CAPTURING THE AESTHETIC: RADIAL MAPPINGS FOR CELLULAR AUTOMATA MUSIC

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ABSTRACT

We introduce and demonstrate a new mapping for generating music from the 2D Cellular Automata "Game of Life" (GL). The core of this mapping is based on a polar co-ordinate system with origin at the GL grid centre. Such a polar approach is designed to better capture the radial symmetry inherent in the rule set for GL. The radial symmetry of the GL rule set is key to the visual experience of observing the GL, and therefore we have argued that polar coordinate system captures this key aesthetic element of much of GL more precisely.

1. INTRODUCTION

Cellular Automata (CA) were first proposed in the 1960s by John von Neumann and Stanislaw Ulam as a model of a self-reproductive machine [1]. They wanted to know if it would be possible for an abstract machine to reproduce; that is, to automatically construct a copy of itself. The model consisted of a two-dimensional grid of cells, where each cell could assume a number of states representing the components from which the self-reproducing machine was built. Completely controlled by a simple set of rules, the machine was able to create several copies of itself by reproducing identical patterns of cells at another location on the grid. Since then, CA have been repeatedly reintroduced and applied to a considerable number of fields.

Included in these fields is the field of music composition [2]. One model of music composition is as pattern propagation with the formal manipulation of the propagation parameters. Since CA can produce large amounts of patterned data, it comes as no surprise that composers have utilized the cellular automata for music representation in order to generate compositional material.

Iannis Xenakis used CA in the mid-1980s "to create complex temporal evolution of orchestral clusters" for his piece *Horos* [3]. A number of pioneering experiments on using CA for generating music followed by composers such as Peter Beyls [4], Dale Millen [5] and one of the authors of this paper [6].

2. GAME OF LIFE

In this paper we will focus on one particular CA called the Game of Life (GL). GL is a two-dimensional automaton introduced by John Conway. "Conway was fascinated by the way in which a combination of a few simple rules could produce patterns that would expand, change shape, or die out unpredictably. He wanted to find the simplest possible set of rules that would give such an interesting behaviour" [7].

GL consists of a finite [m × n] matrix of cells, each of which can be in one of two possible states: alive represented by the number one; or dead - represented by the number zero. On the computer screen, living cells and dead cells can be given different colours (e.g. black and white). In Figure 1, where living cells are coloured black.

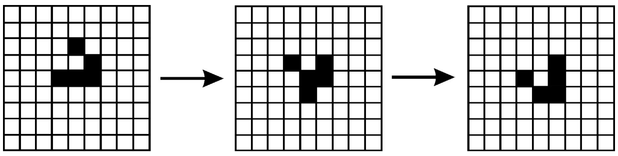

Figure 1: Game of Life

The state of a cell as time progresses is determined by the state of its eight nearest neighbouring cells, as follows:

- "Birth": A cell that is dead at time *t* becomes alive at time *t* + 1 if exactly three of its neighbours are alive at time t
- "Death by overcrowding": A cell that is alive at time *t* will die at time *t* + 1 if four or more of its neighbours are alive at time t
- "Death by exposure": A cell that is alive at time *t* will die at time *t* + 1 if it has one or no live neighbours at time *t*
- "Survival": A cell that is alive at time *t* will remain alive at time *t* + 1 only if it has either two or three live neighbours at time *t*

Suppose E is the number of living neighbours that surround a particular live cell and F is number of living neighbours that surround a particular dead cell. Then another way of describing the CA is to say that the life of a currently living cell is preserved whenever $2 \leq E \leq 3$ and a currently dead cell will be reborn whenever $3 \leq F \leq 3$.

3. COMPUTER MUSIC AND GL

There are two main reasons why GL has been at the centre of a significant number of algorithmic composition methodologies:

1. Comtivity - The generation of complexity in music [8, 9]
2. Inspiration - A desire to capture the aesthetic of GL in a non-visual art form: music [10]

Although much of the previous work claims (1) is the motivator, they are clearly also motivated by (2) - the beauty of GL. Now at the core of all GL composition methodologies lies a pair of elements: (a) one or more GLs running in parallel or serial; and (b) a mapping from the cell outputs of the GLs into some musical domain. In previous work the mappings into the musical domain do not fully address (2), the "Inspiration", because they do not fully address what we believe to be a core element of the GL aesthetic: radial symmetry.

