Simulation of Natural Selection

Richie Pajak

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Contents

1 Abstract

This project is a simulation of an environment where natural selection takes place. Natural selection is a large part of the theory of evolution which has been observed in creatures in the wild. According to natural selection, creatures that are well suited to survive in their environment are naturally selected to live and create offspring. Because offspring are often genetically similar to their parents and thus have similar traits as their parents, the population evolves to have traits that are suited for survival within the constraints of their environment. Creatures that have unfavorable traits die before they are able to create offspring and therefore their traits are not seen within the population. In order to simulate this phenomenon, an environment for creatures to live has been created using python with certain requirements for offspring creation. Simulated creatures that meet these requirements will have offspring and their traits will be seen within the simulated population over time.

2 Introduction

Natural Selection is a field that has been extensively researched already. Dating back to the 1830s, scientists have observed evidence of natural selection in animals and plants across the globe [2]. Natural selection is the process that allows animals, plants, and all sorts of living things to evolve over the course of many years. This evolution is based on how the different traits that a creature possesses allows them to interact with their environment. As generations of creatures live, interact with their environment, and die, random genetic mutations cause offspring to have and express traits that are different from their parents.

How these traits are expressed in each creature will determine whether that creature is successful within its environment. Those that are successful will reproduce and create offspring that are similar, but not exactly the same, as their parents. This process of selecting the creatures with the most advantageous traits will cause the population as a whole to evolve in accordance to what their environment demands.

This simulation will feature creatures in an environment that contains food. A creature's fitness will be determined by how much food a creature can collect. The creatures will have to compete with other creatures to collect food. They will have several traits that will vary and evolve over the generations of creatures to suit their environment. As time and the simulation persist, there will be trends that show the most beneficial and advantageous traits for creatures to have.

There are other simulations that have been created to display natural selection. They all include similar features such as creatures and an environment. Most natural selection simulations that already exist are designed to teach the concept of natural selection to students [1]. This project will focus on analysis of the results of natural selection and the impacts of environmental changes rather than teaching the concept.

3 Project Goals

The main goal of this project is to use research to create a functioning simulation which simulates and displays natural selection in real time. In addtiion, it will be important that the simulation is easily viewable and understandable to people that have limited previous experience with natural selection. Another goal for this project is to be able to understand how different environmental factors impact the ways that a population evolves. In order to understand the impacts of changes in different environmental factors, data from the simulation will be used. The final goal of the project is to export data from the simulation to Microsoft Excel and visualize changes that occur due to environmental shifts.

4 Natural Selection

4.1 Natural Selection in the Wild

As observed in the wild, there are several requirements for a population for natural selection to occur. According to Endler, these requirements are

1. Variation among individuals in some attribute or trait: variation;
2. A consistent relationship between that trait and mating ability, fertilizing ability, fertility, fecundity, and, or survivorship: fitness differences;
3. A consistent relationship, for that trait, between parents and their offspring, which is at least partially independent of common environmental effects: inheritance [2].

If these requirements are met, then natural selection will occur. As time passes and generations of creatures live and die, certain favorable traits will be seen in a large portion of the population.

It is important to note that when discussing evolution, only a population can evolve. Once a creature is created, its traits are fixed and cannot be changed. Creatures do not evolve, populations do.

It is possible that traits that are not seen at one point in a population can be seen in the future of a population. When a creature has offspring, the parent's DNA is copied and given to the child. It is possible that during the copy process, a mistake is made and the offspring's DNA is slightly different from its parent's [3]. Even a small change or mistake in DNA can cause a significant change in a creature's appearance or traits. Because of this chance for mutations, it is possible, especially in a population that survives for many generations or has a large population size, that new traits emerge that were not seen in the population initially.

4.2 Natural Selection in a Simulation

According to Perros, there are five basic features of a simulation that must be addressed. They are

1. Environment: Each system can be seen as a subsystem of a broader system.
2. Interdependency: No activity takes place in total isolation.
3. Sub-systems: Each system can be broken down to sub-systems
4. Organization: Virtually all systems consist of highly organized elements or components, which interact in order to carry out the function of the system.
5. Change: The present condition or state of the system usually varies over a long period of time [4].

These features can be translated to features of natural selection. For environment, a simulation of one species evolving via natural selection can be seen as a sub-system of an entire ecosystem. For Interdependency, each action one creature takes can impact another creature and its choices or outcomes. For sub-systems, a population of creatures can be broken down to just one creature living and functioning in the environment. For organization, each creature is organized and has a function that it carries out in order for the entire environment and population to exist. For change, as the creatures carry out their functions, the population changes and evolves to create new versions of the population.

