Celerina – A Generative Music System Using Aesthetical Reduction Applied to Simple Cellular Automata

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Abstract

Celerina is the software core of a realtime system for dynamic music generation. Several one-dimensional binary cellular automata generate melodic patterns that are subsequently reduced and processed to form musical motifs and gestures. The music generated by Celerina is set to conform with such musical styles as jazz, classical or ambient music.

Introduction

The idea for Celerina was born in 2002, when we were contacted by Syntharp® Instruments, a small Swiss instrument manufacturing company (see links in appendix section). At that time, the company was looking for possibilities to expand the application range of their novel musical instrument. The Syntharp is a 12-string, five feet tall instrument whose strings are driven purely by magnetic resonance. The initial target customer base for the instrument consisted of musicians and composers. However, it was decided that the Synharp's application range could be significantly broadened by transforming it into a self-contained, autonomous, and interactive musical installation, which is able to create an acoustical ambience suitable for public and private places. Celerina forms the generative music system, which drives the Syntharp installation.

Research in generative music software has been conducted since 1950 (Miranda 2000). Lejaren Hiller and Leonard Isaacson were the first composers to combine a stochastic approach with a system of musical constraints (Hiller 1959). Ten years later, Allen Forte stated that it would only be a matter of time until artificial intelligence based methods would allow the analysis and resynthesis of musical scores (Hiller and Isaacson 1959). At the same time, Herbert Simon and Terry Winograd presented a pattern recognition system based on systematical grammar (Winograd 1993), which clearly highlighted the practical potential of combining artificial intelligence and music. Hidden Markov Models (HMM) represent a frequently used technique in generative music (Fine et al. 1998). HMM can be employed to mimic a particular musical style by analyzing pre-existing musical data and building a weighted stochastic sequence (North 1989). Eduardo Reck Miranda (Miranda 1994), the author of Cellular Automaton Music (CAMUS), was amongst the first composers to extensively apply cellular automata (CA) to the generation of music. CA were invented by Stanislaw Ulam and are heavily influenced by John von Neumann's theory of self-replicating machines (Von Neumann 1966). The most popular example of CA is the famous "game of life" by John Horton Conway (Gardner 1970). Since then, many applications, which employ CA for music generation, have emerged (see links in appendix section).

Celerina is a generative software that combines one dimensional CA with a rule based system for aesthetical reduction. It benefits from the CA's emergent pattern generation capabilities. At the same time, it relies on a rule-based system in order to conform to specific musical styles. The CA outputs raw musical data, which are then fed through several processing units. These units conduct several reduction steps, which shape the musical quality of the final output. The style of this final output is best described as a mixture of jazz, ambient and classical music. We deem these styles to be very suitable for background music in public places. However, the user of Celerina is able to easily change the stylistic parameters in order to create entirely different styles.

As critical listeners, we have high demands with regard to the musical quality of instrumental music. Our ear is trained almost exclusively by human-made music that combines emotional and cultural aspects. Generative music has so far not been able to live up to these standards and is therefore often faced with suspicion. Important aspects of instrumental music, which both serve as listening cues and quality criteria include melodic phrases that are recognizable as motifs throughout the piece, harmonic progressions that oscillate between tension and relief as well as instrumentation and arrangement of voices that enable the differentiation between the leading voice and its accompanying voices. Furthermore, variation in melodic and rhythmic motifs is essential in creating the impression of musical depth. We believe, that Celerina succeeds in meeting some of these musical requirements.

Concepts

Celerina relies entirely on CA as a source of musical material. It avoids the reuse of archived musical patterns in order to create musically meaningful material. Therefore, Celerina acts as a creator of truly original music.

Celerina implements CA in their simplest form: as one-dimensional binary cellular automata. However, unlike other systems, Celerina introduces a melodic pattern reduction technique in order to extract and enhance the aesthetic content of the CA's initially fairly cluttered output. In this context, melodic pattern reduction refers to a decrease in a pattern's density, value range and further specific musical aspects, which will be discussed.

Even in this simple form, CA are able to generate a wide variety of different patterns. According to Wolfram's classification scheme for CA (Wolfram 2002) there exist three fundamentally different types of patterns: steady-state patterns, repetitive cycle patterns and random-like patterns. Usually, both steady-state patterns and random-like patterns are unsuitable for generative systems, since they lead to a final output that either lacks diversity or structure. Due to a combination of the fact that Celerina employs several CA simultaneously (one CA per instrument channel) and subjects each of them to a pattern reduction process, even these types of CA can lead to interesting melodic structures (see results and discussion section). Celerina deals with other commonly undesired aspects of CA in a musically meaningful way. Extinction, for example, is used to delimit melodic phrases (see implementation section).

