Simulating the Natural Selection of Speed in a Population of Animals

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Abstract

Natural selection is the differential survival and reproduction of individuals due to differences in observable characteristics or traits. In this project, the evolution of the trait 'speed' through natural selection in a population of animals living in a simple environment with finite food resources is studied. A simple NetLogo [7] model was used to simulate such a population and study the emergent properties of the system. Specifically, the emergent value of the average speed of the population was estimated and possible factors that could influence it were investigated. BehaviourSpace experiments were performed on NetLogo to determine factors that could influence the emergent value of the average speed of the population.

1 Introduction

Natural selection is the differential survival and reproduction of individuals due to differences in observable characteristics or traits. Charles Darwin terms it as the 'principle by which each slight variation (of a trait), if useful, is preserved' [1]. The concept behind the theory of natural selection is that individuals best adapted to their environments are more likely to survive and reproduce. As long as there are heritable variations, there will be a selection of the most advantageous variations. Since individuals with advantageous variations are more likely to survive longer and reproduce, their variations are more successful in being passed on to future generations, leading to a progressive evolution of the population of a species [1, 3].

The variation in observable characteristics or traits (also known as phenotypes) is based on genetic variation. There are multiple sources of genetic variation, including mutations, genetic recombination and genetic drift [5]. However, mutations are the primary sources of genetic variation and we will be considering only mutations as sources of variation in this study [4]. Mutations are alterations in the nucleotide sequence of the genome of an organism [6]. The most common causes of mutations are errors in DNA replication during reproduction. Mutations may or may not lead to detectable changes in the observable traits (phenotype) of an organism.

The aim of this project is to study the evolution of the trait 'speed' through natural selection in a population of animals living in a simple environment with finite food resources. Studying the emergence of a value for the average speed of the population and investigating factors that could influence it are also important goals of this project.

The rest of this report is structured as follows. Section 2 describes the methodology of the research and of the analysis of simulations. Section 3 presents the results that were obtained with the simulations and their analysis. In Section 4, a discussion of the results is presented and Section 5 concludes the report.

2 Methods

A NetLogo model was used to simulate a population of animals living in a simple environment with finite food resources, and to study the emergent properties of the system when random mutations were introduced that altered the observable trait 'speed'.

2.1 Model Description

2.1.1 Agents

There are two types of agents in this model - animals and food. Both of them are turtle breeds. Food cannot move in the environment and spawns at random locations at the start of each generation. The number of food that spawns at the start of a generation is given by the global variable `food-count`. Animals can move around in the environment and eat food. They spawn at random locations at the start of a generation. However, the number of animals that spawn at the start of a generation is not fixed. At the end of each generation, an animal can die, survive or survive and reproduce depending on the number of food it collected in that generation. The number of animals that spawn in the first generation is given by the global variable `animal-count`. Food have the following variables: `xcor`(x coordinate, set randomly), `ycor`(y coordinate, set randomly), `size`(set as default value 1), `shape`(set as dot), `color`(set as cyan). Animals have the following variables: `xcor`(x coordinate, set randomly), `ycor`(y coordinate, set randomly),`size`(set as default value 1), `shape`(set as default), `color`(set as green), `energy` (keeps track of the energy of an animal, initialized using the global variable `max-energy` at the start of a generation), `speed`(distance that the animal can move in a time step, initialized to equal the global variable initial-speed when the model starts running), `cost`(amount of energy used in a time step for moving, set to be equal to $\texttt{speed}^2$), `collected-food`(keeps track of the number of food collected by the animal in the current generation).

2.1.2 Environment

The environment consists of all patches. The patches make up a square grid world of 33 x 33 patches that wraps around both horizontally and vertically.

2.1.3 Global Variables, Monitors, Plots

The global variable `max-energy` denotes the maximum energy an animal can have. The `energy` of each surviving/created animal is set to `max-energy` at the start of each generation. `food-count` is the number of food that spawns at the start of each generation, while `animal-count` is the number of animals that spawns at the start of the first generation. `initial-speed` is the value of speed that all the animals have at the start of the simulation. `mutations?` is a Boolean variable that denotes whether mutations are turned on or off. Monitors are present for average `speed` of the animals and the population size(count) of the animals. Plots are present for average `speed` of the animals vs time, the population size(count) of the animals vs time and the speed distribution of the population.

