Timbre Control by Modulation of the Partial Tone Structure Using a Cellular Automata

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ABSTRACT

Music is the organization of sound patterns in time and thus the compositional process is iterative by nature. Evolutionary Computation is one possibility of utilizing algorithms to generate music. In this project a Cellular Automata, namely Conway's Game of Life has been used to implement the control of parameters in the realization of a formalized musical piece. The framework was used to develop a model to control the sound synthesis of 196 sine oscillators playing four different notes with various partial tone structure with the Cellular Automata. The model is introduced, described, and assessed, contributing to the ongoing evaluation of the potential of Evolutionary Computation in the search of new sound.

1. INTRODUCTION

When we talk of music, we talk of patterns. Music is the organization of sound in time. The compositional process is thus usually based on rules to organize sound vertically, in the very moment, and horizontally, meaning throughout time. It is iterative by nature. Consequently, it seems to be an obvious choice to utilize algorithms to make decisions when organizing sound. One possible approach is the utilization of Evolutionary Computation such as Cellular Automata in the process of music generation (respectively sound organization). The potential of Cellular Automata for sound generation has already been subject to various investigations. The aim of this project is to contribute to that body of works, longing for new synthesis methods.

2. EVOLUTIONARY COMPUTING IN MUSIC

Artificial Intelligence is one of the biggest topics of our time. It is already used and applied in music technology as well as for music generation. But the idea of using algorithms to make music is not new. With the introduction of the early computers various composers such as Xenakis applied different mathematical models that they thought to embody the compositional process [1]. Amongst those models utilized in the compositional process were for example, combinatorial systems, grammars stochastic models and fractals [2]. Later, also techniques used for solving problems in engineering were adapted for making music.

Amongst those approaches are also evolutionary algorithms that are potentially more interesting for the application in music than Artificial Intelligence [1]. Whereas AI is trained to compose in a certain musical style and imitate existing music by learning its patterns, Evolutionary Computation has the potential to lead to discovery of entirely new patterns and approaches. According to Miranda [2] those approaches can be classified in the three following categories:

1. Engineering Approaches
2. Creative Approaches
3. Musicological Approaches

The *Engineering Approaches* were initially used by engineers for problem solving. Later they were successfully applied to music technology as well, for example for the optimization of synthesis parameters or to reproduce given sounds [2]. In the software Chaossynth [3], [4] for granular synthesis, which uses Cellular Automata to control the production of the grains. It can produce granular sounds of very good quality and proved to be more efficient than probability tables.

The initially mentioned mathematical computer experiments are so called *Creative Approaches*. In the past decades many of those approaches proved that Evolutionary Computation can successfully used to generate musical compositions [2]. In many cases Cellular Automata were used. The standard idea was to associate the states of the cells to musical notes and then play them via Midi on an additional instrument. A more advanced usage of a Cellular Automata can be found with CAMUS [5] that does not simply associate the value of a cell with a simple note. Instead, it adopts a two-dimensional representation where the cell's coordinates represent the intervals to two musical notes. Like this one single cell represents an ordered set of three musical notes.

Musicological Approaches utilize models that seek to find answers to the origins of music [2]. Those complex models try to remodel for example the evolutional survival mechanisms that led to certain melodic preferences or reinforcement through repetitive interaction.

3. FORMALIZED MUSIC

The compositional process can be pictured as a process with certain dynamics. Besides a set of rules, it also involves iterations. For his composition *ST* Xenakis structured the individual steps of the compositional process in a scheme that contains the following eight phases [6]:

1. Conceptions initiales
2. Définition d’êtres sonores
3. Définition des transformations
4. Microcomposition
5. Programmation séquentielle
6. Effectuation des calculs
7. Résultat final symbolique
8. Incarnation sonore

The fourth phase *Microcomposition* is dedicated to mathematical programming [7]. It connects the musical events and puts them through a calculatable process into relation. It can be considered as a micro-compositional computational plan regulating various musical parameters [7]. In the recursive sequential processing parameters like the length of sequence, density, timbre proportion, tone starting point, instruments, pitch, glissando speed, tone duration and tone dynamics are processed. For his stochastic approach Xenakis relied on great number of samples [7].