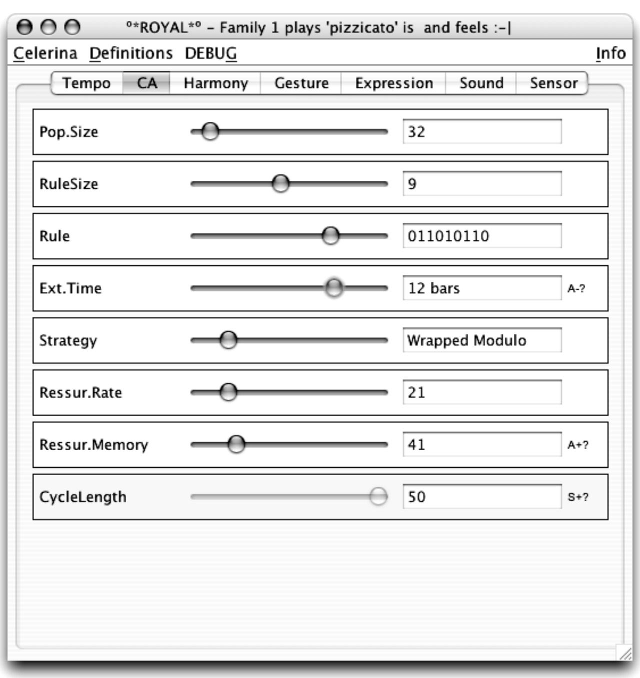

Figure 1: Celerina's CA engine

A further central aspect of Celerina involves its usage of processing units as an automated means to control various compositional parameters. These parameters include CA properties, pattern reduction control variables, and instrument selection. Here, the term processing unit describes a functional entity, which possesses a single parameter and controls the processing of musical data according to this parameter. Parameters are chosen probabilistically and each parameter possesses its own probability density function (see figure 2). There exist a total of about 60 different types of processing units for each instrument channel. With regard to the scope of this publication, we will focus on the processing units involved in the homophony reduction process. This process reduces the number of notes that are played simultaneously by a single instrument, hence the term homophony. An overview of the entire system of processing units is available in (Flury 2005). Units that perform similar and related tasks are grouped inside an engine. Figure 1 shows a CA engine. Each slider represents a processing unit.

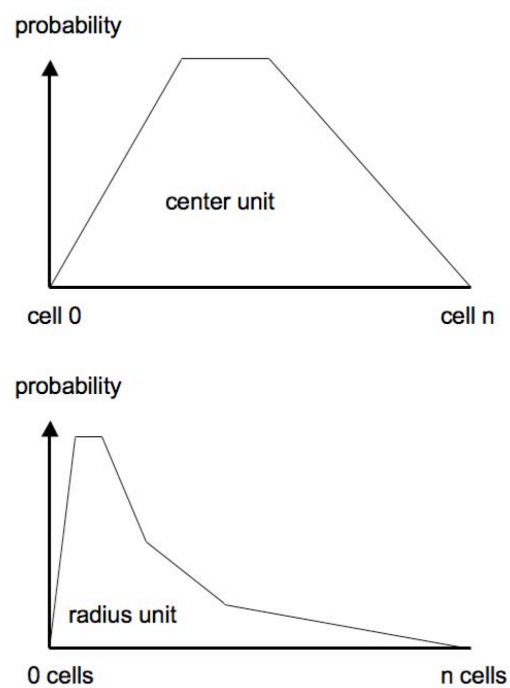

Figure 2: Probability density functions for the units *center* and *radius*

Implementation

CA models

Celerina makes use of only the simplest types of CA, the one-dimensional binary standard and modulo CA. See (Wolfram 2002) for a detailed description of these CA.

Unlike the standard model, the modulo model possesses no explicit rule set but rather employs a single rule pattern. The comparison of this pattern with the cell activity in the previous CA generation (t-1) dictates the activity of the cells in the next CA generation (t). This principle is depicted in figure 3. While the rule pattern traverses the cell array of the previous generation, the number of matches in the overlapping region are calculated for each step. For each rule pattern position, the sum of matching

