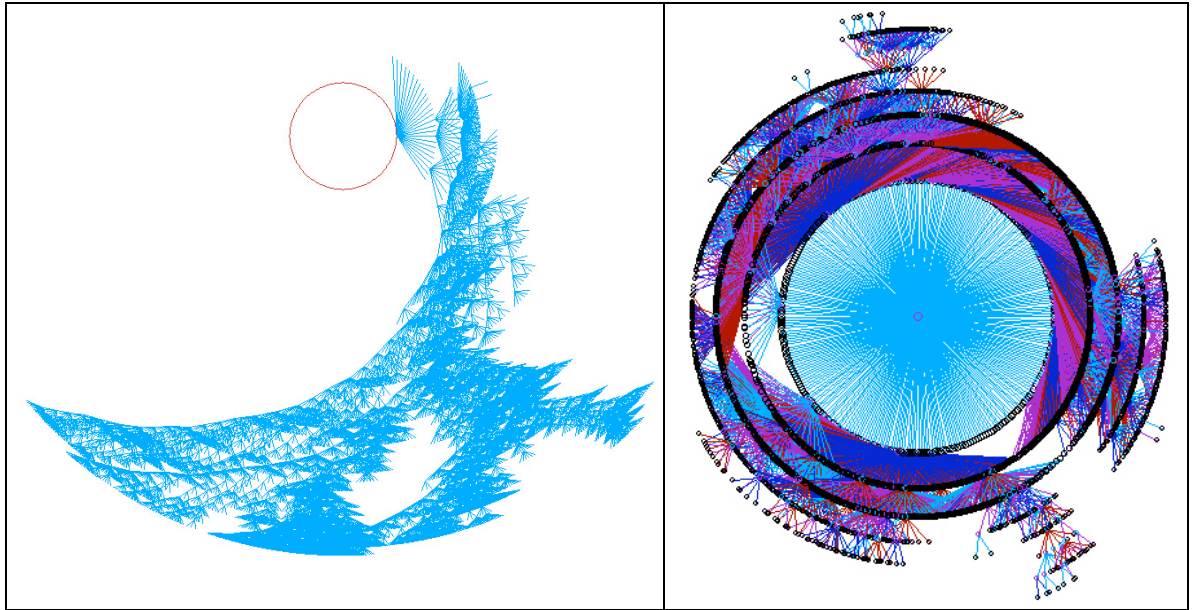


Figure 6. Complex rule behaviour : Partial subtree of an attractor cycle (left) and a section of eight transient levels from random seed (right).

