Synthetic Harmonies: an approach to musical semiosis by means of cellular automata

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Abstract
This paper deals with a software environment based on cellular automata devoted to musical experimentation, realised through a methodology by which, mathematical structures, produced by AL models, the general theory of signs, as proposed by Charles Peirce and music, which consists of acoustic and perceptual relationships are connected. The main features of this environment are the following:

1. semiotics and musical language as tools for reading and interpreting mathematical configurations generated by cellular automata and other AL models;
2. musical expression as creative artefacts;
3. artificial universes as contexts in which to detect perceptual patterns and the correlated emotions music produces;
4. experimentations in aural perception in humans as a method for evolving musical artefacts.

We can know the real world which is near us and the artificial world which is in the computer only by means of thought. Artificial worlds can be equivalent to the phenomenological world and both could be manipulated and organised by thought. We have to apply to artificial worlds the same method humans have developed in organising and giving meanings to the physical world. It will be necessary to detect patterns generated by Artificial Life machines and to give them meanings. We are trying to apply this methodology through mathematics and music, combining them in a semiotic approach.

Introduction
Cellular automata and AL models have extraordinary capacity for representing some of the biological characteristic of life [24], utilising mathematical structures. This potential (which has not yet been fully explored) seems to have some basic peculiarities in common with language and natural languages, and with semiotics on the one hand. On the other "music is a sign in itself, and the various ways of organising musical material can be viewed as forms of semiosis" [19]. This relationship realises a triangle of signification where, at one vertex we can find mathematical structures produced by cellular automata systems. At the second vertex, there is the codification system we can use. At the third vertex, there are the various kind of representations (visual, aural, but also space-temporal, multidimensional and multimodal) we can obtain, according to the kind of codification systems we have chosen. One interpreter reads these mathematical structures, chooses an appropriate codification and translates them into other languages, producing artificial artefacts of a different kind, whose artistic potential has to be further exploited. We have chosen music as one of the codification systems to be used in the conceptual framework we propose and have translated the mathematical structures produced by cellular automata in musical compositions. Human subjects have listened to these compositions, interpreting them.

The computer is the context in which these semiotic structures live, develop and are represented. As Wolfram [25] points out the computer is a virtual environment in which experimentation and computation allow us to re-create natural phenomena.

The computer is the place where Artificial Life is growing up, or, as Langton [16] says: "a field of study devoted to understanding life by attempting to abstract the fundamental dynamical principles underly-
It is possible to create artificial universes we can manipulate and testing”.

It is possible to create artificial universes we can understand through naturalistic and artistic mimesis, giving life to new forms of reality, which have the following characteristics:

1. productivity and many production rules;
2. an infinite number of productions;
3. general and abstract character of productions;
4. arbitrariness of codification and representation;
5. many kind of semantics related to representations;
6. many kind of readings it is possible to do in the mathematical configuration spaces;
7. many patterns, both local and global, which have relationships with other patterns;
8. many behaviours of evolution.

There are many semantic tools we can utilise in order to know and to describe the worlds generated by artificial systems. In this paper we’ll utilise mathematics and music, through a double process of codification: first by translating cellular automata space-time dynamical patterns into musical variables and then reading them by using the tonal scale of musical notation. The computer allows us to produce musical phenomena through a correlation between a numerical set associated with cellular automata and some physical variables. A computer programme can simulate music, like some other natural event. Computer programmes developed in the musical sector have algorithms and procedures, which reproduce some types of musical composition. Many researchers are studying fugues, canons and everything which is related to mathematical formalisation of musical composition. The computer has played an important role in developing digital music and computer music [18], [17].

The need for improving musical creativity has pushed some researchers to use new concepts that scientific theories have developed. Evolving music is based on cellular automata, genetic algorithms, L-systems and many other tools, which allow the artists to generate music in a non-traditional manner [10].

Music and Mathematics are expressions of human creative thought. They can be studied from the point of view of their relationships, as many philosophers, both ancient and modern, have pointed out. They can be analysed by means of the perceptual patterns the human mind utilises in hearing behaviour. They can produce emotions, creating what Leibniz calls the arithmetic of soul. They can be analysed by means of the mental patterns artists utilise in their compositions, a topic which is interconnected with some scientific models such as chaos, complexity, recursion and so on [22].

