Hacking Natural Selection: CS5804 Mini-Project

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ABSTRACT

Natural selection is a process by which individuals with preferred traits in its environment and population are more likely to survive and reproduce, while those with less advantageous traits are less likely to do so, influencing the traits of the subsequent generation. Evolution refers to the process by which species change over time through genetic variation and natural selection. These changes can result in the development of new species and the extinction of others. Together, natural selection and evolution are the mechanisms by which life on Earth has diversified and adapted to changing environments over billions of years.

KEYWORDS

reinforcement learning, natural selection

1 INTRODUCTION AND MOTIVATION

This project seeks to simulate natural selection phenomena with nondescript agents in an two-dimensional environment. This way, the nuanced factors that play a role in natural selection are removed and trait adaptation exists in the rawest form. Some of these external factors range from sexual selection, environmental adaptation, existence of predators, types of food available, fitness, and complex inter-species interaction. Controlling for these factors allows us to extract raw trait mutation as it would occur without the presence of unforeseen external factors under the Darwinism umbrella.

Primarily, how would the most basic traits change over n generations, such as speed and size, given a finite script of rules and a small probability of random variation?

Research uncovered a YouTube video which served as the motivation for this project [5]. The video models evolving populations by means of inserting creatures into a simple environment and assigning them traits. The Primer system consists of creatures that live on the plane. Each daily cycle, food appears on the plane, then creatures traverse from their home to eat the food. If a creature fails to find any food throughout the day, it will die. If it finds one food, it will live on to the next day; if it finds two food, it will survive and replicate itself, adding another creature to the population for the next day. In addition to this rule, there are three mutable traits for these creatures: *speed, size,* and *sense.* Creatures will evolve each trait as they survive over generations. At the end of simulation, a variety of creatures with different traits are observed as a result of natural selection.

2 APPROACH

2.1 Game Description and Rules

This project recreates certain aspects of the Primer project while keeping other factors constant and building on principles covered in the video. This project does not share any code with the Primer project.

The underlying model resembles reinforcement learning by rewarding agents that possess successful trait configurations and removing agents with less successful trait configurations. Success is measured by survival, with the corresponding reward being replication. Unsuccessful agents are removed from the environment.

Beginning at generation 0, agents and food are randomly spawned into a rectangular environment. Key agent field variables are *energy*, *speed*, and *size.* Agents start with a finite amount of *energy* and a *speed* of 1. Each time step, all agents will search for the closest piece of food and determine whether the energy expenditure associated with moving to that food will be net positive. If the agent chooses to move to that food, it will expend energy at the rate $(size)^3(speed)^2$. Simultaneous decision making often leads to competition over a single piece of food. Food consumption results in an energy reward to the consuming agent. The consumed food will no longer be available for other agents.

If an agent determines that the closest food is not worth the energy expenditure, it will remain stationary and constantly lose energy at a rate less than movement alone. It flags itself as "satiated" via the field variable `Agent.satiated==True`. A generation is complete when all agents are satiated.

The conclusion of a generation removes all agents depleted of energy. All surviving agents spawn successors with matching traits. There is a small probability that the *speed* and *size* traits will mutate. All new and surviving agents are then randomly distributed into the environment with a new physical distribution of food. The amount of food available to the entire population remains constant to simulate scarcity and competition.

Speed
- 80% chance of consistency
- 20% chance of increase/decrease by 1

Size
- 80% chance of consistency
- 20% chance increase/decrease by 15%

2.2 Parameters

Population outcomes are largely dependent on the tuning of several model parameters, most notably:

iterations: the number of generations to run the simulation for

num_agents: the number of starting agents distributed into the environment for generation 0

num_food: the amount of food that spawns in the environment each generation

height, width: the size of the environment grid

Agent.energy: the amount of energy each agent starts with so they are able to move to food initially

Agent.food_reward: the amount of energy rewarded to the agent when food is consumed

Agent.stationary_penalty: the amount of energy consumed per stationary time step to represent agent base metabolic rate

speed_boost, size_boost: the probability distribution for the trait mutations

3 RESULTS

Simulation results are consistent with Darwinist principles. Traits that provide utility to the agent become more prominent in future generations, whereas undesirable traits become "vestigial" over time. In addition, this simulation is also able to model periods of food shortage, overpopulation, and competition.

