Natural Selection Simulation

AASMA 2020/2021 - Project Implementation

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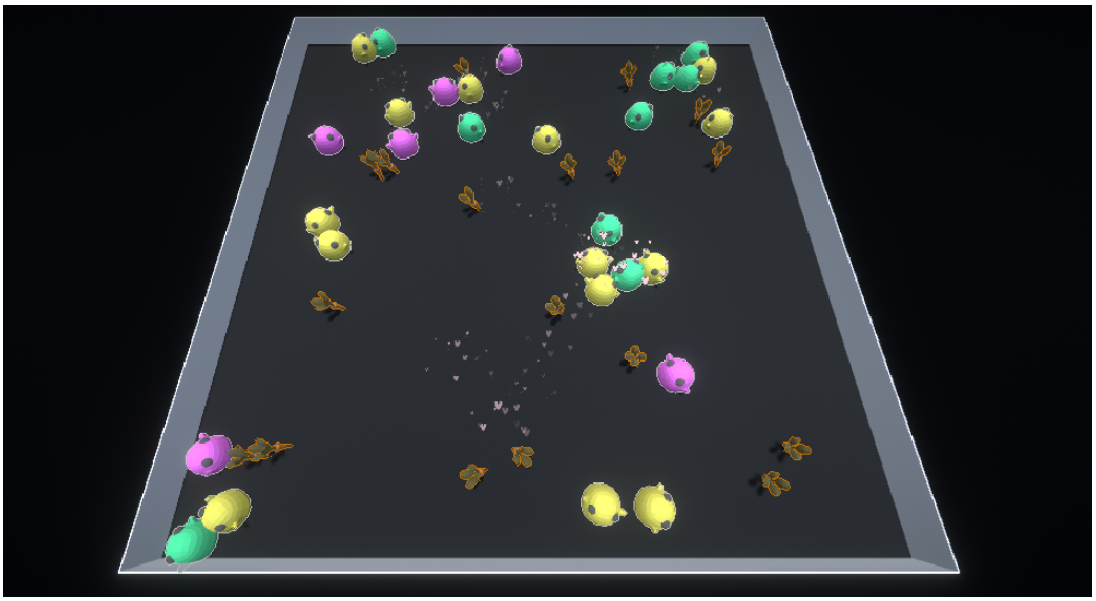

Figure 1: The system.

ABSTRACT

This paper describes the design and implementation of a multi-agent system based on surviving within a simulated ecosystem with an aim on observing Natural Selection. Agents have conflicting goals as they need to survive feed themselves and reproduce. Different decisions to make such as to run from other agent or to fight it, or to accept a mate. Different capabilities and physical attributes like strength, speed and sensory traits. All of those different characteristics derive from an agent's genome. A set of inherited parameters that is subject to random noise, or mutation. Competition naturally emerges as survival strategies. It is intended that the agents use the developed structure in order to survive and assure the continuation of the species.

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INTRODUCTION

We intend to simulate the evolution of populations using a multi-agent system. Evolutionary processes are by nature decentralised, the agents act on their own and have direct interactions with the environment and the other agents. The properties of the agents are encoded in their genome and they are able to reproduce and pass their genes to future generations. Moreover, the agents have to compete for resources or they will eliminated, only the fittest individuals survive resulting in Natural Selection.

In this project we want to explore how the inherited information affects the behaviour of the agents and conclude which traits are more important to the adaptation to the environment. We also want to explore how Natural Selection specializes agents to certain environments conditions. [1]

Motivation

We decided on implementing a multi-agent system mimicking natural selection [2] [3] as a way to observe how the autonomous agents would showcase various survival strategies according to their various characteristics. This allows us to better understand ecological complexity and observe Darwin's key aspects of evolution first hand.

Problem Definition

The various agents must be able to encounter supplies that meet their needs in order to be able to reproduce. If they fail to find food and are too weak to have children, the species will be driven to extinction. However agents that are successful will pass on their traits and make them more prominent in the gene pool.

Requirements

In order to simulate natural selection it is necessary that each agent's traits are defined from a genome that is inherited from it's progenitors and also affected by random noise, simulating mutations. The genome will not only define physical characteristics, behaviours should also be affected so that it can be tailored to match the agents capabilities.

- Observe the different strategies the agents are developing to better adapt to the environment
- Have the agents compete with each other for their own survival
- Observe the evolution of the population over time to determine what kind of agents emerge
- Test different parameters within the environment, and make conclusions on how those impact resulting agents
- Observe population growth and evolution rates
- Experiment with different mutation rates and draw conclusions about what rate is optimal
- Experiment with different selection criteria for reproduction

APPROACH

We implemented the system in Unity 2020.2.4f1.