The close connection between Music and Mathematics had already been recognised by Pythagoras, who found that particular relationships allowed sounds to fit well together, realising beautiful melodies for the human ear. According to Pythagoras, universe is made up of these numerical properties, and man has only to read them. The synthetic worlds elaborated by Artificial Life machines can be interpreted as harmonies. In fact, a key concept in Pythagorean philosophy was harmony. Harmony is the principal quality of numbers by means of which opposites (like form and substance) are combined. Philolao (fragment D44B6), one of Pythagoras’s disciples, points out that it is necessary to have godlike abilities to understand the substance of the universe, which is made of different things. For this reason an ordered process, which is harmony, has combined different elements of the universe. If the elements of the universe were the same, harmony wouldn’t be necessary. Only harmony is able to unify the universe. Nothing would be comprehensible, neither things nor their relationships, if there weren’t number and its substance. But this, harmonising in the soul everything through perception, made things and their relations knowable (Philolao, fragment D44B4).

In this fragment Philolao stresses the connection between number and the sensory world, which has been apprehended in the Pythagorean philosophy and will be later used by modern science to give a mathematical explanation of physical world and of some of the sensory and perceptual processes. This interpretation of the world made by Philolao is a characteristic of gnosiological thought and could be a modality to use in experimenting in artificial worlds. Is it possible to provide a semantic for artificial worlds? The answer could be yes, since we give meanings to every thing. We know real world which is outer and the artificial world which is in the computer only by means of thought. Artificial worlds can be equivalent to the phenomenological world and both could be manipulated and organised by thought. We have to apply to artificial worlds the same methods humans have developed in organising and giving meanings to the physical world. It’ll be necessary to detect patterns and give them meanings. We are trying to apply this methodology through mathematics and music, combining them in a semiotic approach.
Does a semiotics of Artificial Life exist?

Semantics is the science of meaning. The scientific study of meaning is one of the more complex things in the Human Sciences. Psychology, Linguistics, Anthropology, Arts, Literature, Information Theory and so on deal with meaning. According to Linguistics, Semantics is also the study of the signification process; of how people give meaning to things and what relationship meaning has with linguistic signs. People often superimpose Semantics upon Semiotics, since these topics are closely interconnected: both deal with the process of giving meanings to things. For Semiotics, semantics is one of its topics, since Semiotics is the science of signs [21], or the theory of signs. It involves the study not only of what we refer to as signs in everyday speech, but also to anything which stands for something else. In the semiotic approach signs include words, images, sounds, gestures and objects. Such signs are studied not in isolation but as part of a semiotic sign system. Morris [20] divides the subject into three branches:

1. semantics, the science of meaning (the relationship of signs to what they stand for);
2. syntactics (or syntax), the relationship between signs;
3. pragmatics, the way in which signs are used and interpreted.

Could Semiotics be applied to the analysis of cellular automata signs? Which methodology might be necessary? In the following, we’ll try to explain, in a comparative manner, some of the methodological assumptions Semiotics uses and how it is possible to translate them into the context of Artificial Life worlds. Many researchers study meaning in relationship to the contexts in which it occurs. The difference between common thought and mathematical or logical thought resides in the fact that context is very relevant to the first way of thinking whereas context is not so influential in the second. An artistic form is acceptable or unpleasant according to the different relationship it has with all the other forms in a context. A mathematical expression isn’t influenced by a context. It is not possible to deal with meaning by extrapolating it from the context in which it occurs. Similarly, the cellular automaton plays its role in the relationship it activates within its neighbourhood to develop its configurations. Different neighbourhoods lead to different configurations and so to different kinds of signs and meanings. Wuenische [27] writes: “Processes consisting of concurrent networks of interacting elements which affect each other’s state over time occur in a wide variety of natural systems, the dynamics depending both on the pattern of connections (wiring) and on the update rules for each element.”