Examining the rules of GL described earlier, it can be seen that a cell's state is determined by the state of the cells *around* it. The neighbourhood could be rotated around the centre cell by 90, 180 or 270 degrees, and it would still have the same effect on the cell's state. This is a key reason that such attractive symmetric patterns emerge during iterations of GL. A number of researchers have discovered what are now well-known symmetrical life evolutions, and there is some discussion of the symmetrical tendencies of GL [11]. And even for those evolutions which are non-symmetrical, the emergence of complex broken symmetries from simple symmetrical rules is one element that appeals to our aesthetic sense during GL iterations.

However, the mapping rules used for music in previous investigations have involved some form of *linear* mapping of cells. For example [2] and [12] discuss the use of Cartesian (x,y) co-ordinates of a live cell in generating musical notes.

4. A MUSICAL MAPPING WITH RADIAL SYMMETRY

We propose a mapping which better captures the radial symmetry inherent in the aesthetic of the GL –polar co-ordinates. In this mapping, the origin is placed at the centre of the GL board, and each live cell is mapped into the musical domain based on its (r,θ) co-ordinate rather than its x or (x,y) co-ordinate. This mapping approach is illustrated in Figure 2. Once this radial mapping is chosen a decision needs to be made as to what to map (r,θ) on to.

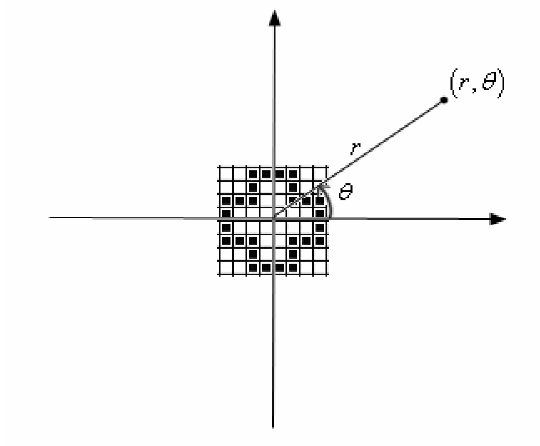

Figure 2: A radial mapping for GL

For the purposes of this investigation the following algorithm was used.

1. Choose a BPM (beats per minute) value. Initialise a variable *baseBeat* to 0, choose a fixed note duration D
2. Run a generation of the GL
3. Iterate θ around the board from 0 to 2π in 127 steps. For each of the 127 values of θ, iterate r from the centre of the board to the board's edge, one cell at a time.
4. For each of the iterated values of r, examine the cell at (r,θ). If it is alive generate a MIDI note with pitch proportional to r, and of duration D. Locate the MIDI note at beat: *baseBeat*$+ D+(16*(\theta/(2\pi)))$
5. After completing the nested iterations of (r,θ) over the whole grid, update *baseBeat* to the beat of the last generated MIDI note.
6. Go back to (2) and repeat.

To illustrate this algorithm, let us consider the cell with (x,y) co-ordinate $(2,2)$ in Figure 2. By performing the standard transformations from Cartesian to Polar co-ordinates (which will not be detailed here for space reasons) we get a quantized (r,θ) coordinate of $(3, \pi/2)$. This is halfway across the GL grid in Figure 2, so the proportional MIDI pitch value will be 64 (halfway up the MIDI pitch range of 0 to 127). Looking at step (1) above, if we assume a duration D of 1 beat and a starting value of *baseBeat* of 0, then the start of the beat for the MIDI note calculated by step 4 is: $0 + 16$

$(\pi/2)/(2\pi) = 5$. So $(2,2)$ will generate a MIDI note of pitch 64 at beat 5.

This algorithm has been kept as simple as possible, on the basis that if we are trying to capture the elegance of the Game of Life, the mapping should be as direct as possible, while still being musically interesting. Step (4)'s assignment of beat location was one possible approach to capturing the comtivity element of the GL. It created interesting rhythms based on the angle of the live cells relative to the board-centre.