Environment

The environment consists of flat terrain and food pellets that randomly spawn throughout. Food attracts agents to a place forcing them to compete and interact with each other. We decided to make the environment simple as most of the interaction will come from species interacting with each other.2

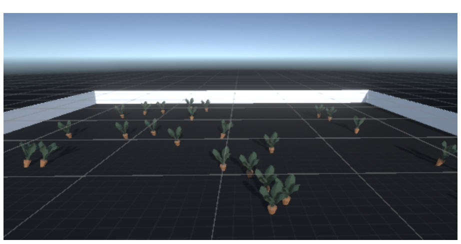

Figure 2: Small Environment

Food

There are two types of foods that we built onto the environment. The first one appears with a given frequency in a random place within the boundaries of the environment. This type is less nutritive than the following one, we choose a model of a carrot to represent it. When an agent dies it's transformed into meat, making it our second food type. This was our choice so to make attacking other agents more desirable and rewarding. 3

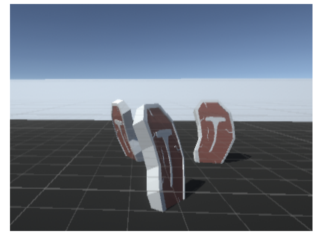

Figure 3: Second type of food

Environments

We experimented with two different sized environment. One has more area [240x240], the agents have to walk longer distances but the food is more spaced. The other one is smaller[40x40] which increases the agents interactions since the agents are forced to compete more often.

Agents

Besides searching for food agents need to make certain decision along their lifespan from accepting or denying mates, to fight or flight in confrontations. It's a treacherous world out there and only sound strategies will thrive.

Genome

Each agent is defined by a set o values representing it's genome. The genome will contain genes for characterising within the following categories:

- **Physical traits** define physical characteristics for the agents:
  1. **Speed** This gene is a trade-off as this also increases energy expenditure, requiring that the agent consume more food.
  2. **Vitality** This gene determines the HP (health), agents with more vitality are more resistant to attack.
  3. **Starving Damage** Determines the resistance to starvation. How faster a agents loses health when hungry.
  4. **Strength** Determines the force of the agent's attack.
  5. **Intimidation Factor** Determines the strength an agent appears to have even if it is not true.
- **Behavioral traits** define decision making parameters. Taking the form of probabilities that impact behaviour.
  1. **Wander Rate** This gene affects how often an agents changes direction when exploring.
  2. **Procreate Modifier** Affects the desire to procreate.
  3. **Attack Modifier** Affects the desire to attack.
  4. **Minimum Hunger** It influences the answer to a procreate request from other agent. Since procreating increases hunger.

- **Sensory traits** define the accuracy and range of the agent's senses. The senses inform the agent of the direction and the distance of the source of a signal.
  1. **Smell To Sense Ratio** The smell radius determines the circle of vision of an agent to food and the sense radius the vision of an agent to other agents. The Smell To Sense Ratio gene controls how much an agent has of both. However, its a trade-off, if you have to much of one you will have less of the other.
  2. **Perception Accuracy** This gene determine the accuracy an agent can detect others' strength so that it can choose to attack or to run from an attack.

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State
Each agent is aware of how much HP(health) and the level of hunger it has at any given time. This knowledge allows it to make better and more conscious decisions. For example, The agent will not try to procreate or accept a mate if it is too hungry, according to the minimum hunger parameter.

Sensors
The sensors help in obtaining relevant information about the world the agent is in. At all time, the agents is able to observe the food and agents around him within a certain radius. So, the agent has two sensors: one for food and other for agents, both cover different distances

Actuators
Actuators allow the agents to interact with the environment and other agents.

- **Movement Actuator** Allows the agent to walk towards a desired target or in a random direction when exploring, also allows stopping when necessary. 4

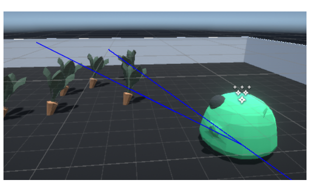


Figure 4: Agents walking towards food

- **Attack Actuator** The purpose of this actuator is to perform attacks on other agents. The amount of damage an attack does is proportional to the agent's strength. if the agent inflicts too much damage, the other agent involved in the fight can die, this depending on its HP value. 5