3.1 Greedy Search

Agent movement is determined by a simple greedy search. Iteration order through the agent population is determined randomly. Once this order is set, for each time step, each agent calculates its distance to the closest piece of food.[1] If the calculated energy expenditure given the manhattan distance to this food is less than the amount of energy rewarded by consuming the food, the agent will move exactly *speed* spaces on the grid. Energy will be decremented accordingly and this agent's turn is over. All agents will take turns performing this calculation and moving. If the agent remains stationary, a base amount of energy will be decremented to represent base metabolic rate and the agent will set the parameter *Agent.satiated==True*. Time step iteration ceases iff. every agent in the population is satiated.

Structuring agent movement in this manner fosters competition. For example, an agent may target a specific food and move *speed* steps towards it. If the distance to the target food is greater for this agent than another, or if *speed* is lower than for another, the food may be consumed by an adversary. This will force the agent to select a new food target or remain stationary, wasting the energy required to move in previous time steps.

3.2 Population Size, Competition, and Food Scarcity

The simulation reveals that population size tends to remain at an equilibrium level determined by the model parameters. Brief periods of overpopulation are corrected within ≈ 5 generations as the fixed amount of food cannot sustain such a population. This is a demonstration of the competition behavior spurred by the finity of food.

3.3 Trait Selection

Traits that provide utility to the agent tend to increase over time as they are favored by natural selection. For instance, increased speed allows the agent to traverse the grid more quickly, consuming more food and increasing chances of survival.

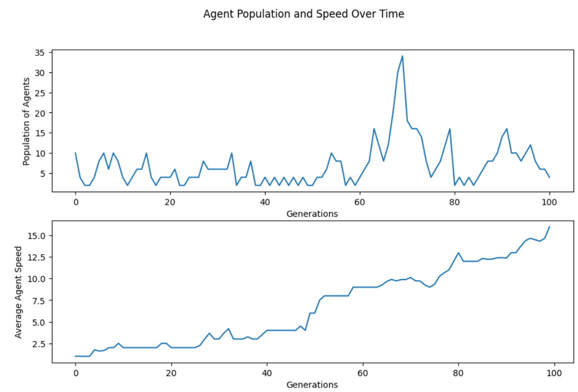


Figure 1: Overpopulation

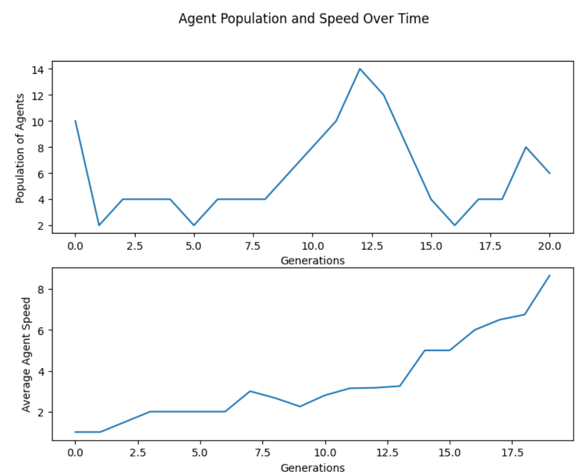


Figure 2: Evolution of Speed

As demonstrated in figure 2, the average population speed quickly increases regardless of the population size. This phenomenon can be accelerated if additional constraints penalize agents more severely for remaining stationary.

There comes a threshold where the additional energy cost for additional speed is too great and the trait no longer mutates. This threshold can be identified in figure 3 as *speed*=7. The speed term in the energy consumption formula is quadratic, meaning there are diminishing returns on speed increase.

