Music as Ecosystem

Music Generation by Self-Organization and Genetic Evolution

Background

While Charles Darwin (1809-1882) identified two phenomena — variation by random mutation and adaptation by natural selection — in his theory of evolution, he did not provide a mechanism for inheritance. Although, at the time, Jean-Baptiste Lamarck (1744-1829) offered a theory of inheritance of acquired traits, it was soon supplanted by the classical theory of genetics, founded by Gregor Johann Mendel (1822-1884) in his pea experiments and later elaborated by Thomas Hunt Morgan (1866–1945) in his chromosome theory. Recently, with the advent of the field of epigenetics, Lamarckism has experienced a revival.

Although examples of evolution by natural selection is ubiquitous, it is but one system of an encompassing phenomenon of self-organization. Self-organization is a process by which global pattern emerges solely from local interactions among components of a system. The rules specifying such interactions are executed using local information, without reference to the global pattern.

Neo-Darwinian Evolution

1. Variation — Random mutation
2. Adaptation — Natural Selection
3. Inheritance — Genetic reproduction

Order can emerge from apparent chaos of a self-organizing dynamical, complex system. In living systems, self-organization is responsible for social behaviors in insects, patterns in animal body coverings, networks of spiking neurons, selection of division sites in cells, formation of microtubules, etc. In non-living systems, self-organization is involved in nonequilibrium thermodynamics, molecular self-assembly, diffusion, crystal formation, geological formation, sand dune ripple formation, etc.

In the study of fractal geometry, where we try to make sense of chaotic patterns in space and time, it is believed that self-organization follows fractal laws and fractal patterns emerge from self-organizing systems. With the same logic, the process of genetic evolution emerges from information provided by living systems, and species arise from genetic evolution. Arguably, such observation is consistent with phenomena ranging from the behavior of elementary particles to the state of the universe, and just about everything in between.

Self-Organization

- Emergent property
    - Not imposed by an external ordering influence
    - Arises from interactions, direct or indirect, among the system’s components
- Local interaction
    - No central authority
    - No blueprints
    - No recipes
    - No templates

Keywords: dynamical systems, complexity, chaos, synchrony, fractal, emergence.

Currently, self-organization as applied to the human society is widely studied — from market economics to linguistics, from herd behavior to drug trafficking, and from computer networks to social networks, all of which operate within the framework of a system undergoing natural selection.

Another widely recognized emergent property is synchrony. Activities of spiking neurons, flashes of fireflies, chirps of crickets or applause of an audience falls quickly into a pattern without direction from a central authority. In music, a jam session produces ordered sound without a director. It is conceivable that if we treat music as a multi-species evolutionary system, where rudimentary musical phrases are primitive organisms undergoing genetic evolution and community self-organization, an optimized piece of music will emerge.

Building an Ecosystem

In building an optimized biological ecosystem, the goal is to evolve and concurrently self-organize populations of species into interacting, stable communities.

The method is to build on a rudimentary genetic algorithm with computational techniques based on self-organization principles.

A Simple Genetic Algorithm

- Create an initial random population
- For each generation
    - For each organism
        - Determine fitness for survival
    - For every two organisms
        - Select two parents based on fitness
        - Reproduce
        - Mutate
- Replace old population with new population
- Stop after specified number of generations
- Return one optimal organism

Genetic Evolution

A species adapts to its environment by undergoing the following stages of neo-Darwinian evolution:

- Selection of the fittest
- Recombinant reproduction
- Variation by mutation

A common genetic algorithm models a organism with one strand of DNA undergoing the these three stages of adaptation.

For our purposes, the evolutionary process is implemented computationally by an enhanced genetic algorithm, which emulates an ecosystem with the following elements.

- An **ecosystem** consists of multiple species.
- Each **species** consists of a population of organisms.
- Each **organism** contains one or more chromosomes.
- Each **chromosome** consists of two strands of DNA, each comprises a sequence of nucleotides.
- Each **nucleotide** is the basic unit of genotype which undergoes reproduction and mutation.
- Each **gene**, which consists of one or more nucleotides, is expressed as a phenotype of an organism subject to selection.

The goal is to evolve one or more species, with each organism of a species possessing a random set of genetic materials, into an optimal population based on fitness criteria. In each generation, each organism's genes are evaluated and assigned a fitness value. Then the organism are selected for mating. The fitter the organism, the more probable that it is selected for mating and more of its phenotype will be inherited. Reproduction is optional under the constraint of a reproduction rate of a species. During reproduction, each parent's DNA is cut at a common point. The sections are swapped by crossover and recombination, producing two children. Mutation of the offspring is optional based on a small mutation rate imposed on each nucleotide. When it does occur, a random nucleotide replaces an existing one. The process continues for the new generation.