4. IMPLEMENTED MODEL

Like some of the introduced Engineering Approaches and Creative Approaches the presented model relies on Cellular Automata. The idea is to utilize the Cellular Automata to take care of the fourth phase of the compositional process for generation of formalized music introduced by Xenakis. Therefore, some additional parameters will be calculated while others while not be adapted.

4.1 Conceptions initiales

The conceptional idea is to have groups playing different musical tones where the fundamental tone is missing. Within each group the instruments vary in their accuracy of the partial tones that they are playing.

4.2 Définition d’êtres sonores

There are four groups playing four different musical tones, namely C2, F2, A2# and D#3. Each group contains n x n sine oscillators producing the corresponding partial tones two to nine. Within each group the instruments vary in their distortion of the second and third partial tone, while the others remain the same.

All instruments play the in Figure 1 exemplary portrayed dynamical scheme that varies.

4.3 Définition des transformations

In terms of macro-compositional aspects there are supposed to be no transitions to other macro-structural parts only the emphasis on the micro-compositional aspect.

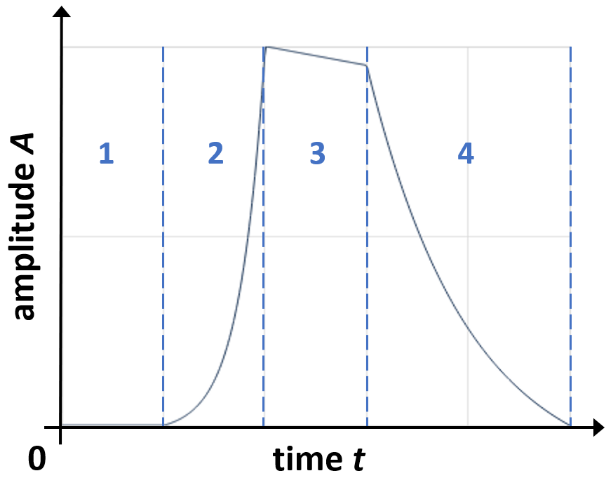

Figure 1. scheme of dynamics the played tones, consisting of variable 1.) delay, 2.) crescendo, 3.) duration, and 4.) decrescendo.

4.4 Microcomposition

This is where the Cellular Automata comes into play. Based on the values of the grid cells various musical parameters will be calculated. This enables the control of a great many numbers of parameters simultaneously.

4.4.1 Sequence Length

The sequence length l_i represents the duration between grid actualization and thus sound calculation. It depends on a given initial start value for the duration between the calculation of two sets of tones (l_{inital}). In the following computational process, it will be updated depending on the grid population, meaning the share of cells being alive (value = 1). Thinking that the speed of life increases with an increasing population, for each grid update of the Cellular Automata the sequence length l_i is calculated according to this formula:

$$l_i = l_{inital} \cdot \frac{1}{{c_{var}}^{5\cdot(rel.population_{start} - rel.population_i)}} \quad (1)$$

Parameter c_{var} regulates the variation of the variation in the sequential length l_i, when for smaller values of c_{var} the variation increases and vice versa. The parameters c_{var} and l_{inital} are global and can be adjusted.

4.4.2 Instruments and pitch

The instruments are selected based on the values of the corresponding cell of the Cellular Automata. If the value equals zero (meaning the cell is dead), the instrument is not activated thus no sine oscillator producing sound will be generated. The generated pitch depends on the instrument’s membership to one of the four mentioned groups. The grid with the dimensions h x v consists of $2n$ x $2n$ cells in four quadrants of the size n x n, each associated with one group of instruments, where n is the amount of horizontal and vertical cells associated with the group. Thus n x n represents the number of sine oscillators in one group. For each of the cells in the $2n$ x $2n$ grid the new cell value is calculated based on the rules of Conway's *Game of Life*. The rules state that [8]:

a. A dead cell with exactly three living neighbors is brought to life in the next generation.
b. A living cell with less than two living neighbors will die (of loneliness) in the subsequent generation.
c. A living cell with two or three living neighbors will remain alive in the next generation.
d. A living cell with more than three living neighbors dies in the subsequent generation (from overpopulation).