The software used for this project combines these sets of requirements and meets both in order to make a functional simulation of natural selection. Objects to represent creatures are created which meet all of the requirements of natural selection. The creatures have varying attributes that dictate their success within the environment and they pass these attributes down to the children that they create. These creatures exist within an environment where they compete with each other and function to create a constantly evolving overall system.

When various parts of the system interact, they create state-dependent events. A state-dependent event can only occur when certain requirements in the system are met [5]. For example, a child creature can only be created if a parent creature exists that has collected enough food units during the simulation.

5 Software Description

5.1 Pygame

The simulation that has been built for this project is written in python. In order to create objects that exist in an environment and interact with each other, pygame is mainly used. Pygame was selected because it has built in features for creating visual objects on a plane, moving objects fluidly, and dealing with collisions between these objects. It also lets users easily manipulate the maximum frames per second of the simulation so the speed of the simulation can be easily changed. This allows a fast simulation so that many generations can be simulated in a short amount of time, or a slow simulation so that the generations can be viewed and the interactions between creatures and environment can be observed.

5.2 Environment

The main two objects that exist in the simulation are creatures and food objects. Creatures begin each round at the edge of the environment and food is concentrated in the middle of the environment. At the start of each round, food is placed within the environment, and creatures go out searching for and eating food. At the end of each round, any food that was uneaten is destroyed, and any creatures that were not successful in feeding are also destroyed. Creatures that were successful in feeding live on to the next round and also create children. As seen in Figure 1, the food objects are pink, and the creatures are of various colors searching for food.