Traits that negatively impact an agent will naturally devolve over generations. For example, the *size* term in the energy consumption formula is cubic, meaning that there is a significant penalty for larger agents. Figure 4 demonstrates both how disadvantageous traits may devolve and how the population as a whole is able to grow when the average value of such a trait decreases. Note that the advantageous trait *size* simultaneously increases as noted previously. The rate at which *speed* increases and *size* decreases is proportional to the exponents of the *speed* and *size* terms in the movement energy function.

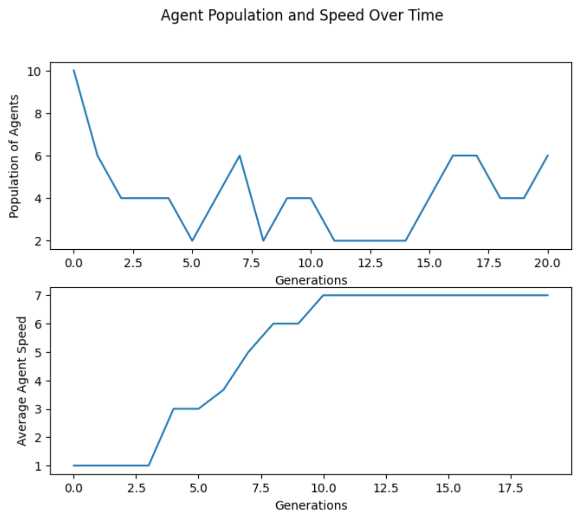


Figure 3: Speed Given High Stationary Cost

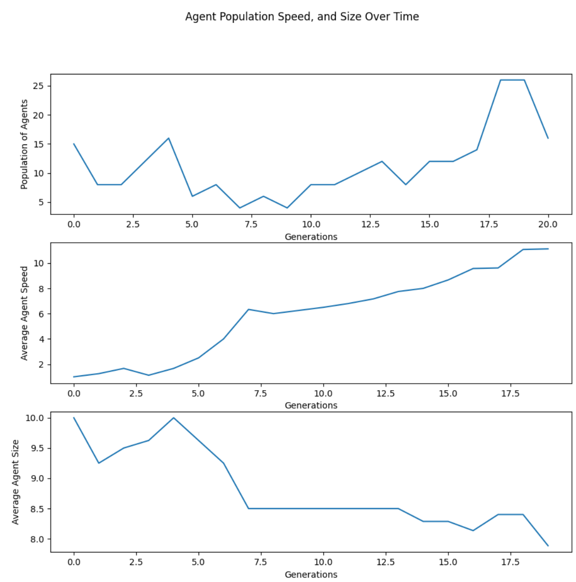


Figure 4: Evolution of Size

3.4 Relation to Real-World Natural Selection

Charles Darwin who was a British naturalist proposed the theory of biological evolution by natural selection. Natural selection is the mechanism that he proposed for evolution. Since resources are limited in nature, organisms with heritable traits that favor survival and reproduction will tend to produce more offspring than their peers, resulting in certain traits increasing in frequency over generations. The key observations that Darwin's concept of natural selection include: Traits are often heritable; more offspring are produced than can survive. Offspring vary in their heritable traits. Some individuals will have traits that are favorable for survival and reproduction. As these agents produce more offspring, these selective traits tend to become more common in subsequent generations.

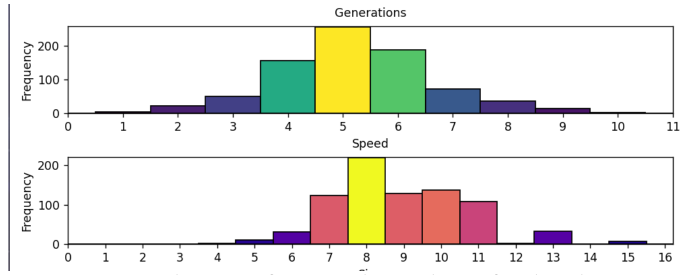


Figure 5: Distribution of size and speed in a food-rich environment where the starting values are *speed*=5 and *size*=10