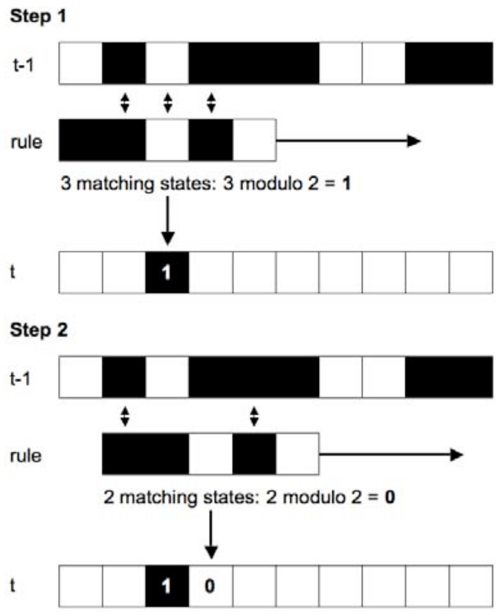

Figure 3: Modulo CA

cell activities modulo 2 sets the activity level of the corresponding cell in the next generation. This modulo calculation asserts that the number of active and inactive cells is more or less equal in each generation. Therefore, modulo CA are less likely to die out than standard CA. Currently, Celerina implements both CA models. However, modulo CA are chosen more frequently than standard CA.

Our choice of these very simple CA types is entirely based on musical considerations. The auditory perception of a CA's output differs fundamentally from its visual perception. Successive generations of even a simple CA generate a pattern, which may look relatively simple if spatially aligned, but is perceived as a fairly complicated temporal structure. Therefore, the generation of interesting temporal structures doesn't necessarily require complex types of CA. Furthermore, Celerina possesses several instrument channels, each of which is controlled by its own CA. The interplay of several simple concurrent CA creates a much more complex musical super structure. Finally, the CA's output doesn't directly determine Celerina's musical output. Many of its musical attributes emerge throughout subsequent steps of pattern reduction. Therefore, the musical complexity and variety of the final output is only partially dependent on the complexity and variety of the used CA model.

Every CA implementation must treat cells located at the border of the CA differently than the interior cells. There exist essentially two ways of processing these border cells. The neighboring cells, which lie outside of the cell population can be wrapped to the other end of the population (see figure 4, top). Alternatively, these neighbors can be reflected back into the population on the same side of the population (see figure 4, bottom). These border conditions have an important impact on the musical result (see results and discussion).

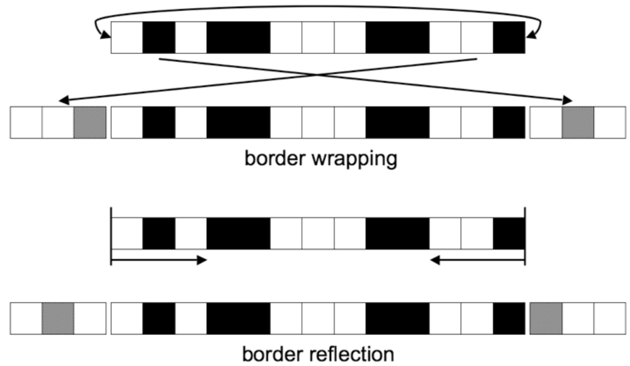

Figure 4: Border handling strategies

Extinction phenomena (steady-state patterns) are very common in CA. Instead of avoiding these seemingly unfortunate cases, Celerina utilizes extinction as a compositional element. When a population has become extinct for a few generations, Celerina resurrects the population either by setting the cell states to random values or by resetting the cell states to some previous initial values. The time span until this resurrection takes place is set to comply with the rhythmic metric structure of the specific instrument channel.

Pattern Reduction

The process of pattern reduction diminishes the number of active cells in each generation. A generation in a CA's pattern represents a time step and each cell of a generation is mapped to a specific pitch. This pitch mapping is determined by a harmonic subsystem whose description can be found in (Flury 2005). All cells that are active in one generation represent the pitches of concurrent notes. If an active cell has been active in the previous generation as well, the according note is simply held longer. Even when using only a single CA, the resulting homophonic density can be very high. This may be desirable for contemporary music, but it is simply too dense for more popular styles of music. Celerina's strategy to extract a melody from this homophonic input is based on the following two observations: The pitches of notes in a melodic structure are usually relatively close to each other (otherwise, melodies can sound jumpy and overly nervous), homophonic melodies tend to avoid particularly small intervals (such as second intervals).

Motif-Gestural Reduction

Based on the first observation, we implemented two processing units that operate on the tonal range of a melody. One unit controls the tonal center whereas the other unit controls the radius of the tonal range. Figure 2 depicts the respective probability density function of these two parameter values. Another pair of processing units is responsible for moving the tonal center, which causes a gestural movement in the melodic progression.