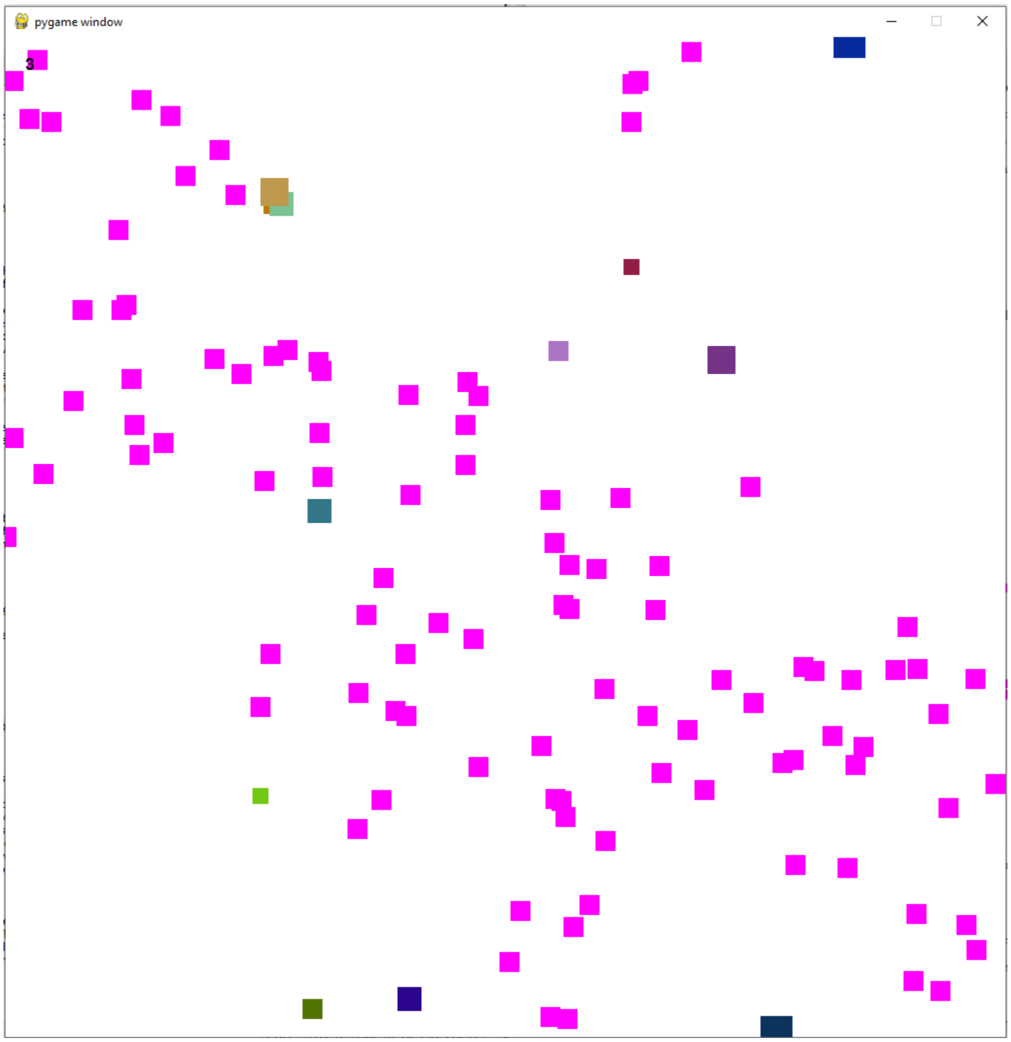

Figure 1: The simulation in progress

5.3 Creature Behavior

A creature's goal is to acquire as much food as it can during a round. It can do this in two ways. A creature can eat food objects that are placed in the environment. A creature can eat a food object simply by being the first to touch it. When a food is eaten by a creature, it is destroyed and no other creature can benefit from that food object. Each food object gives the creature that ate it one unit of food. The second way that creatures can obtain food is by eating other creatures. If two creatures touch each other and one is significantly larger than the other, the larger one will eat the smaller one. The small creature is destroyed, and the large creature is given five food units. During a round, the creatures only make decisions based on where food objects are. At all times, a creature moves as fast as it can toward the closest food object. If that food object is eaten, the creature immediately starts moving toward the next closest food object. Creatures do not attempt to move away from potential predators or toward potential prey. When a creature is created, it is placed at an edge of the environment. The location where it is placed is designated as its home location. It will begin and end each round at this location. As creatures move, they use energy. When a creature runs out of energy, they return home and wait there for the round to end. Creatures can live for up to five rounds. After five rounds, they die regardless of how much food they collect.

5.4 Simulation Core Loop

The simulation is divided into many rounds. Each round consists of several phases where different state-dependent events occur. During the first phase, creatures are simply told that they need to seek out food. During the second phase, new food objects are placed in the environment. The third phase is where the bulk of the simulation occurs. Creatures move about the environment attempting to eat food and other creatures. This phase ends when all creatures have returned to their home locations. Creatures move toward their home locations when they are out of energy or when there is no more food available. In the fourth and final phase, any creatures that did not collect enough food or have lived their maximum number of rounds are destroyed. In addition, any creatures that were able to collect a sufficient amount of food create a child.

5.5 Creature Traits

Each creature has two main traits. These traits are speed and size. Speed is how fast a creature moves, and size is how large it is. Speed is beneficial because it allows a creature to get to the food before other creatures. The benefit of size is that if a creature is more than twenty percent larger than another creature that it comes in contact with, it consumes the smaller creature. However, each of these traits also come with a downside. Each creature has a certain amount of energy. That amount is constant among all creatures. Each time a creature moves, it costs energy. The energy cost is calculated as

$$z = x^2 + y^3$$

where x is the speed of the creature, y is the size of the creature, and z is the energy cost of each movement. This function was chosen for two main reasons. The first factor that went into creating this function was the difference in cost between speed and size. It is important for size to be more costly because being able to eat other creatures gives an incredibly large benefit compared to eating just a food object. In addition, larger creatures do not have to move as far to get from one food to another. With both of these advantages in mind, it was clear that a large size should come with more of a penalty than a large speed. Additionally, within nature, a creature's volume scales cubically as it grows. Thus, the function y^3 was chosen for size. The second factor that influenced the creation of the energy cost function was that a creature with lower speed should be able to move further than a faster creature of the same size. The function x^2 makes this a reality. When this is the case, a creature can evolve to be slower and sacrifice its speed to be able to move further during a round. If a creature runs out of energy, it can no longer eat food or other creatures, however it keeps any food it has eaten up to that point. At the end of a round, if a creature has collected more than six food units, it creates a child. If a creature has collected less than five food units, it dies. If a creature collects exactly five or six food units, they survive until the next round but do not create a child. There is no additional benefit for a creature to eat more food beyond seven besides denying competitors that food. When a child is created, its size and speed are randomly determined based on its parent's size and speed. The child's size and speed can be one less than their parent's, one more, or the same. Each of these three outcomes have the same chance, one third. Creatures have a third and final triat, color. Each creature's color is completely random and has no impact on their survival or fitness. It simply adds to readability of the simulation and makes specific creatures and their interactions easier to keep track of.