The reproduction and mutation processes are enhanced with self-organizational computations.

An emergent property of Darwinian evolution is speciation by divergence, where under certain conditions, a population of organisms branch to evolve as a different species. The enhanced genetic algorithm includes this evolutionary process. Interdependent species may co-evolve from the start under the condition of the environment while other species evolve, after several generations, when they diverge from established species. Another mode of speciation is hybridization where a new species emerge from genetic materials of two existing species.

Epigenetic Inheritance

While genetic evolution enables heritable changes in the DNA sequence, or nucleotides, thus determining the genotype of an organism, mechanisms of epigenetic inheritance enable such changes in gene expression thus determining the phenotype. It is the phenotype of an organism that undergoes selection. The mechanisms used in our model include adaptation algorithms following self-organization principles.

Community Organization

Given a primitive species, genetic evolution with epigenetic inheritance promises to produce a population of organisms with improved fitness. In building an optimal community, organisms in each species interact with each other, while multiple communities of species synchronizes with each other. Whereas adaptation by evolutionary inheritance proceeds vertically in time, organisms in an ecosystem may organize laterally to build a community. A stage is added to the evolutionary algorithm in order to enable

1. Members of each species to organize among themselves to form a fitter community
2. Multiple species of the ecosystem organize with each other to form stable inter-species community

Self-Organization in Evolution

The evolutionary algorithm applies several self-organizational methods for computation. Cellular automaton and neural network are adaptation method that are used in the genetic expression and species selection. The phenomenon of fractals is used in species organization.

Building a Musical Equivalent

The goal is to evolve and concurrently self-organize sets of random musical events into an optimized song in MIDI file format.

The method is to model the musical system after an ecosystem, where the world contains multiple species that evolve and interact under conditions of their environment and rules for fitness into an optimal state.

In emulation of an ecosystem, the music generation process is implemented computationally by an enhanced genetic algorithm with the following elements.

- A **song** consists of multiple parts or MIDI tracks, usually organized by instruments.
- Each **part** consists of a population of phrases.
- Each **phrase** contains one or more chords or harmonic parts.
- Each **chord** consists of two distinctive strands of musical units arranged in sequence.
- Each **unit** undergoes reproduction and mutation.
- Each **event**, which consists of one or more units, is expressed as a musical note of a phrase subject to selection.

As in genetic evolution, the goal is to evolve one or more parts, with each phrase of a part possessing a random set of musical units, into an optimal song based on fitness criteria. As in Darwinian speciation a song containing multiple parts may co-evolve in synchrony, under the constraint of initial conditions and criteria for optimal sound. While other parts may diverge from partially developed parts, existing parts or a hybrid may form from two existing parts.

Whereas genetic evolution enables heritable changes in musical units, mechanisms of epigenetic inheritance enable such changes by the interpretation, and realization, of the units into musical events. It is the expressed musical events of a phrase that undergoes selection.

Given a primitive set of musical units, genetic evolution with epigenetic inheritance promises to produce a population of phrases with improved fitness. From these phrases, the algorithm constructs a musical architecture with self-organization principles to enable the following activities.

Ecosystem-Music Equivalence

World	Song
Species	Part
Organism	Phrase
Chromosome	Chord
Nucleotide	Unit
Gene	Event

1. Members of each parts to organize among themselves to produce a musical track
2. Multiple parts of the song organize with each other to a synchronized song

<table>
<tr>
<th>An Example of an Enhanced Evolutionary Algorithm</th>
<th>Musical Equivalence</th>
</tr>
<tr>
<td>

For each species of the world

For each organism in the population

Create a random set of genetic material

For each generation

For each species

For each organism

Express genes
Determine its fitness for survival

Adjust environmental conditions
For every two organisms

Select two parents based on fitness
Reproduce
Mutate nucleotides of two offspring

Speciate by divergence from an existing species
Organize community
Replace old population with new population
Stop if optimal fitness of all species is achieved or maximum number of generations is exhausted

Return one ecosystem

</td>
<td>

For each part of the song

For each phrase in the population

Create a random set of musical units

For each generation

For each part

For each phrase

Express note events
Determine its musical fitness

Adjust parameters
For every two phrases

Select two phrases based on fitness
Reproduce
Mutate units of two child phrases

Create a new part by cloning an existing part
Build architecture from musical phrases
Replace old population with new population
Stop if optimal fitness of all parts is achieved or maximum number of generations is exhausted

Return one song

</td>
</tr>
</table>