The *Game of Life* used in the composition does not have hard borders, instead, the bottom edge and the top edge as well as the right edge and the left edge are treated like neighbors, reimagining the globe.

4.4.3 Timbre proportions

The timbre proportions for each instrument are calculated based on the corresponding cell's location within the grid. The location determines the group to which the instrument belongs (and thereby what missing fundamental it reproduces). Within each group the timbre proportions are calculated according to the following scheme that is also portrayed in Figure 2.

In the horizontal dimension of the grid is the second partial tone determined. For calculation of the frequencies of the second partial tone and the third partial tone the following formulas are used:

$$f_2[h,v] = f_{fundamental} \cdot \left(2 + \left(h - \frac{n-1}{2}\right) d\right) \qquad (2)$$

$$f_3[h,v] = f_{fundamental} \cdot \left(3 + \left(v - \frac{n-1}{2}\right) d\right) \qquad (3)$$

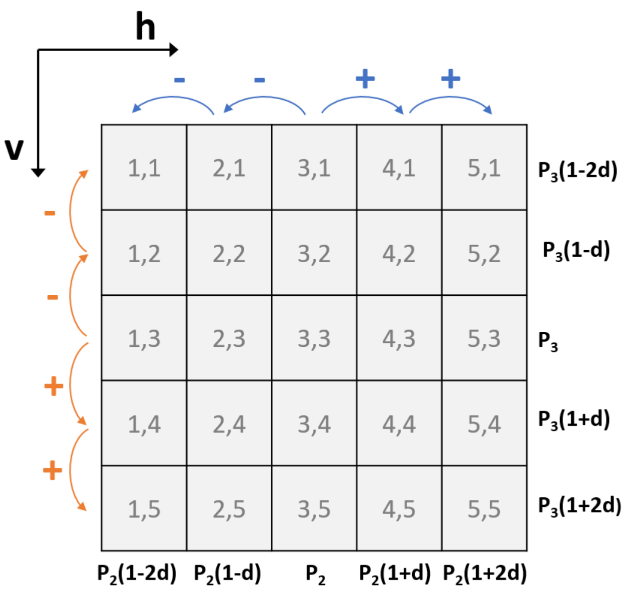

Figure 2. Timbre determination of the partial tones based on the cell location within the grid (here shown for one group).

The variables h and v denote position of the cell in the grid. The fundamental frequency $f_{fundamental}$ depends solely on the group (and thus quadrant) of the instrument while the distortion factor d is a universal parameter of the composition that can also be edited.

4.4.4 Tone dynamics, starting point and duration

The dynamics for each sound generated by an activated instrument follows the scheme displayed in Figure 1. The temporal aspects are treated like the condition depending on an individual's circumstances such as the stage of life and the environment such as living in a crowded or calm space.

The tone starting point is defined by the delay $t_{delay,i}$ which is calculated according to this formula:

$$t_{delay,i}[h,v] = M_i[h,v]\frac{l_i}{4} + n_{neighbor,i}[h,v]\frac{l_i}{7} \qquad (4)$$

The majority M_i is calculated based of the state of the cell in the previous iteration $i-1$, declaring it as a child ($M_i = 0$) if the cell was newly born in this iteration i or as an adult ($M_i = 1$) if it was previously alive. The parameter $n_{neighbor,i}$ represents the number of neighbor cells being alive in the current iteration i.