In fact, cellular automata, like signs, are organised within a syntagmatic structure (the horizontal dimension of a net), which involves studying their structure and the relationships between their parts. Signs and their correlate meanings have a pragmatic aspect, that is, the way in which signs are used and interpreted. This characteristic translates meanings into social behaviour. According to the concept of semantic potential, every time a speaker has to behave linguistically, he/she makes a choice from a wide array of items. This array of choices represents the paradigmatic dimension of a language. Cellular automata have also a paradigmatic structure, which means studying the patterns of evolution of a net. In particular, it is possible to identify the signification of the evolution of a pattern and that particular occurrence rather than another pattern. It is also possible to detect the underlying meaning of that pattern, such as one pattern with certain characteristics as opposed to another one with different characteristics. We could use Wolfram’s classification of the cellular automata dynamics to operate these kinds of discriminations/oppositions. In this way, we’ll arrive at individuating of the invariants of artificial worlds. Could an interpreter, through the medium of music notice this invariant? And if these models of intensity, frequency and separation are pointed out by an observer, what could be the learning process or the notational system the observer uses to communicate to other people how he/she has worked on the artificial world? This idea leads us to reflect on how the recognition process of musical models occurs. We can use the same methods Psychology uses in discrimination tasks with humans [5]). To notice a pattern we can use templates, or global representations of a pattern; features description, or the conditions or characteristics useful in detecting a pattern and structural description of a pattern [4]. It is also possible to describe a musical pattern produced by artificial worlds, utilising the visual medium, by linking computer graphics with evolving music. Pattern recognition based on template matching has some problems: a note occurring on the first beat of a measure will sound different and carry a different musical meaning from the same note occurring on the second beat, even if both are played in exactly the same way. And if we want that musical composition to function as a sign, or to be recognised as a meaningful musical object, it must be apprehended as a gestalt, i.e. a form or a structure taken as a whole, and not as the sum of its components, a form that can be perceived against a ground [7]. One problem is that the template has to have the same position, orientation...
and size as the pattern to be recognised. Furthermore, any object of perception can signify (take on meaning) only in relation to the space within which certain types of activity have the potential to take place.

A second problem is the extreme variability of patterns (a slight different pattern could be produced by the same rule of evolution). A third problem is the grade of difference amongst patterns. A matching between two patterns could indicate that they are similar because one is superimposed upon the other. But this matching says nothing about how they are different, because to have a measure of the difference it is necessary to take note of the specific properties of each pattern. Moreover, each pattern could be described by means of a minute analysis. By codifying the artificial world into music, it is possible to study the perceptual organisation of hearing phenomena, moving from simple to complex patterns, from local to global dynamics. There is another important characteristic of meaning, which distinguishes between logic and emotional meaning. This dichotomy is based on the difference between the communicative function of language, intended as a means of transmission of thought, and the expressive function of language, as an expression of emotions. Music generates emotions [9]. If cellular automata could be translated into music and music, like voice [23], generates emotions, then cellular automata can produce emotions. Music is, for the human brain, a dynamical organisation of time. It seems that the quality we perceive immediately in a musical composition is the quantity of rhythm (quantity of notes in the time unit). The perceptual aural models we perceive are sequences of notes (or sounds), with some expressive qualities directly linked to the emotions. There are as many musical perceptual models as there are principal emotions (or their variants). This is certainly the most complex and broad field of musical/perceptual semiotic inquiry. In fact, if we think of every emotion we can experience and their potential combinations and if we make an analogy with the musical models which can produce emotions, we gain an idea of the great creativity of the musical medium. In our conceptual framework, we'll examine the relationship between mathematical structures, music, and emotions.

Related Works

The idea that a sequence of numbers could generate music has been used in the literature since modern technologies, Artificial Intelligence and psychological research on cognitive abilities have shown that a musicians compositional selections imply mathematical parallels. Combinatorics, fundamental constants, functions, prime numbers and so on are some of the kind of mathematics practised. Recursion, iteration and complex mathematics can be seen as an extension of traditional music compositional practice. Algorithms generate sequences of numbers which, appropriately coded and transformed into musical parameters, such as frequency and duration, can produce pleasant harmonies for the humans. The results depend on both algorithms and musical rendering techniques.

Using recursive functions that work on a feedback process produces generative music in analogy with the ways musicians unconsciously scaled, shifted, flipped, expanded and compressed melodies in their mental musical spaces. The resulting algorithms are organised on the mathematical models science has produced, such as chaos [6], fractals [1], the theory of complexity [26] L-systems [8] and so on.

Many musical systems have been realised using techniques related to the mathematical models of Artificial Life. By analysing the literature present on the Internet, it is possible to organise the following musical systems' taxonomy:

- Fractal music;
- Music produced by chaotic structures;
  - Chua’s circuit;
- L-systems;
  - Used to generate Midi files;
- Generative music based on grammars;
- Evolutionary music based on genetic algorithms;
  - Lee Spector has used genetic algorithms to produce interactive jazz music;
  - GenJam is a GAs based program, which learns to play jazz songs;
- Genetic music;
  - DNA sequences are used to generate MIDI music;
- Music generated by Cellular Automata.

