Modeling the Evolution of Mimicry

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Abstract

- A novel agent based, artificial life model, for the evolution of mimicry is presented.
- This model is a predator-prey co-evolution scenario where pattern representation phenotype is simulated with Cellular Automata (CA) [4], while behaviors of pattern recognition is configured with Hopfield Network.
- A visual three dimensional toroidal cube is used to construct a universe in which agents have complete freedom of mobility, genetic representation of behavior and reproduction capability to evolve new behaviors in successive generations [1].
- Agents are classified into categories of predator and prey species. Genome of prey species control their mobility and palatability, while 2D CA is used to represent a pattern, where the rule to generate the CA is also genetically represented.
- Using the above construction of ideas, successful emulation of the natural process of mimicry is achieved. Also complex behavior pattern of Batesian and Mullerian mimicry is simulated and studied.

The Inspiration: Mimicry

Batesian Mimicry

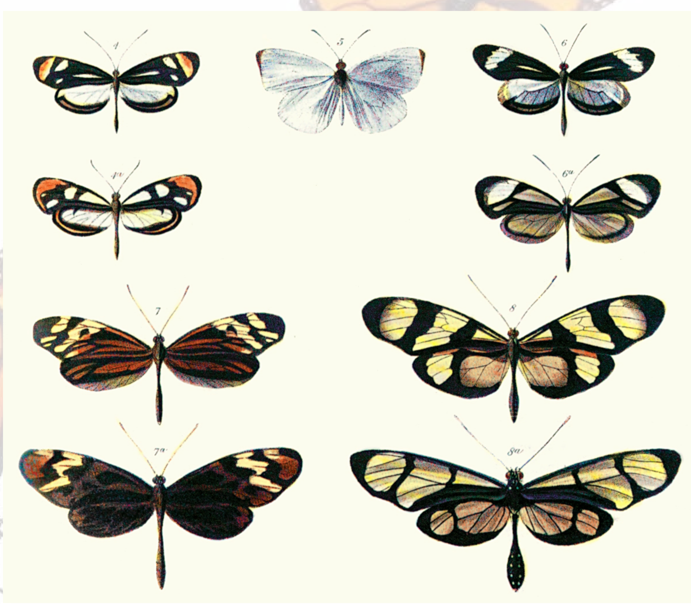

Figure 1: Plate from Bates (1862) illustrating Batesian mimicry between Dismorphia species (top row, third row) and various Ithomiini (Nymphalidae) (second row, bottom row)

- Henry W. Bates first published in 1862 his findings about the similarities and dissimilarities between Heliconiinae and Ithomiinae butterflies.
- He found butterflies having similar appearance, exhibiting morphological features which point to completely different species even families.
- Even though Heliconiids are conspicuously colored, they are extremely abundant and slow in mobility. Still predators in the surrounding area, mostly insectivorous birds do not prey on them, because of their inedible and unpalatable nature.
- Other edible and palatable species such as ithomiinae and pieridae, pretend to be heliconiids and thus enjoy protection.
- In general, the animal which is avoided by predator for unpalatable behavior is called the **model** and the imitating animal is called the **mimic**.

Mullerian Mimicry

- Occasionally two inedible unrelated butterfly species are amazingly similar in appearance. An explanation for this was provided by Fritz Muller in 1878.
- When there are multiple inedible species it is hard for predators to recognize each of them to know which one to consume and which one to avoid.
- Because of the predator's limited memory, all these species still lose their number even after being inedible.
- So to save this loss, and to prevent more sacrifice of their own kind, inedible species from different families also tend to evolve to have similar appearance.
- This phenomena is referred to as Mullerian Mimicry in the name of Fritz Muller.
- Like Batesian mimicry, Mullerian mimicry can evolve in two stages: the mutational, one way convergence stage followed by the gradual, mutual convergence stage.

The Model: Evolution of Mimicry

- Our model initializes with three kinds of agents. These agents have properties and behavior similar to the **model**, the **mimic** and the **predator**.
- We represent evolution of pattern for the model and the mimic with the help of **CA**, as **CA** can be easily represented by simple rules.
- Each predator is equipped with a Hopfield network, which gives it pattern recognition capability. The process of evolution occurs at the genetic level.