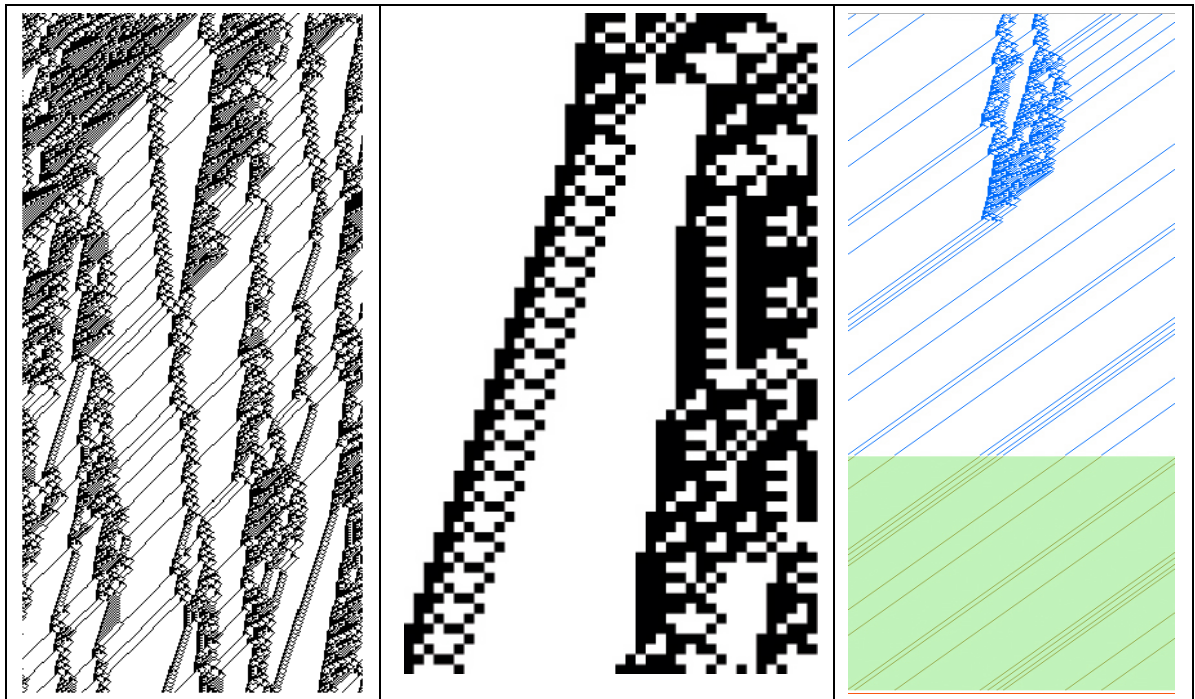


Figure 7. Example spacetime plot of complex behaviour (left) and a small section close up (middle). Locating an attractor, the shaded area, after several thousand generations (right).

An example spacetime plot of a complex rule is shown in Figure 7 (left). A close up section of the lower right edge is shown in Figure 7 (middle) where the complex behaviour can be seen more clearly. In order to capture the complex behaviour well before an attractor cycle is entered, it is helpful to use DDLab's histogram analysis function. This gives information regarding how many timesteps are required before the attractor cycle is entered. Figure 7 (right) shows DDLab locating an attractor, the shaded area, after several thousand generations. The attractor in this case is a simple shifting sequence of states.