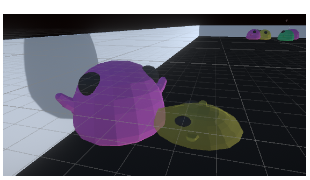


Figure 5: Agents after deadly fight

- **Procreate Actuator** This is for the reproduction. It sends a proposal to another agent. If the chosen partner accepts the mating, the agent creates another creature with a new genome. The new genome is going to inherit some characteristics from one parent and others from the other with a slight probability of occurring mutations. This process increases hunger in both parties.6

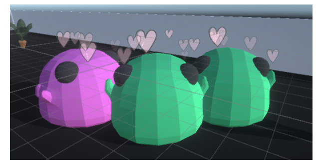


Figure 6: Agents after procreation

Decision making
There are 4 distinct states the agent can be in, depending on which action is currently being performed. Wandering, walking towards food, chasing another agent to attack or to try to procreate To select between different actions the agents use an intention module. When the agent is without an action, or is reconsidering is current one. It will calculate a desirability value for each possible action. He will then commit to the most desirable action. The following formulas were used for each action's desirability

$$Wander = 0.15 \tag{1}$$

$$GetFood = \frac{hunger}{100} * (1 - \frac{distToFood}{smellRange}) \tag{2}$$

$$ProposeProcreate = \frac{100 - hunger}{100} * (1 - \frac{distToTarget}{senseRange}) * C * procreateMod \tag{3}$$

$$Attack = (\frac{100 - hunger}{100})^2 * (1 - \frac{distToTarget}{senseRange}) * C * attackMod \tag{4}$$

C being confidence or how strong the agent thinks he is in comparison to the target. This perception can be clouded by the targets intimidation factor and cleared by the agent's perception. The attackMod and procreateMod are behavioral traits that remain constant. The first factor in the Attack formula was squared as to make the agent´s consider attack more heavily than other traits. Without this populations could quickly crumble due to excessive unnecessary attacking. The wandering action has a fixed yet small desirability because if this was zero the agents could resort to making bad decisions when no action was appropriate. Simply because a very low desirability value would still be the greatest. To fix this issue the wander rate was given that desirability to serve as a baseline.

Architecture
The agents are autonomous and lack any centralized control. Their actions will be generated using a hybrid architecture, that reactive and deliberative. Reactive behaviours are adequate for simulating searching behaviors like scavenging. It is also useful that reactive agents are computationally lighter, since we'll need to have hundreds of simultaneous agents. However,

some behaviours like deciding whether to focus on eating or looking to reproduce will require some deliberation. Weighing the agents' perception of other agents with their behaviour traits to decide how to react.

EMPIRICAL EVALUATION

In order to test if our agents are evolving to become fit to their environment we defined metrics to confirm it.

- number of individuals, it is expected that the number of individuals in the environment will rise until it reaches the threshold of the environments' capacity.
- number of children per individual
- average lifespan
- gene pool specialization, as the agents become fit it is expected to see several agents have similar traits, as well as to find more than one cluster of similar agents, each cluster representing a adequate strategy for survival. We can measure the amount of different strategies/clusters using clustering techniques on the gene pool.
- observation of logical behaviours and different strategies
- specialization to the environment, agents should become fitted to their environment, as such, when repeating experiments on environments of different sizes and food densities the emergent species should vary.

EXPERIMENTS + ANALYSIS

We exported all of our data regarding the state of the agents and the environment over 100 days per trial (24s * 100 = 40m) and used Python to process the data into graphs presented in this section in order to facilitate the analysis and the discussion.

Population Evolution

The number of individuals varies according to the quantity of food available in the environment. If there is a spike in the number of food it will reflect in the number of agents a few days later. This can be observed in the following image.7

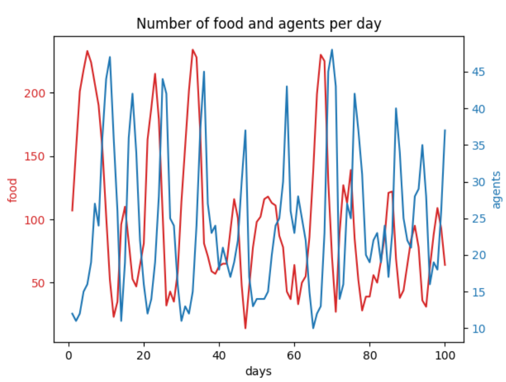


Figure 7: Comparing Number of Food and Agents per day

We conducted an experience starting with only two agents at the beginning of the run. We wanted to test how the population would evolve over time. After analysing the result the came to the conclusions that after a while the number of individuals starts to seem confined to a certain interval, in other words It seems to be getting stable. 8