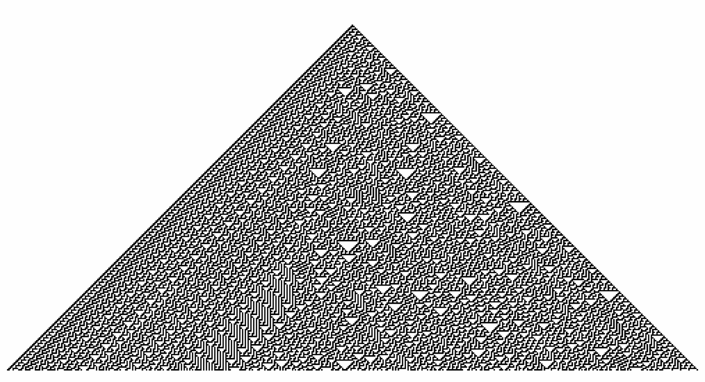

Figure 2: Cellular Automata Rule 30 (Image Credit: Wikipedia)

The Prey: Models and Mimics

- Every prey organism contain a binary genetic representation of CA which generates a fully developed pattern of size 16 by 16 bits from its initial state.
- With this pattern the predator will identify the prey and store its level of palatability in memory.
- We choose CA as its decimal rule can be easily represented with the help of a binary genome and evolutionary operations on the genomic representation, such as mutation and crossover can easily be applied.
- To store in Hopfield memory we take a linear representation of this 2-D pattern.
- To find similarity between two patterns we calculate the hamming distance between their linear representations.

Reflection of punctuated equilibrium

- Punctuated equilibrium is more inclined to cladogenesis instead of gradualism. Also Turner [3] emphasizes on punctuated equilibrium to describe the evolution of mimicry instead of phyletic gradualism.
- The design of this model also follows Turner's explanation in terms of evolving mimicry.
- New CA patterns evolve from existing ones in prey population just by a single mutation in the pattern gene.

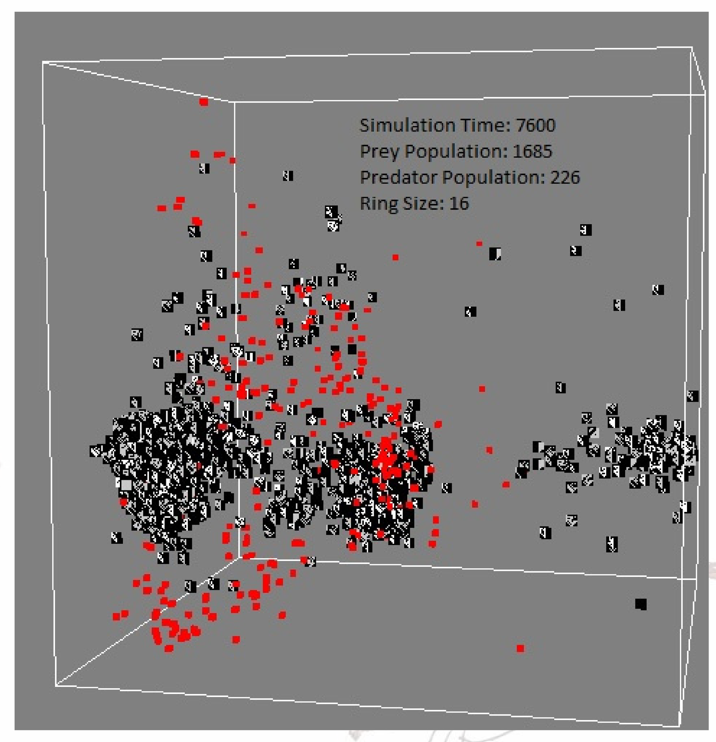

Figure 3: Graphical representation of the model, simulation time: 7600

Predator

- Predators in the system are designed to provide selection pressure to *models* and *mimics* for the evolution of mimicry.
- These agents are equipped with Hopfield Network Memory to be able to learn and recognize patterns of the prey species.
- Their mobility and reproduction capability are controlled at the genetic level, while their memory is not genetically controlled, as we could not find a suitable encoding for the genetic representation of Hopfield Network.
- Every new predator is born with zero memory and with no inheritance from parents.

Learning

- The objective of a predator's interaction with prey is always to consume it. But based on the prey's pattern and palatability, the predator will either be able to consume it or throw it back to the environment.
- At this event the predator needs to learn the pattern with which the prey has been represented. The pattern represents palatability of the prey species, at least to the predator.
- Every time a new interaction is made by the predator its memory is initialized with all the existing pattern that has already been encountered and the new one.
- The learning procedure used for this memory is Hebbian Learning [2], which represents a purely feed-forward, unsupervised learning.

The Results

- Data and analysis in this simulation has been concentrated on evaluating whether evolution of mimicry has taken place.
- This evaluation can be made with the number of different rings that has been created and the size of each of those rings along with the population of palatable and unpalatable species.
- Also it can be established whether Batesian Mimicry and Mullerian Mimicry have taken effect by analyzing the data set of these populations.