2.1.4 Flow of Events

Every 240 time steps is called a generation. At the start of each generation, food and animals spawn at random locations. During a generation, animals move around in the environment. In each time step, an animal moves a distance equal to its `speed` variable and its energy decreases by an amount equal to its `cost` variable. If it finds a food within a radius of 1 unit, it eats the food. When a food is eaten by an animal, it dies and the `collected-food` variable of the animal increases by 1. At the end of a generation, an animal dies if its `collected-food` variable is 0 and survives if its `collected-food` variable is greater than 0. An animal that survives creates (`collected-food - 1`) new animals by reproducing. When an animal reproduces, the new animal has a 50% chance of having a mutation if `mutations?` are turned on(0% chance if `mutations?` are turned off). A mutation may cause its `speed` to increase or decrease by a number less than 0.1. The color of the new animal is set to red, yellow or green depending on whether its speed is greater, lower or equal to `initial-speed`. The `cost` also increases or decreases according to the relation between `cost` and `speed`. The `energy` and `collected-food` of the surviving animal is reset to `max-energy` and 0 respectively. The remaining food is cleared and the next generation begins.

2.1.5 Trade-off between Speed and Cost

The relation between `cost` and `speed` is considered to be $\texttt{cost} = \texttt{speed}^2$. This choice is based on the fact that kinetic energy is given by the equation $\frac{1}{2}mv^2$, where m and v are mass and velocity respectively.

Since `cost` is the amount of `energy` that is used per time step, it is dimensionally the same as `energy` and hence it can be assumed to depend on the square of the `speed`. This relation ensures that there is a trade-off between `cost` and `speed`. Animals that have higher a `speed` have to pay a higher `cost` to move at that `speed`. Therefore, being faster need not be a good thing since it also means that you use up your `energy` faster and might not find any food before that.

2.2 BehaviourSpace Experiments

The following experiments were performed using the BehaviourSpace tool in NetLogo.

2.2.1 Effect of Initial Speed on Emergent Speed

In this experiment, `max-energy`, `food-count`, `animal-count` and `mutations?` were fixed to be 120, 80, 80 and true respectively and `initial-speed` was varied from 0.6 to 5 in steps of 0.1. Each run had 250000 steps and the average value of `speed` at the end of each run was recorded.

2.2.2 Effect of Food Count on Emergent Speed

In this experiment, `max-energy`, `initial-speed`, `animal-count` and `mutations?` were fixed to be 120, 1, 80 and true respectively and `food-count` was varied from 30 to 100 in steps of 2. Each run had 250000 steps and the average value of `speed` at the end of each run was recorded.

2.2.3 Effect of Maximum Energy on Emergent Speed

In this experiment, `initial-speed`, `food-count`, `animal-count` and `mutations?` were fixed to be 1, 80, 80 and true respectively and `max-energy` was varied from 50 to 300 in steps of 5. Each run had 250000 steps and the average value of `speed` at the end of each run was recorded.

2.2.4 Effect of Mutations on Population Size

This experiment consisted of two BehaviourSpace Experiments. In the first one, `max-energy`, `initial-speed`, `animal-count` and `mutations?` were fixed to be 120, 1, 80 and true respectively and `food-count` was varied from 30 to 100 in steps of 2. Each run had 250000 steps and the population(count of animals) at the end of each run was recorded. In the second one, `max-energy`, `initial-speed`, `animal-count` and `mutations?` were fixed to be 120, 1, 80 and false respectively and `food-count` was varied from 30 to 100 in steps of 2. Each run had 250000 steps and the population(count of animals) at the end of each run was recorded.