6 Exporting to Excel

Over the course of many rounds, many creatures are created and those that are successful in eating food create children while those that are not die. The population of creatures evolves to have higher or lower speeds and sizes depending on what is most beneficial to the population within its environment. Throughout these rounds, there are many different variables that change and they are able to describe what is happening within the population. Data is collected and saved each round. The data points collected each round include

- The number of creatures present during that round
- How many food objects are left uneaten
- The average speed of the population
- The average size of the population

Because these data points are of interest, it is necessary to collect and analyze them to understand from a data driven perspective how the creatures within the environment are behaving and how the population is evolving. This data can paint a clear picture as to how changes in the environment effect the population of creatures. Each round these data points are saved within a CSV file. Then, when the simulation is terminated, all of the data is imported from the CSV file and exported to the Excel spreadsheet. The CSV file reading and writing is done with python's built in CSV library. The Excel exporting is done using the Pandas library. Pandas has very easy to use functionality for exporting data in a CSV format into Excel which is why CSV was chosen as the format to save the data in as the simulation progressed.

7 Starting Menu

There are many factors that are set at the beginning of the simulation that can determine the evolutionary course of the population. Before the main simulation begins, a menu can be used to change these variables. The variables that can be changed include

- The number of food objects that are created each round
- The number of creatures created at the start of the simulation
- The amount of energy each creature has
- The speed of the original creatures
- The size of the original creatures

Changes in these variables can greatly impact how a population evolves and survives within its environment. This is done through a series of text boxes to enter values for each variable. Default values for each parameter are pre-entered in each text box that correspond to that variable. Figure 2 shows the menu in its default state with the default values.

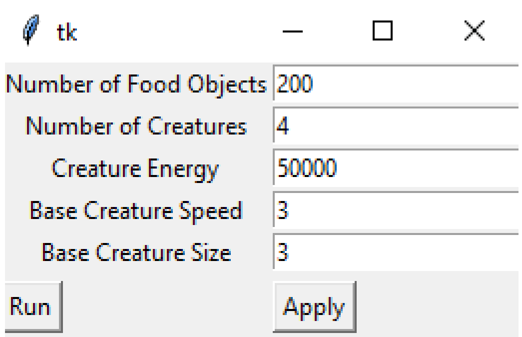

Figure 2: The starting menu for the simulation

8 Findings

In order to test how altering different environmental factors will change how the creatures evolve, several trials of the simulation were run. In each trial, the simulation is run for 300 rounds, then data about that trial is collected and analyzed.

There are several noticable trends that emerge from the selection that happens within the simulation. Figure 3 shows data collected from the first trial. This graph shows that

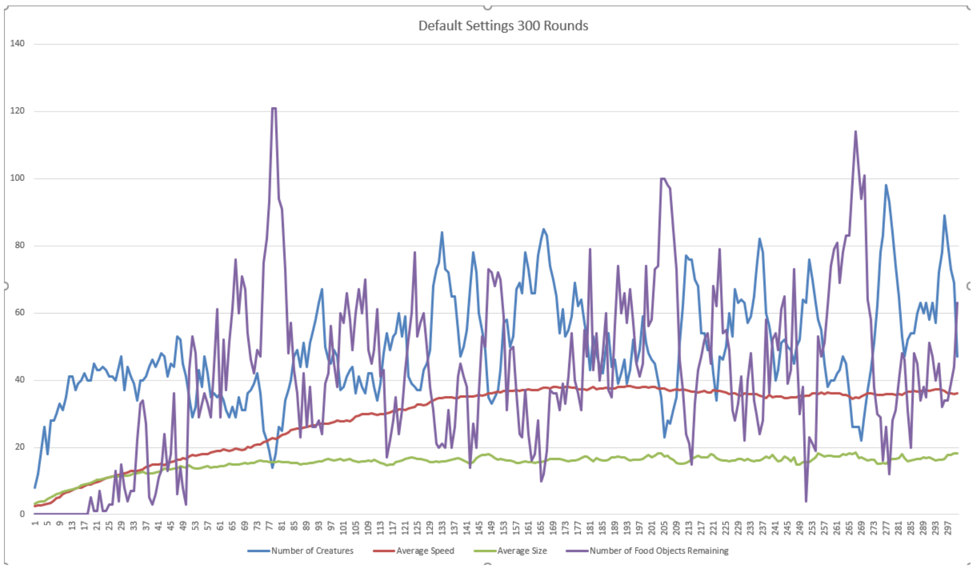

Figure 3: Graph from the first trial which used default settings.

from the start of the simulation, both speed and size rise at a similar rate. However, after about 40 rounds, the size leveles out at around 15 for the remainder of the simulation, while the speed levels out at around 36 after 130 rounds. It makes sense that speed would be higher than the size overall because of how the energy cost is calculated. By contrast, the number of creatures present in any given round and the number of food left on the board afterwards are both much more volitile. However, one noticable trend is that any time the number of food left increases, the number of creatures for that round decreases. This is due to a significant number of creatures in the environment evolving inefficiently and not being able to collect as much food as they need. Then, these inefficient creatures die out and the population count decreases.