For example, Chaosynth [11] is a system that uses the ideas of granular synthesis to generate music and is based on cellular automata. Each granular sound produced by Chaosynth is made by many components, using three parameters: frequency, amplitude, and duration. Chaosynth checks frequency and duration values, while amplitude values are configured by hand, before starting the process of music generation. Camus and Camus 3D [12] [13] [14] use Life and Demon Cyclic Space cellular automata to generate musical compositions. The first space is necessary to determine a triad that will be played at a certain time in
the composition, while the Demon Cyclic Space’s state will be used to fix the orchestration of the song. In this system, Cellular Automata drive the composition processes, utilising well-known forms of pattern propagation, while stochastic selection routines are used as they constitute a method of specifying long term structure to be used in compositions.

The Isle Ex system also uses cellular automata to generate sequences or numbers that later will be rendered by musification maps. These maps are rather complex and operate both on cycles and transient structures. Some related internet address are given in Appendix A.

The system which has been realised
To exemplify the conceptual framework we have designed, we developed Musical Dreams. It is a software environment based on cellular automata, devoted to musical experimentation. The main features of this environment are the following:

1. semiotics and musical language as tools for reading and interpreting mathematical configurations generated by cellular automata;
2. musical expressions as creative artefacts;
3. artificial universes as contexts in which to detect perceptual patterns and the correlated emotions music produces;
4. experiments in aural perception in humans as a method for evolving musical artefacts.

Our idea is to let the system become an environment in which to investigate the different features related to AL models and some different kind of codification systems in order to get different production rules, to be utilised in musical compositions.

From the technical point of view the system is made up of three main workspaces (Figure 2). Ideally, these environments correspond to the signification triangle. There is a pattern generator, to produce cellular automata structures or other kind of AL tools. A codification system, which contains a directory of codes, the user can choose, like different types of grammars, to vary the kind of music he/she can obtain. A musical meanings system (or representational workspace), with a rendering engine, which transforms the codification system utilised in a MIDI file, giving to the output the particular features users have chosen.

In the patterns generation workspace, a given input is inserted into the cellular automata space and the resulting numbers, once an appropriate codification system has been chosen, are rendered to produce an output, which represents the musical composition.

We preferred to distinguish clearly between the pattern generation task and music production (also at the interface level of the tasks’ organisation) because both of them use arbitrary mechanisms that can give different results, depending on the choices made by the users.

The first element of the system is a classical multiple states cellular automata space. In fact, the first version of the system is actually limited to one-dimensional networks. At the interface level, the window shows three main frames (Figure 3). The left-hand highlights the network evolution in a graphical form, the central one shows the transition rules and in the right-hand, users can work with various tools, in order to vary the graphical aspect, modify the transition rules and generate the initial state condition.

The network has a dimension of 100; the CA has 8 states and both the initial state and the transition rules have been generated randomly.

Simply interacting with the system by means of the mouse, users can specify particular sequences of the initial data. Moreover, rules can be inserted one by one. This is not advantageous for automata with many
states, since it is impossible to obtain significant patterns, if the user doesn’t define (by hand) a high number of rules (for example the entire rule set for a four states automaton is made up of many rules). Another possibility is to generate the entire sequence of transition rules on which to operate randomly, or by hand, directly on a specific rule. The resulting pattern can be zoomed in and out by the magnifying lens tool.

In the codification system workspace there is a directory of the codification systems it is possible to use.

1. **Simple musification.** Let the user control only the frequency parameter. In a network, a column corresponds to a note. If the state for that position is equal to 1 or greater, the note is played. If the state is zero, no note is played. The user can choose which octaves to play on a given sequence. No control of the tempo is given. This kind of codification produces very simple sounds, which are not perceived as melodies by human subjects.

2. **Random musification.** This is analogous to the former, but random choices are made between the columns and notes, from row to row. This process changes from one row in the pattern to another. The user can choose which parts of the pattern to render. This kind of codification gives different kinds of sounds which have the characteristics of not being well fitted to human subjects since they cannot identify a melody. Random choices seem to make worse the musical production we can obtain.