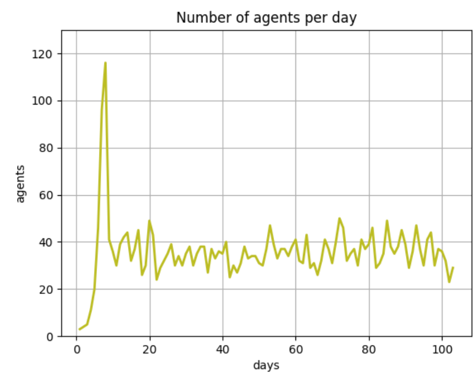


Figure 8: Number of agent per day, starting with 2 agents

Environment Dimension

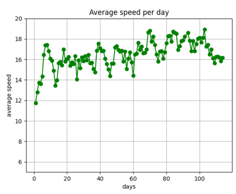
We started out by changing the environment dimension, as it was said above in this paper we have two environments, one larger than the other. In order to test how the amount of space affected the population we conducted two experiments with the same settings one in the smaller space and other in the larger space.

As we expected the population in more unstable in the smaller space, things happen more quickly. Decreases and increases the number of individuals more often.9

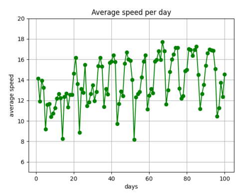
Figure 9: Number Agents per day in a smaller and large space

The blue curve corresponding to the smaller space changes direction more often than the other curve. Having too many agents in less space causes more stress, the environment doesn't allow that much individuals and they have to adapt more quickly. However, the bigger the space the more the population grows without constrains until it reaches its limit and decreases more drastically, we can observe this by inspecting the peaks of both curves. If we look at the orange curve, we see that reaches higher population values but also the lowest values. The population in the larger space is in more danger of extinction because if it grows too much, the environment will not be able to restore the resources in time to sustain it, this can lead to famine periods that can, in turn, lead to extinction.

We could also observe that the agent adopted different strategies for each environment. In the smaller space, being the first to get to the food seems to be the best an agent can do to survive. In the larger environment the creatures seem not to prioritize as much being the fastest to get to the food10, we should note that in this environment the food is more spaced and that travelling further distances uses more energy. Instead, the agents seem to attack more and recover energy by eating other creatures.11

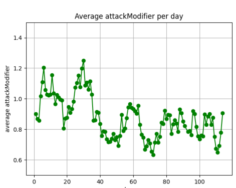


(a) Experiment in the small space

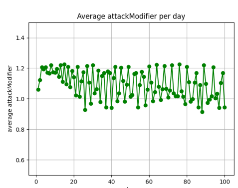


(b) Experiment in the large space

Figure 10: Average Speed Per Day



(a) Experiment in the small space



(b) Experiment in the large space

Figure 11: Average Attack Modifier Per Day

Food Availability

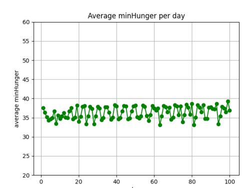
In order to test the impact the quantity of food available has in the system we conducted three experiments with three different types of spawn chances at every 0.1 seconds. 12

1. One hundred percent spawn chance.
2. Fifty percent spawn chance.
3. Twenty percent spawn chance.

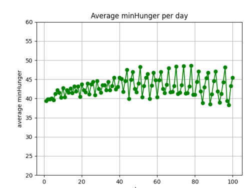
We can conclude that the availability of food matters to the growth of the population. In the experiment 3 the agents weren't able to survive past day 10. However, 1 has the largest amount of individuals per day out of all the experiments.

Figure 12: Number of Agents per day, comparing different spawn chances for food

Another thing that we observed is that the **Minimum Hunger**, the threshold that an agent is willing to accept a request to have a baby, is lower when more food is available and higher when less food is available. We concluded that this aspect has to do with the fact that an agent when reproducing loses more energy , thus in a environment with less resources it can't dispense as much energy. Another evidence to support this is related to the **Average Babies per Agent** in both experiments. The Average Babies per Agent in the Experiment 1 was, approximately, 23.73 babies. And in the Experiment 2 they had less on average, 20.61 babies, approximately. 13



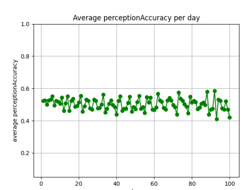
(a) Experiment 1



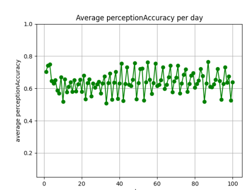
(b) Experiment 2

Figure 13: Average Minimum hunger Per Day

It is also possible to link the access to food to the **Perception Accuracy** gene. If an agent has less food close to him, it is more likely that he chooses to attack the other individuals to get food. In a situation like this, it gets essential that the agent is capable of distinguish among his peers the ones with more strength than him because they could kill him more easily. 14