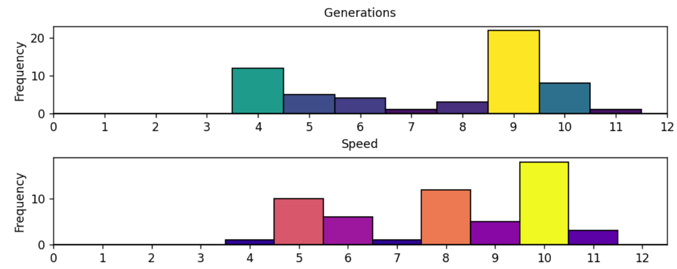
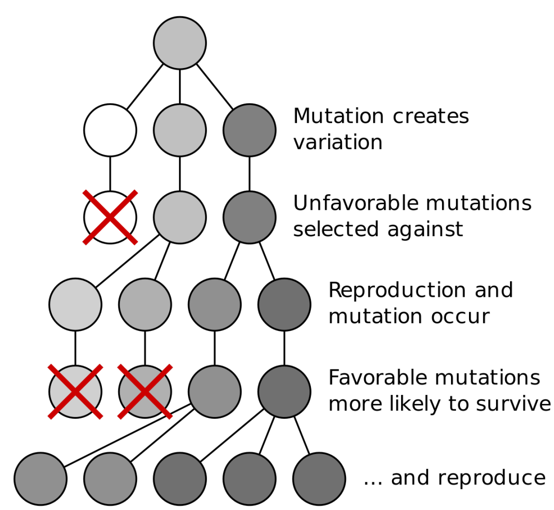


Figure 6: Distribution of size and speed in a food-scarce environment where the starting values are *speed*=5 and *size*=10



Much like the finity of resources in the natural world, this project demonstrates a limitation of resources by means of food availability and environmental size constraints. Given these laws defined in the simulation, it is observed that *speed* increases and *size* decreases over generations. This implies that the former is more favorable trait and the latter is less favorable for survival and reproduction as would be described in Darwinism.

4 LIMITATIONS

There are a number of essential evolutionary principles that were not modeled in this simulation.

Sexual selection is the process by which certain physical and behavioral traits in individuals increase their chances of mating and reproducing, leading to the evolution of exaggerated characteristics that may sometimes be detrimental to survival.

Sexual Reproduction would be modeled by successor creation blending traits between two predecessors. This model relies on **asexual reproduction**, or mitosis. A model relying on mitosis is weaker than a sexual reproduction model because it lacks the genetic diversity and variability introduced by sexual recombination, leading to slower adaptation and less efficient elimination of harmful mutations.

Relationships between agents occupying the same habitat include mutualism, commensalism, and parasitism. These inter-species relationships are an essential factor in measuring evolution patterns within a habitat, but add a complicating factor not accounted for in this simulation. For example, a secondary scavenger species would thrive in an environment where there are high death rates of the primary species.

5 CONCLUSIONS

The goal of this project was to simulate the natural selection process using nondescript agents in a two-dimensional environment, with a focus on basic traits such as speed and size. The project was inspired by the Primer YouTube video, which models evolving populations by means of assigning creatures with traits that evolve over time.[5]

The approach taken in this project was to build on principles covered in the Primer video while keeping some factors constant, such as the presence of food, and modifying others, such as how energy is expended by agents. The model resembled reinforcement learning, rewarding agents that possessed successful trait configurations and removing those with less successful ones.

Through this simulation, a variety of agents with different traits emerged as a result of natural selection. Further work could include adding more complex factors, such as sexual selection, environmental adaptation, and predator-prey interactions, to the model to study their effects on natural selection and trait adaptation.

APPENDIX

- Code is available on github here. Reference the README.md for instructions on how to run the simulation.
- Class presentation can be found here.

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