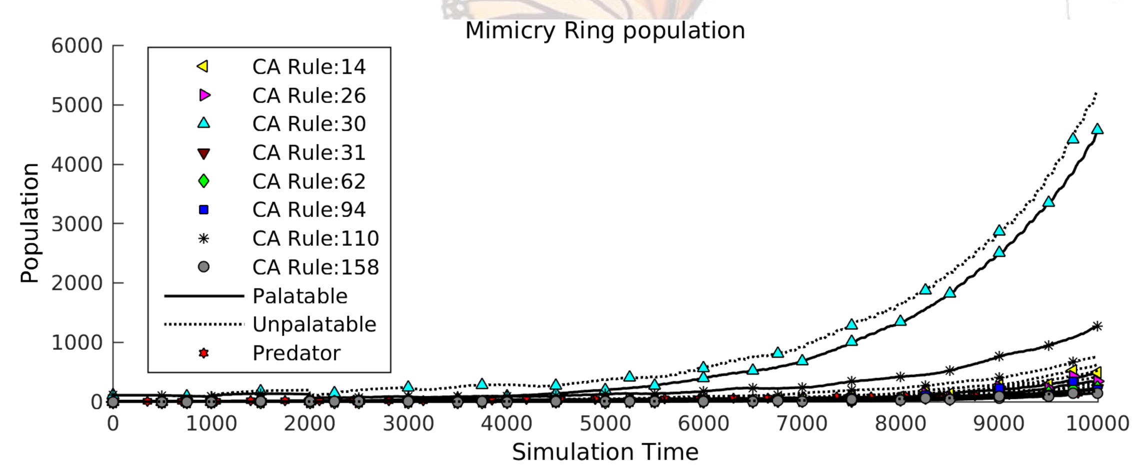

Figure 4: Population distribution of mimicry rings, initialized with 2 prey species, 10k iterations

Analysis

- Batesian mimicry has taken effect as it can be observed (figure 4) that for every ring of unpalatable species there is an existence of the palatable ring racing to reach the population count of its unpalatable counterpart.
- Effects of Mullerian mimicry can also be observed best for the experiment initialized with only unpalatable prey species (figure 5). We initialized the model with 4 rings of unpalatable species with no palatable ones and after nearly 10K iterations, all of the initial unpalatable rings have survived with dominance.

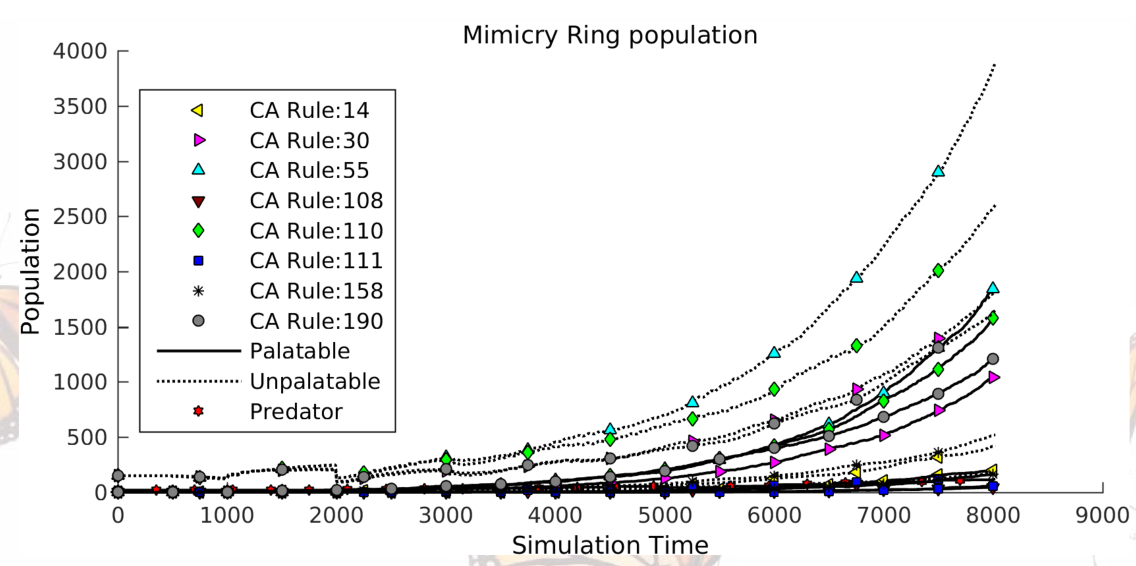

Figure 5: Population distribution of mimicry rings, initialized with 4 prey species all unpalatable

Conclusions

- Analysis of the results tell us that we have successfully been able to simulate the evolution of mimicry.
- This model provides a more accurate simulation of the fascinating natural process of mimicry rings and their shift in population.
- This model also verifies the theory of Turner in explaining the evolution of mimicry with punctuated equilibrium.

References

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