For the second trial, the number of food objects placed in the environment each round was reduced to 80 from the default 200. A graph for this trial can be seen in Figure 4. As expected in this trial, there are fewer creatures overall. In the first trial, the average number

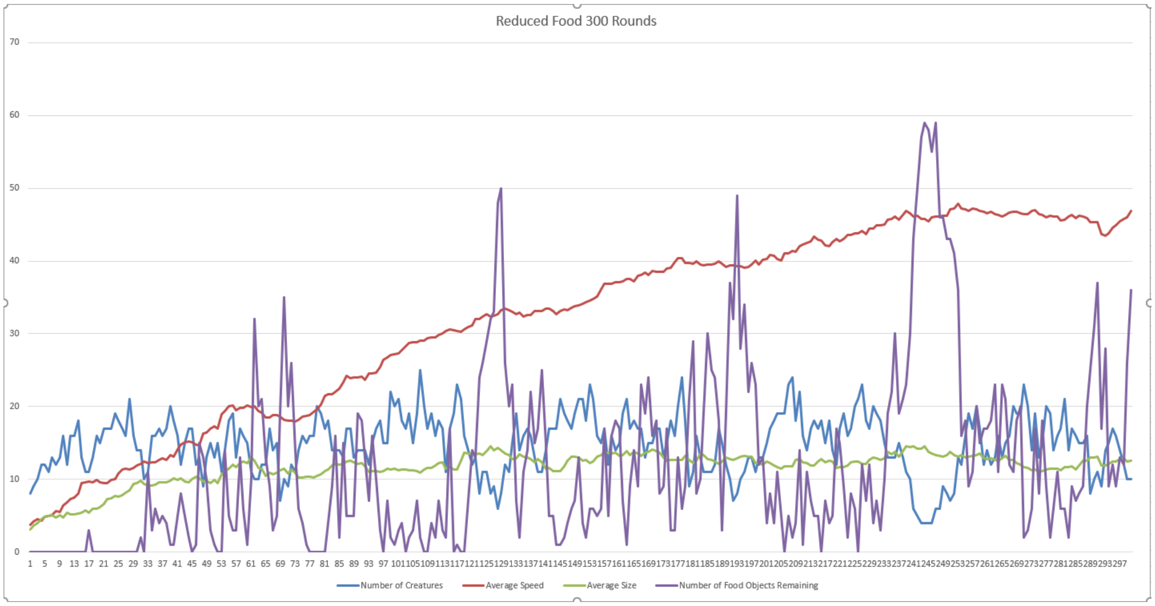

Figure 4: Graph from the second trial which used a reduced number of food objects.

of creatures across all rounds was 49, while in this one it was 15. It makes sense that with much less food, the environment cannot sustain as many creatures. In addition, with less food, competition for food is more fierce and speed becomes much more important. The average speed among creatures increased throughout the trial, ending around 45. This is much higher than the previous trial. The average size of creatures leveled out again fairly quickly, this time around 12. The size of creatures in the second trial had to be lower to make up for the increase in speed. Again in this trial, we see the number of creatures present and the number of food objects remaining moving in opposite directions consistently for the same reasons as they did in the first trial.

For the third trial, the number of creatures alive at the start of the simulation was drastically increased from 4 to 70. Despite being a large change, this trial had very similar outcomes to the first, as seen in Figure 5. The average size flattened out again around 15. However, the speed increased slowly but steadily throughout the simulation, ending at around 42. Other than this, there were no significant differences between this trial and the first. This is likely because any creatures that could not be sustained within the environment were lost after the first round and the maximum number of creatures that the environment