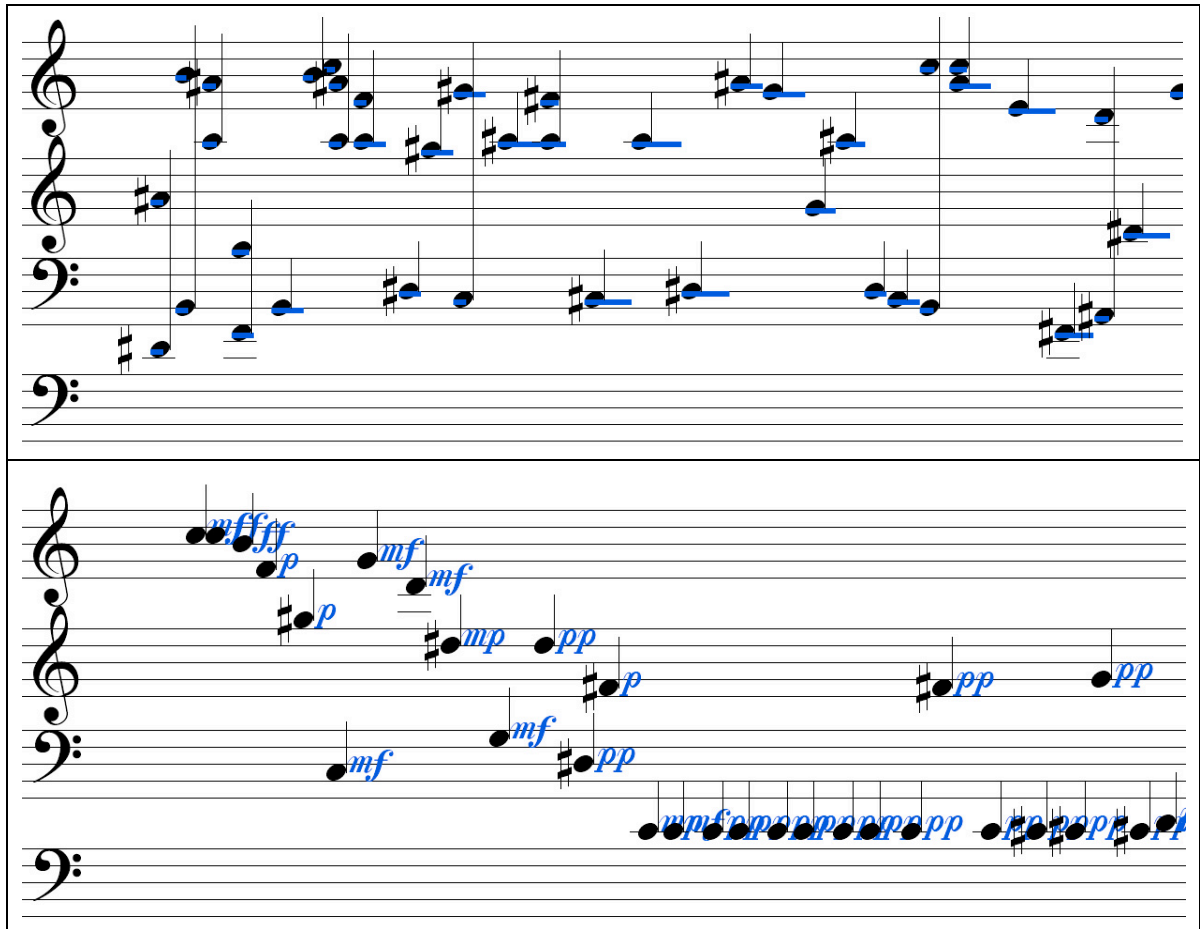


Figure 8. Musical mappings of complex behaviour. Chord-like structures including durations (top) and single note sequence including loudness (bottom).

A reasonably universal process for experimenting with generative music production by CA was suggested in [24]. Mathematica [27] can be used to generate CA data and convert the binary output into decimal format text files. Code for generating data files using Mathematica's built in Cellular Automaton function is given in [24]. This code is quite general and can be used for any size, generations and number of data files. Musical mappings of complex behaviour are shown in Figure 8. The mapping process was implemented using AC Toolbox [28] controlling note, velocity and rhythmic timing. A linear conversion was utilized in order to rescale the large data range to desired compositional ranges. Chord-like structures can be produced if the note onset time mappings are particularly low valued, as seen in Figure 8 (top). Particular attention should be given to the single note sequence shown in Figure 8 (bottom), a result of the linear mapping from the large data range. A deterministic CA will never enter an attractor cycle and then depart from this without reseeding, or changing the rule in a time dependent manner. A diversity of material has been produced from CA, and many of the authors compositions are freely available on-line at [29]. The results of the work described in this section have inspired new methods of sampling rule space [30] and alternative views of the CA rule space structure [31].

A recent generative music performance piece *Babelitis* has been realised to explore and question the universe as a computer concept, comparing this quest to the Tower of Babel [32]. It is realised through a hybrid of mediums, analogue/digital synthesis and old/new computer technology. Events in the universe are mapped to microtones and real/synthetic speech events. Synthetic speech events using allophone sequences are created by mapping universe states over time. Real speech events, in the form of sound samples, are modified over time in a similar manner. This has the effect of creating a babble leading to the hypothetical medical condition *Babelitis*.