(a) Experiment 1

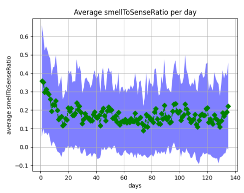


(b) Experiment 2

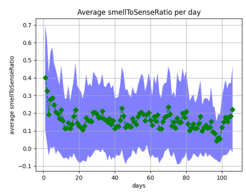
Figure 14: Average Perception Accuracy Per Day

Mutation Rates

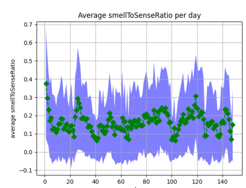
We tested different mutation rates to see how it would affect the evolution of agents. A mutation rate is how likely a gene is to suffer from mutation when an agent's genome is being generated from its progenitors. When a mutation occurs there is a 50/50 chance of being a positive or negative change. The actual change in the value derives from a normal distribution making small changes more likely than bigger ones. The amount of change is also proportional to the difference between a gene's minimum and maximum values. We performed 3 trials with mutation rates of 2 percent, 10 percent and 50 percent respectively to observe how it would impact the evolution of the population's genome over time.



(a) Experiment 1

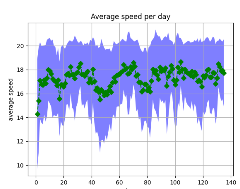


(b) Experiment 2

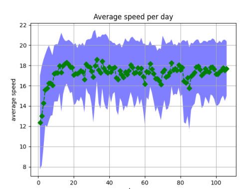


(c) Experiment 2

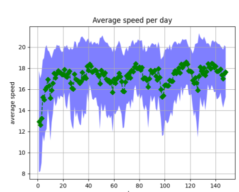
Figure 15: Average Smell to Sense Ratio Per Day



(a) Experiment 1



(b) Experiment 2



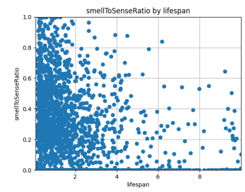
(c) Experiment 2

Figure 16: Average Speed Per Day

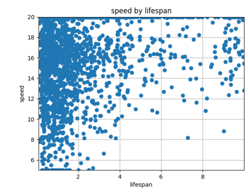
By observing the data we conclude that a mutation rate of 50 percent can lead to unstable evolution with averages shifting quickly. However, between 10 percent and 2 percent it seems to be a trade-of. A rate of 10 percent can be less stable than 2 percent. However, 2 percent might take longer to converge.

Lifespan

We can draw some conclusions if we look into what agents live longer. Having high speed and a big sense radius to food seem to be more important to the lifespan of the agent. Note that a lower Smell To Sense Ratio means a less radius to feeling agents and more radius to food. 17



(a) Smell To Sense Ratio by Lifespan



(b) Speed by Lifespan

Figure 17: Days lived

Genes specialization

After observing the evolution of the genome throughout multiple trials we have made some conclusions about the utility of different stats, and how crucial they are to survival. Speed seems to be the most important trait. However, the optimal speed value depends on the size and food scarcity of the environment, since higher speeds also require more food. Even in environments where high speed were thriving, sometimes the low speed trait became dominant as the slower agents could survive famines that would wipe out most of the faster agents. Smell to sense ratio also seems to be a prominent feature. And its utility is tied to aggressive parameters. Higher sense is useful in environments with less food density where agents resort to violence more quickly. One interesting recurring occurrence in gene specialization is the birth of a hyper aggressive, intimidating, strong agent. If such an agent is to arise, we can decimate an entire population, specially on smaller environments. Thankfully this won't happen in most runs.

CONCLUSION

To summarize, we have described and experimented with a multi agent simulated ecosystem implementation. We concluded on how the size and food scarcity of and environment can impact a population fluctuation in numbers and gene specialization. Small and dense environments leading to high frequency and low amplitude shifts in population size, and tending to fast less aggressive agents. While Larger more scarce environments tend to show lower frequency, high amplitudes shifts in population size and more aggressive behaviors. We have looked at how the number of agents and the food availability of an environment relate. And how the environments conditions can lead to the sustainability of the species. We have devised formulas to calculate the desirability of each action that better leads to agents that can sustain themselves within the environment. We studied the evolution of each genetic value and singled out the more important ones as being speed and sensor range by looking at statistical information.

Finally we identified a trade-off between higher and lower mutation rates. High mutation rates being unstable while lower ones take longer to converge.

ACKNOWLEDGEMENTS

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