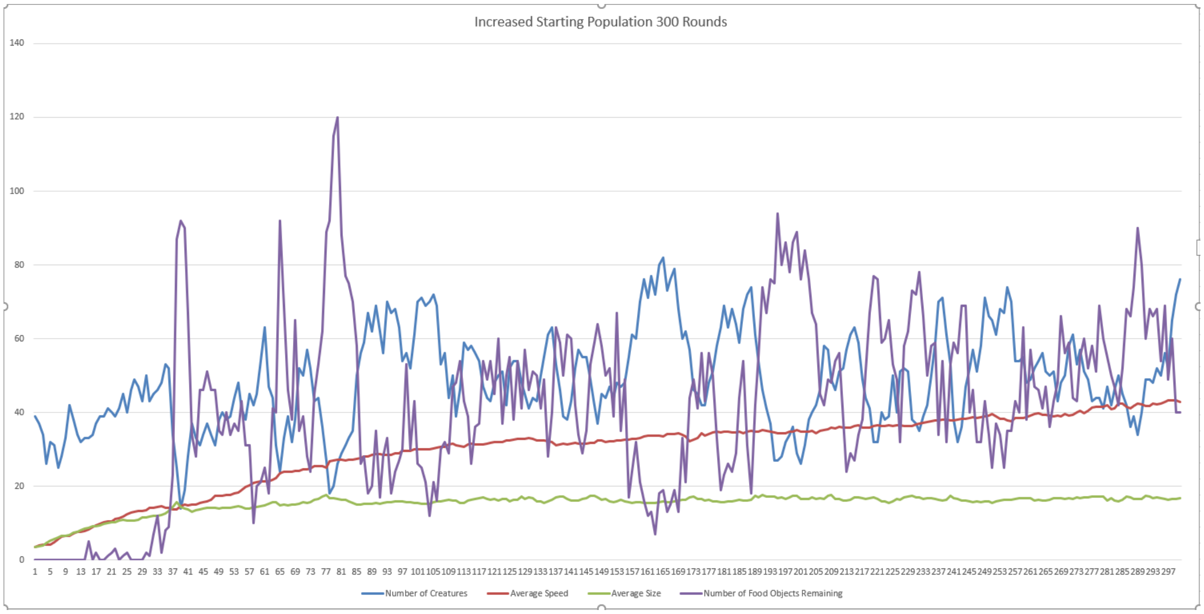

Figure 5: Graph from the third trial which used an increased initial population.

could sustain was reached quickly. This can explain the higher speed of these creatures. They were constantly in competition for food because the environment was as full as it could be for the entire trial.

The fourth trial featured reduced energy for all creatures. The energy each creature could use each round was reduced from 50000 to 10000. This meant that if creatures wanted to be able to reach a lot of food objects they had to sacrifice a lot of speed and size. The effects of this change can be seen in Figure 6. As one would expect, the speed and sizes were much lower in this trial than previous. In this trial, the average speed ended up being around 20 by the end of the trial, and the average size was around 5 for the entirety of the simulation. The most striking aspect of this graph is that for the last third of the trial, a significant amount of food was not being eaten every single round. This is due to competition between creatures. The creatures were forced to become faster and larger in order to survive. This meant that they did not have enough energy to reach food objects that were placed in the center of the environment, furthest from their home locations. Effectively, because of this limitation, there was less food available to the population as a whole because none of the creatures could reach it. Thus, a decline in population count is seen when more food is being