It is worth noting that even more complex interacting rhythms can be generated by swapping the nesting in step 3 – i.e. iterate over r, and for each iteration of r iterate over θ. However the complexity of these rhythms is such that the generated musical score is harder to relate to the GL state by eye. So for the purposes of illustrating the radial mapping, we have used the nesting given in the algorithm steps above.

5. RESULTS

To demonstrate the radial mapping, a GL grid of size 20 cells by 20 cells is used. The GL grid is "seeded" with a pattern which is approximately a circle of radius of 7 squares. It is only approximately a circle since it is built using polar co-ordinates, and the grid quantization mapping does not allow it to be a perfect circle. (The fact that the seed is not perfectly symmetrical actually makes the generated music more complex.) The left hand picture in Figure 3 below shows the seed, in this case white cells are alive, and black ones dead. It can be seen that the second generation of the GL - on the right hand side of Figure 3 - does not have full radial symmetry either. However it still has significant amounts of radial symmetry that will be picked up by the generative polar co-ordinate process.

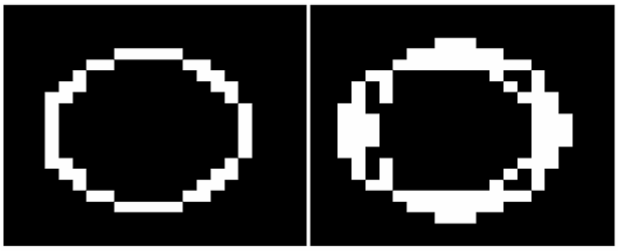

Figure 3: First two generations of a GL starting with a "circle seed" on the left

For simplicity of generated musical score readability, the pitches were scaled between MIDI values 60 and 90. A tempo of 120 beats per minute was used and the global duration D was set to 2 beats.

Figure 4 over the page shows the resulting output of the two GL generations of the circle seed. Looking at the first generation in bars 1 to 8 we can see the melody falling and then rising again. In fact the melody should stay at a constant pitch for a perfect circle seed. But in reality one side of the "circle" is closer to the origin to the other side due to the generating pattern not being a perfect circle around the origin (i.e. a quantization error for such a small circle in GL). Furthermore, in bars 1 to 8, there would only be a single pitch at any time if we had a perfect circle. But the way the circle is generated in the seed causes it to have a thickness of 2 cells in certain places.

From bar 9 onwards the second generation is playing. Some of the "rise, fall, rise"-effect in pitch, seen in the first 8 bars, is still there. This is because the second generation still approximately holds the quantized circle shape. However, as can be seen in the right hand part of Figure 3, the complexity of GL is now starting to manifest in the score. A significant number of new cells have been brought to life, contributing to the harmony. Furthermore, the quantization of the circle leads to θ generating slightly more complex rhythms.

Despite the quantization errors, these two generations show how the polar mapping is starting to capture the outward symmetrical complex movement of the circle seed, and thus better captures the aesthetic of the visuals than a linear mapping would. (Note, quantization can and should be done either manually or automatically. We have decided to leave this example non-quantized on purpose, for the sake of clarity of the explanation of the mapping.) This can be compared to more linear mappings such as mapping *(x,y)* to *(beat, pitch)* or mapping a row of GL board cells onto a binary number b (where each digit of b is 1 or 0 depending on whether a cell is alive or dead); and b can then represent pitch. Such mappings will not produce music that captures the symmetrical aesthetic of GL as successfully as the radial mapping. We will not report on our experiments with linear mappings here due to space limitations.

6. CONCLUSIONS

We have introduced and demonstrated a new mapping for generating music from the 2D Cellular Automata Game of Life. The core of this mapping was based on a polar co-ordinate system with origin at the GL grid centre. Such a polar approach is designed to better capture the radial symmetry inherent in the rule set for GL. The radial symmetry of the GL rule set is key to the visual experience of watching the GL, and therefore we have argued that polar coordinate system captures this key aesthetic element of much of GL more precisely.

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Figure 4: Music of the first 2 generations of a GL, as shown in Figure 3.