Even within a tonal range, the amount of homophonic content may still be too high. Four additional homophonic reduction strategies take care of this problem. A dedicated processing unit is responsible for choosing one out of these four strategies that will be applied. The names of the four strategies reflect their respective means of selecting a particular pitch. The *Top* strategy picks the highest pitch within the tonal range. The *Bottom* strategy does the opposite. Likewise, the *Center* strategy selects the pitch, which is closest to the tonal center of the range. The fourth strategy called *Nearest* selects the active cells that are closest to the active cells of the previous generation.

In order to introduce a controllable amount of variation to the emerging melodies, a processing unit entitled *Health* randomly removes a small number of active cells. This procedure is actually applied before the homophonic reduction takes place. That way, the *Health* unit affects the outcome of the homophonic reduction by slightly varying its input patterns. It is crucial that the *Health* unit inactivates only a very small number of cells. Otherwise, the resulting melody may sound entirely different from the initial melody.

Dissonance reduction

Based on the second observation, we implemented an important processing step, which reduces the amount of homophonic dissonance introduced by a small interval distance. Each of Celerina's channels is allowed to exhibit a homophony of up to three voices. Depending on their frequency ratios, these three voices may sound very dissonant. Dissonant intervals are a compositional tool to create tension where appropriate. However, in most cases and particularly in tonal harmonies, they must be avoided. There are two processing units in Celerina that are assigned to the task of dissonance reduction. The first unit defines the critical interval size below which it is considered dissonant. A second unit is responsible for choosing an appropriate dissonance resolution strategy whenever an interval has been identified as dissonant. The two strategies, which are currently available, are called *ornamentation* and *hammering*. *Ornamentation* simply takes the two notes of a dissonant interval and plays them in succession (see figures 5 and 6).

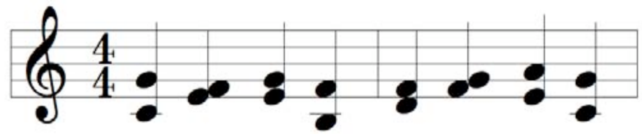

Figure 5: Melody in two voices showing two occurrences of small dissonant intervals

Figure 6: Small dissonant intervals resolved as melodic ornamentation

The temporal order of the two notes is defined by the harmonic weight of each note. The example depicted in figures 5 and 6 contains two dissonant intervals {E,F} and {F,G}. Since the root key is C, E will be the fist note, followed by the harmonically less important note F. Likewise for {F,G}, G will be followed by the less important F. The magnitude of the harmonic weight is defined by the overtone scale, beginning with its root key. The earlier a key appears relative to the root key in this overtone scale, the higher its weight. This order aligns well with human perception of relative harmonic importance and is independent from the issue of musical style.

Figure 7: Dissonant interval resolved as *hammering*

The *hammering* strategy plays the two notes in succession as well, but this time, the harmonically less important note is played first as a grace note (see figure 7). The term *hammering* comes from a playing technique applied by guitarists. A grace note has a similar effect as a glissando, which forms a melodic decoration by sliding from one pitch into another. The decision whether to use *ornamentation* or *hammering* is not mutually exclusive. Instead, the corresponding processing unit is allowed to mix the two strategies. Typically, about 20% of the dissonant intervals are resolved to grace notes and 80% are resolved as ornamentation notes. As a rule of thumb, large intervals are more likely to be resolved as grace notes whereas small intervals tend to be resolved as ornamentations.

To conclude the implementation section, figure 8 shows an overview of the processes described in their order of application in Celerina's sequence of reduction processes.

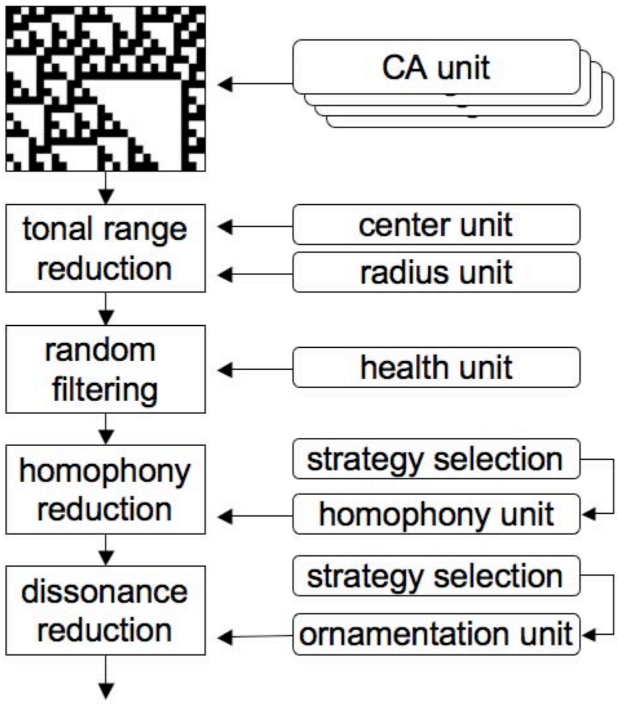

Figure 8: Sequence of reduction processes

Results and Discussion

The musical output of Celerina has been presented to a variety of test listeners, including both professional musicians and lay people. According to their feedback, the melodic decorations introduced by the dissonance reduction processes possessed a very distinct character and grace reminiscent of baroque music.