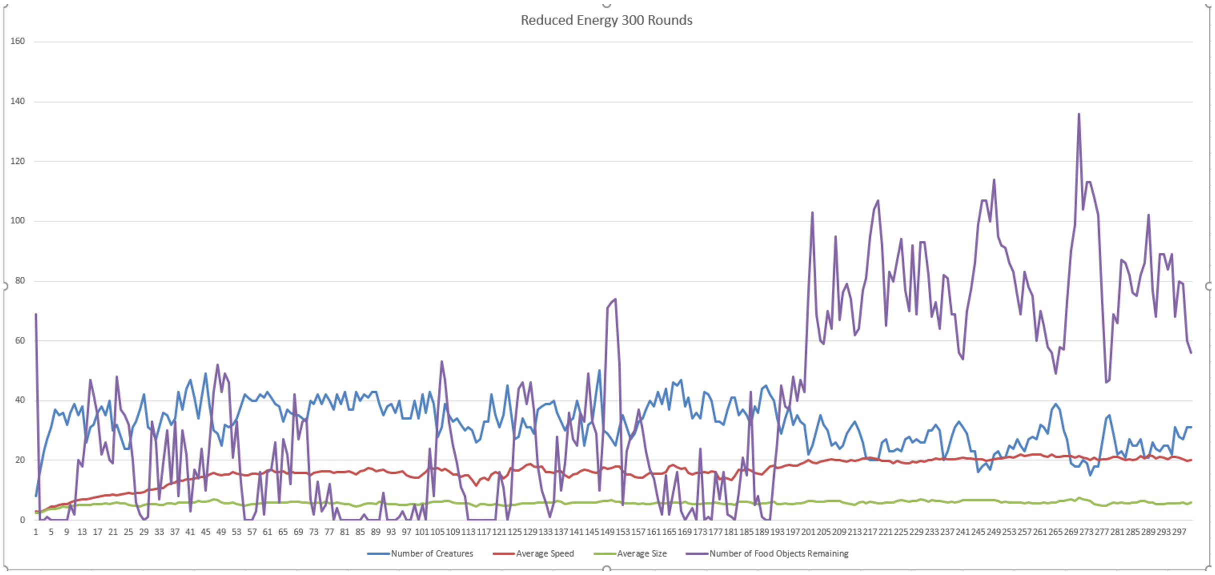

Figure 6: Graph from the fourth trial which decreased the amount of energy available to each creature.

left uneaten.

The fifth and sixth trial increased the speed and size traits respectively for the original creatures. A graph for the fifth trail, which increased the starting creatures speed from 3 to 40, can be seen in Figure 7. it would be expected for this trial that the speed would end up decreasing to a level comparable to what it was in the first trial where the settings were default, which was 36. That was not the case in this trial, the speed actually increased beyond the starting speed and ended up around 45. Also surprisingly, considering the higher average speed of this trial, the average size for the creatures in this trial ended up leveling out around a level similar to the first trial, which was 15. To make up for this increase in speed with the same size, it would make sense that each of these creatures would be able to acquire less food in a given round because they cannot travel as far. Thus, the environment would be able to sustain a larger number of creatures. This was the case. The average number of creatures for each round for this trial was 71, which is much higher than the default trial which averaged 49 creatures per round.

For the sixth trial, the starting size was increased only to 9. This is a much smaller change than has been present in previous trials. This is because with a starting size any

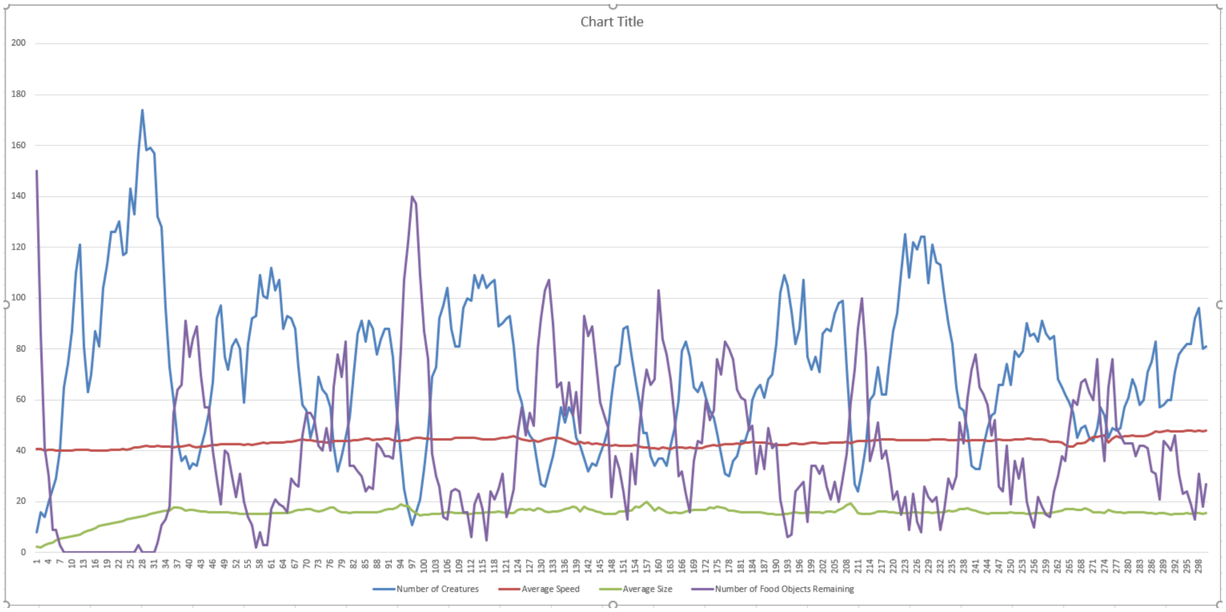

Figure 7: Graph from the fifth trial which increased the speed trait of starting creatures.

larger, the population could not sustain itself for more than 3 or 4 rounds. Large creatures thrive in large populations where they are likely to interact with a creature that they can eat. With a starting population size of only 4, the large creatures had almost no chance of finding prey before running out of energy. For this trial, as seen in Figure 8, the results were similar to the fifth trial. The speed increased steadily until flattening out at around 44, and the size increased slightly from the starting size to about 16 by the end of the trial. Because of the limitations on how large the starting size can be without the population completely dying out, it was difficult to create a meaningful change by only increasing the starting size. Thus, the results from this trial are similar to the results from the fifth and first trials.