## **RD Music**

The behaviour of reaction-diffusion systems has been utilised in computer animation [33] and experimental digital art and computer music [34, 35]. Investigations into the application of Reaction-Diffusion (R-D) systems to generative music has produced MIDI based algorithmic compositions [36] where a number of values are derived from each cell in the system which are then assigned to control tempo, note durations, note onset, note velocity and note value. The initial approach was to utilise partial differential equations differing from the pure computational logic approach of CA. A two dimensional grid of cells was scanned from left to right and top to bottom, giving the effect of “self-modifying repetition”. Similar systems were also applied to the synthesis of sound [37, 35]. These investigations were primarily with 1D R-D systems of both 24 and 32 cells. The output of the R-D systems created scores for an additive/FM CSound system, the number of FM instruments being equivalent to the number of R-D cells. The temporal nature of timbre was emphasized in this study, with instruments having R-D control mappings for peak amplitude, FM rate, FM depth, attack and decay characteristics. In the piece *cicada* [35] multiple R-D systems have been connected in a tree branching structure in order to determine all audio parameters and event structure for an entire sonic composition.

Further investigations have taken place where the behavioural characteristics associated with the ‘state’ of the R-D system, such as equilibrium, stability and chaotic oscillation, control synthesis parameters when excited through interaction [38]. The oscillation of the sum of changes within a stable system is illustrated in Figure 9. Further investigations have been carried out with this type of system where interaction with the system alters the system state and thereby the audio and visual control parameters [34]. A characteristic of this type of interactive work is that the results are stimulus/response (rather than cause and effect) where the outcome is undetermined.

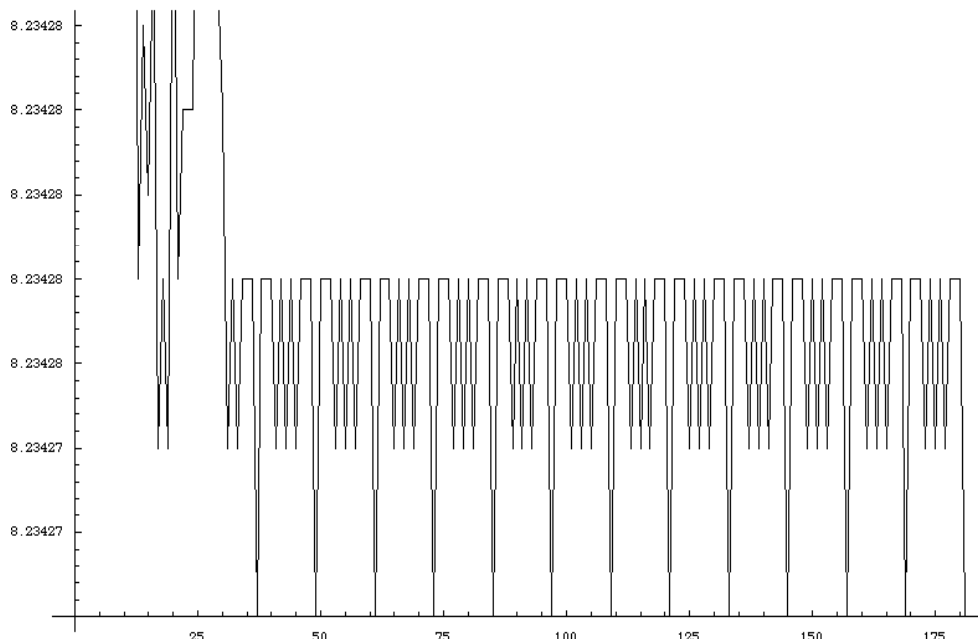


Figure 9. A reaction-diffusion system standing waveform of cell activity over time. Values are then utilised as sound synthesis parameters.

## Conclusions

Unknowable determinism can achieve material tangibility and contribute to artistic ends. Perhaps it is not necessary to understand the algorithmic details in order to make use of it artistically. However, the art constructed by automata and human symbiosis should be viewed as a collaborative process by the human. The artist must be prepared to investigate the theoretical background of these systems in order to successfully employ their digital behaviour within compositional strategy.

The vast behaviour space of automata challenges the limits of human perception. It will remain an untamed wilderness for artistic application unless practical background concepts are acknowledged, and actively researched in an artistic context. This philosophy should encourage the artist to understand automata, even though the automata is unlikely to appreciate art.

## Acknowledgements

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