By resurrecting steady-state CA patterns, Celerina will create musical motifs that tend to repeat themselves after a musically appropriate pause. In Jazz music, these motifs are commonly called hook-ins and play an important role in a variety of music styles (i.e. latin music). Likewise, regular repetitions are particularly important in music generation. Repeating patterns can be associated with a musical ostinato, a repeating melodic phrase, which is often used in classical music for accompanying voices. The length of a repetition cycle depends very much on the population size of a CA. For example, a population size of 7, 14 or 28 is very likely to produce cycles that will fit a 7-beat metric structure over one or more cycles. By choosing CA that belong to the third CA class (random-like), less formal and rigid melodies emerge that possess an improvisational character. By combining several CA classes at the same time, a rich multi-layered musical variety is created.

The choice of a particular border handling strategy has a significant musical effect. Reflected borders tend to disturb the evolution pattern and lead to an output which is similar to that of a random-like CA. On the other hand, wrapped borders produce more natural results and often create repetitive structures. Celerina makes use of this phenomenon to distinguish leading melodies from accompanying voices.

In summary, the application of reduction processes to CA patterns has proven to be an adequate means of creating aesthetic melodic material. Celerina tries to choose reduction strategies that work best for particular musical contexts. Therefore, Celerina creates musical output that usually conforms with a desired musical style and mood. Stochastics plays an important role in the processing unit based parameter control system. It promotes diversity among Celerina's several instrument channels and is an important source of musical variation. Readers can get an impression of what Celerina's musical output sounds like by downloading mp3 sound samples from the following URL: http://www.i-s-o.ch/celerina/

In summer 2005, Celerina was part of an interactive art installation entitled "BioSonics" (Bisig 2003) which was presented during the exhibition "Einfach – Komplex" at the "Museum of Design" in Zurich. Celerina's parameters were significantly changed from the ones devised for Syntharp in order to create a musical style that fits the artistic mood of BioSonics. Celerina responded both to changes in the installation's activity (e.g. changes in the simulated growth processes) and to the participant's interactions. This was achieved by modifications in Celerina's system of processing units that allowed the units to adapt to these influences. Celerina's musical output was combined with an additional sound system, which sonified the simulated biochemistry of BioSonics. This second system created a slowly varying soundscape by crossmodulating an array of periodic sound waves. The combination of this soundscape together with the versatility and originality of Celerina's melodic material was greatly appreciated by the visitors.

Future Work

Further development of Celerina focuses on the implementation of an emotional system, which is affected by user interaction and which influences Celerina's musical output. Via a simple sensory system for proximity and motion detection, Celerina will be able to detect qualitative and quantitative aspects of user interaction and correspondingly change its mood. Subsequently, Celerina's mood is mapped into new parameter ranges for the processing units. To achieve this mapping, we will employ a 3D representation of emotions according to three empotional aspects such as satisfaction, activity and need. Each parameter of a processing unit will be represented by a line that passes through this emotion space. Thus, parameter values can be associated with particular emotions and vice versa.

Furthermore, we intend to improve Celerina's configurability in order to enhance its ability to meet specific stylistic requirements. Users should be able to perform configuration changes via a small set of transparent parameters that doesn't require any knowledge about Celerina's internal structure or music theory in general.

Before introducing Celerina as part of the Syntharp to the music market, we will conduct an empirical evaluation in order to assess the quality and acceptance of Celerina's musical output and it's applicability for different market sectors. Once Celerina is commercially released, we intend to establish a cycle of customer feedback and software adaptations that improves Celerina's quality and adaptability. An online feedback forum will be provided for this very purpose.

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Appendix

Syntharp Instruments web page
http://www.syntharp.com

Wolfram research's own music project using CA
http://tones.wolfram.com/

A site on the usage of different CA types for music
http://jmge.net/camusic.htm

A generative music software written for OS X
http://comp.uark.edu/~dmillen/cam.html