The duration of the crescendo $t_{cresc.,i}$is calculated by using this formula, capturing that with age one gets less hectic whereas in a populated space life is more hectic:

$$t_{cresc.,i}[h,v] = (1 + M_i[h,v])\frac{l_i}{9} - n_{neighbor,i}[h,v]\frac{l_i}{36} \qquad (5)$$

The duration of the tone $t_{dur.,i}$ is calculated according to the following formula:

$$t_{dur.,i}[h,v] = M_i[h,v]\frac{l_i}{6} + \left(3 - n_{neighbor,i}[h,v]\right)\frac{l_i}{8} + \frac{l_i}{5} \qquad (6)$$

The duration of the decrescendo $t_{decresc.,i}$ is calculated using the following equation:

$$t_{decresc.,i}[h,v] = (2 - M_i[h,v])\frac{l_i}{2} - \frac{3l_i}{1+n_{neighbor,i}[h,v]} \qquad (7)$$

The overall maximum amplitude of the tone, referred to as level, is determined by the following equation:

$$level_i[h,v] = 0.9^{(8-n_{neighbor,i}[h,v])} \qquad (8)$$

4.4.5 Spatial parameters: l/r balance, reverberation

In addition to the previously introduced parameters the following spatial parameters are calculated. They reflect the observed individual's situation, such as a sound source being surrounded by many others leading to decrease of reverberation time. Or being framed by the left or right determining how much sound reaches the spectator from left or right. Following these considerations, the l/r balance is calculated according to the formula below:

$$balance_i[h,v] = 0.5^{(n_{right,i}[h,v])} - 0.5^{(n_{left,i}[h,v])} \qquad (9)$$

The $balance_i$ depends on the current number of neighbors to the right $n_{right,i}$ and on the current number of neighbors to the left $n_{left,i}$. For $balance_i$=1 the sound will only

appear on the right speaker, for $balance_i = -1$ only on the left and for $balance_i = 0$ in stereo.
For the reverberation the two parameters room size $room_i$ and the reverb high-frequency damping range are calculated based on the following formulas:

$$room_i[h, v] = 0.9 - \frac{n_{neighbor,i}[h,v]}{10} \qquad (10)$$

$$damp_i[h, v] = room_i[h, v]^{-1} \qquad (11)$$

4.5 Programmation séquentielle, effectuation des calculs, résultat final symbolique and incarnation sonore

The remaining sequential programming of the model has to be done in a suitable environment. In the case of this project *SuperCollider* has been used. It allows programming and just-in-time sound synthesis and will be used for the subsequent steps of the execution of the calculation operation and sonic realization, eliminating the need for musical notations.

5. PARAMETERS

For the realization of the sound sample two glider in the configuration that is shown in Figure 3 (top left image) have been used. The grid size had a total size of 14 x 14, controlling 196 sine oscillators simultaneously. The initial sequence length was set to $l_{inital} = 3$s and the distortion factor $d = 3.5\%$. To see all parameters, check the file in the digital appendix.

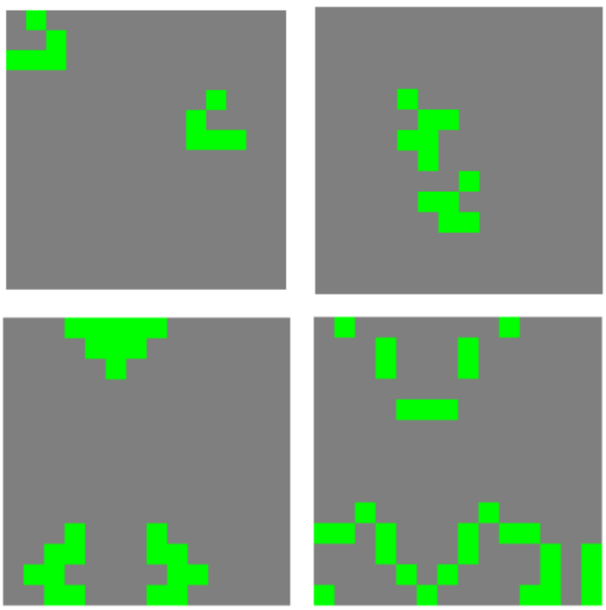

Figure 3. The implemented model in action.

6. CONCLUSIONS

It has been shown that Evolutionary Computation is a sufficient tool to control a great number of parameters simultaneously and in real time. It has the potential to help us find new, yet unheard music and sound, aside from the already known patterns..

7. REFERENCES

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