3. **Musification with evolutionary functions.** It is possible to think that every note undergoes an evolution process, produced by a certain generative function. This function can be of various types: predefined by the user or externally selected, like a logistic map where the user can choose the value of some parameters. In this case, the results become extremely complex, allowing every note to evolve in different ways. The presence of cycles, both in the cellular automata space and in such functions, leads to interesting results from the musical point of view.

4. **Complex musification.** As in Camus, we can think of using other cellular automata spaces to render the patterns. We can also operate as in Isle Ex to start the musification processes, based on triads. The possibilities offered by this codification system are multiple and produce extremely diversified results.

At the moment, the codification process we have chosen has the following conventions. Each column of the cellular automata pattern corresponds to a specific note, the octaves increasing from left to right. The Cell State represents the starting offset for that note with respect to the beginning of the bar fraction that the current row represents. The notes belonging to a row are all played in the time fraction assigned to the row itself.

The other parameters, such as tempo, instrument assignments and other variables are chosen in the MIDI rendering window. The parameters the user can change are:

- the number of cellular automata state transitions per musical bar;
- the musical tempo model (i.e. 4/4, 3/4 etc.);
- the number of beats per minute;
- the instruments split definition and assignment.

In the Representational workspace, once the user has provided the initial data and generated the pattern using the selected rules, the rendering process can be started. The data generated by the cellular automata are transferred to the rendering engine for the MIDIification process. The rendering process is also extremely arbitrary and the results obtained depend strongly on the choices made for the various parameters. The rendering process output is a MIDI file.

The idea behind these arbitrary choices is to have a system which is flexible enough to allow us to investigate both the perceptual features related to the different process of musification, and the analysis of results based on the patterns typically produced by cellular automata. The system has been completely developed.
in Java, in order to be portable on many platforms and to build a set of classes that will be easily used in applet, available on the web.

In particular, we used tite Java Development Kit 1.2.2 with the integration of the Java Media Framework 2.0 beta, in order to provide the Java platform with MIDI functionality.

The need for flexibility, completeness, ease of use and effective visual representation, has guided system development.

The case of Cellular Automata with Boolean states

We have used the system to generate MIDI files using two-state cellular automata networks and we have collected all data. They have been generated for various octaves. Figures 4 and 5 represent the patterns which result for four rules and various octaves. At a first glance, the data present some interesting results.

If we analyse the networks’ behaviour in general, using for example DDLab, we can see different situations. In the case of the first octave, the network dimension is 12, and for rule 22 we will have 5 typologies of basins of attraction and 12 basins in total. For rule 54, we will have 8 typologies of basins of attraction and 33 basins in total. For rule 110, we will have 5 typologies of basins of attraction and 11 basins in total. In practice, as the dimension of the network increases, it is impossible to exhaustively analyse every possibility. From the musical point of view, or, more precisely, from the perceptual side, important results of this analysis are the following. The difference between the various melodies, contained in the MIDI files collected, does not change in a relevant manner as the network dimension changes (the most significant result is the growth of cacophony which makes difficult discrimination between the various emergent structures), while it is rather relevant when different rules are used.

Multi state system and genetic algorithms

In the previous section we hypothesised that cellular automaton could assume just two values (0 and 1) for the state. If we allow it to have different values (ranging from 0 to 3, 0 to 7, 0 to 15 and so on) the results become immediately more interesting. Non-Boolean cellular automata are scarcely studied and there is a lack of classifying rules analogous to those of Boolean networks.

We have used our system to generate music with a four state cellular automaton and a collection of examples, obtained by generating randomly both the initial state and the transition rules, has been collected and stored. The melodies obtained with this method don’t seem to be really significant and a listening group has expressed conflicting opinions in reply to their pleasantness, interest, and acceptability. The subjects opinions about musical compositions are however discordant. Some were inclined to interpret the melodies as horror movie soundtracks, considering the musical compositions to be neither agreeable nor acceptable. Many reported that there were no melodies and that that kind of music was very different from traditional music. It is interesting to point out that music generated by other complex systems, such as Chua’s circuit, was used in movies with special effects and “alien” soundtracks.

The number of possible transition rules for a cellular automaton with four states for every cell and a neighbourhood of three cells is very high \((4^3)\) and thus it is not possible to examine them all. Furthermore, the results obtained are strongly dependent on the initial state, while the dimension of the network seems to be scarcely relevant.

Thus, for simplicity, we have considered a network of dimension 12-24-36.