Overall, the changes that had the largest impact on how the creatures evolve were the changes that impacted the environment over the course of the entire simulation, not just its starting variables. The second and fourth trials changed the number of food objects and the amount of energy that was available to the populations for the entirety of the trials. This made a very strong and obvious impact on how the creatures evolved to fit their environment. The trials that changed factors which only impacted the start of the simulation did not produce as drastic of changes. This is because regardless of how the population starts, it will

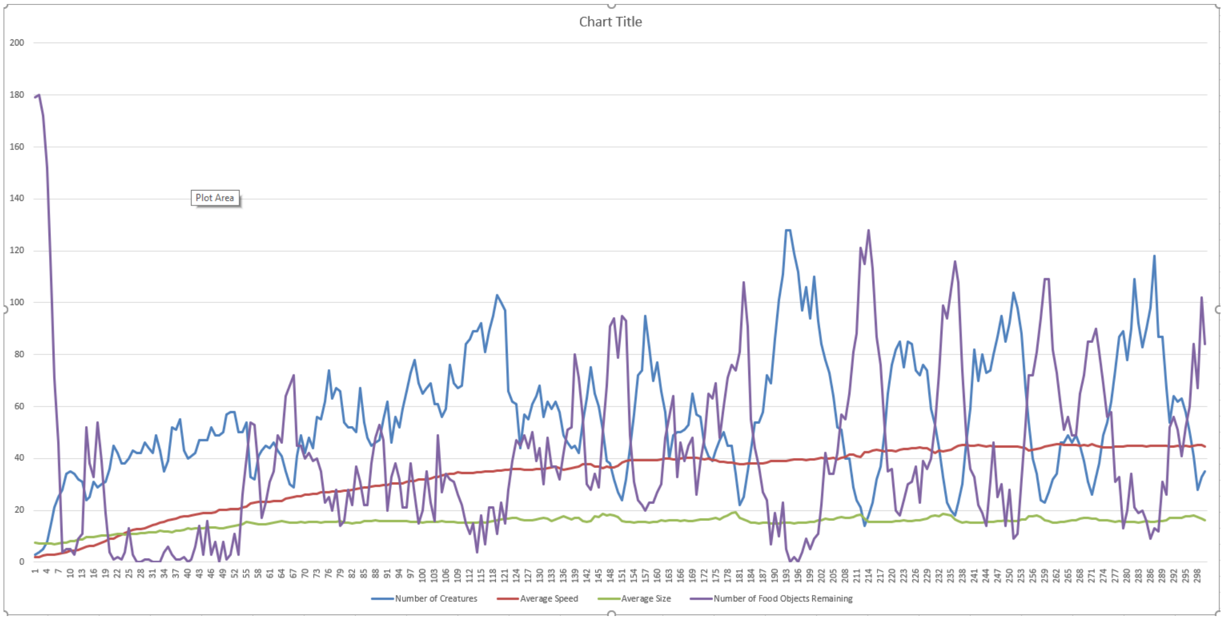

Figure 8: Graph from the sixth trial which increased the size trait of starting creatures.

eventually evolve to best fit the environment that they find themselves in. It is likely that if all of these trials went on for a very long time, they would end up evolving into almost identical populations that best fit the parameters of the environment. This goes to show the power of natural selection and its ability to push populations into positions to best take advantage of the situations they are given.

9 Future Work

Clearly, this simulation in its current form is incredibly simple. There is only one species within a closed and controlled environment. Many more features could be added to the environment and their impacts could be studied. For example, sexual reproduction, smarter pathing for creatures toward prey and away from predators, or different types of creatures within the same environment could be implemented to create a more complex simulation where simple changes in the environment such as food quantity or population size could have much larger impacts on the outcome of the population in question. In addition, adding more factors will make the simulation more represenatitve of the real world and make the results from the simulation will be more impactful and meaninful within a real world context.

10 Conclusion

Natural selection is a powerful part of the theory of evolution. It describes accurately how creatures interact with their environment which includes other creatures around them. It shows how a population can change over time to become more fit within the constraints the environment gives. Using computer simulation, this phenomenon can be viewed and understood as it happens in real time. In addition, many different impacting factors can be changed and their effects can be seen and understood. It is clear to see how certain changes in the environment can impact a population of creatures striving to compete for limited resources.

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