We have produced a set of 100 MIDI files using 100 different rules and we have selected the rules that seem to produce the most acceptable files. As said before, initial data significantly influence the results, while the presence of cycles allows identification of structures inside the melodies, which make these melodies more pleasant.

Few values, different from zero, allow us to better detect these rhythms and self-organising structures.

In Figure 6, the results obtained for some values of the...
initial state are given. In the next step, we started an evolutionary process in the following way. We wrote the above mentioned rules as a sequence of 64 characters (each character could assume one value amongst four), which we will call from now on the genotype. Later, we generated ten different genotypes, which were variations of the first and differed from the first only by one character.

We generated five MIDI files (phenotypes) from each genotype, with the same initial states shown in the figures, using two random initial states. We thus obtained ten families of five MIDI files each.

We proposed the files to a listening group made up of five elements, asking them to assign a score ranging from 1 to 10 to each song. By summing the scores obtained by each file in a family, we obtained the family’s fitness. The families that obtained the greatest fitness were allowed to evolve, in a fashion analogous to that formerly exposed. We produced five new sequences for every family allowed to evolve, thus keeping the number of new phenotype families to ten (Figure 7).

This process was repeated for ten generations. The results obtained can be found on the authors’ reference site (http://uni.abramo.it/esg). We verified that the music varies but not in a significant way, even if the average fitness shows a growth trend in the direction of complexity.

We think that the process needs to be repeated for a very high number of generations, in order that natural selection be effective and in order to surpass the effects related to the initial state and the rendering process. We started with other processes of musification. In fact, there are two important directions towards which we are moving in exploring musical context. The first is a scientific experimentation on the kind of artefacts we can obtain to detect a musical theory that can be utilised to write new kinds of composition in connection with the experimentation on the underlying musical cognition [3]. The second concern musical fitness, which in our hypothesis, can provide us with some global characteristics of a melody and can help us in reconstructing the evolution of Western musical notation. While in evolutionary music, musical fitness is generally operated intuitively by the listeners, we have elaborated a fitness function which allows selection amongst the produced musical pieces. Such a fitness function is based on the theory of Pythagorean consonance [2], since it has been demonstrated that there is a biological basis for consonance [28] [29].

Conclusions

New keys of reading into the global dynamics of Artificial Life machines could be generated utilising the semiotic approach this paper presents. By means of a codification system, represented by musical language, it is possible to give meaning to many characteristics of the patterns global dynamics produce and to use the results in the Computer Arts dominion. At the moment of writing this paper, only a part of the proposed methodolgy has been developed in the software Musical Dreams, but the authors idea is that the system will become an environment for analysing music generated by cellular automata and other AL models. The resulting structures are complex enough to effect self-organisation and evolutive processes, while the patterns generated give us new insights for improving the semiotic approach. The system is already complex and even insignificant variations on one element or a different kind of codification produce important variations in the music we can obtain. The music it
is possible to produce depends on the kind of analysis we have organised. It’ll be possible to analyse how different kinds of cellular automata contexts will produce different kind of music. It’ll be possible to make an analysis of cellular automata patterns by means of syntagmatic and paradigmatic analysis. It’ll be necessary to carry out exhaustive experiments with human subjects in order to individuate perceptual organisation of dynamical patterns on the one hand and the continuum of emotions cellular automata music can produce from the other. Furthermore, many studies of musical tone systems established in different historical and ethnic cultures suggest that their evolution is mainly dependent on perception of the audible frequency range, and harmonic consonance. It’ll be possible to search for fitness functions in music through genetic algorithms to ascertain if the strong relationship between the historical evolution of tone systems and their cultural refinement by emphasis on consonant aspect of music is true or not.

Appendix

Fractal music:
- http://hometown.aol.com/strohbeen/fml.html
- http://www-ks.rus.uni-stuttgart.de/people/schulz/fmusic/

Music produced by chaotic structures:
- http://www.ccsr.uiuc.edu/People/gmk/Projects/ChuaSoundMusic/ChuaSoundMusic.html

L-systems:

Generative music based on grammars:
- http://cs.eou.edu/ jefu/Grammidity.html

Evolutionary music based on genetic algorithms:
- http://hampshire.edu/ lasCCS/genbebop.html
- http://www.it.rit.edu/ jab/genjam.html

Genetic music:
- http://algoart.com/

Use of neural networks:
- http://www.nici.kun.nl/mmm/

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