3 Results

Figure 1 shows the results of the experiment studying the effect of `initial-speed` on the emergent value of average `speed`. We observe that `initial-speed` has no effect on the emergent value of average `speed` since it stays roughly constant. Figure 2 shows the results of the experiment studying the effect of `food-count` on the emergent value of average `speed`. We observe that as `food-count` increases, the emergent value of average `speed` also increases, but slowly(slope is very close to zero). Figure 3 shows the results of the experiment studying the effect of `max-energy` on the emergent value of average `speed`. We observe that as `max-energy` increases, the emergent value of average `speed` also increases and that it is a stronger factor than `food-count` since the slope is greater. Figure 4 shows the results of the experiment studying the effect of mutations on the population size. We observe that the population when `mutations?` is on is always lesser than the population when `mutations?` is off. We can also observe that the fluctuations in population size are higher when `mutations?` is on.

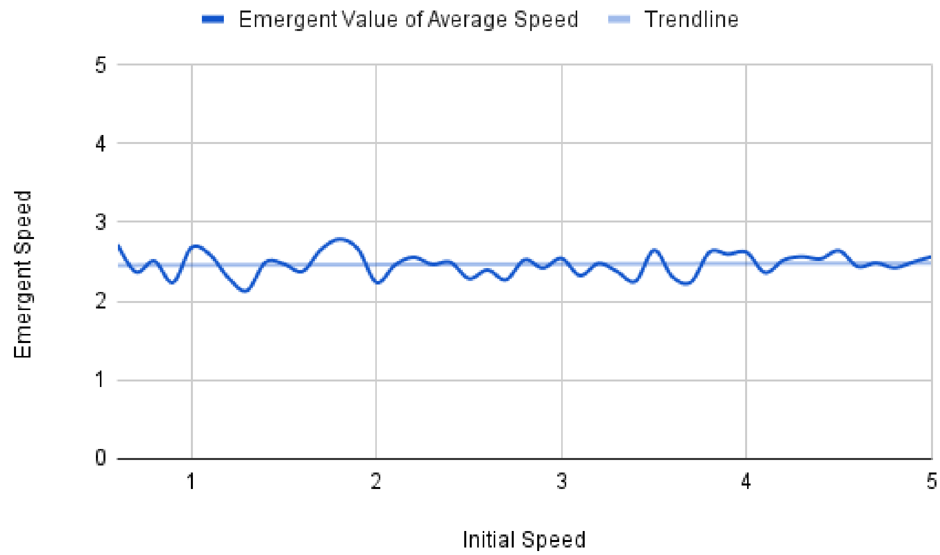

Figure 1: Effect of Initial Speed on Emergent Speed

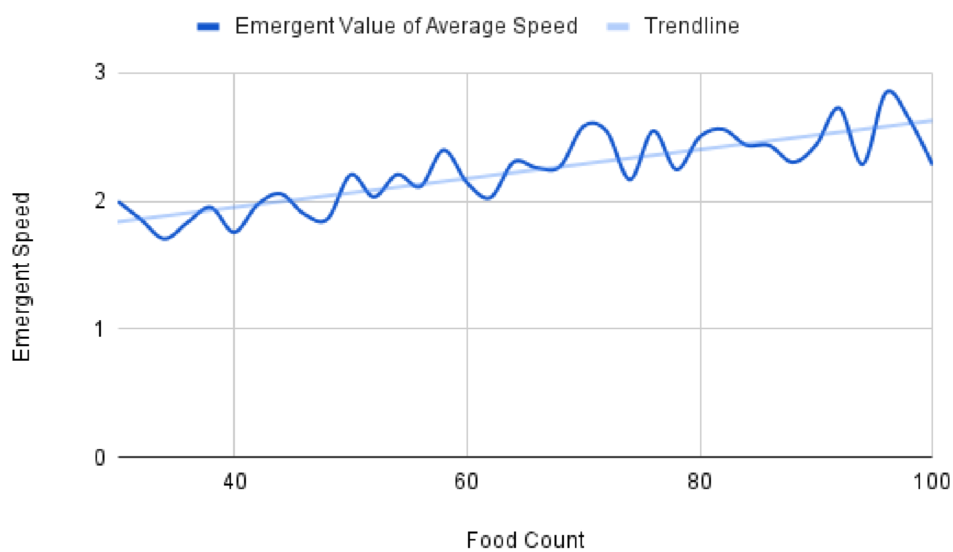

Figure 2: Effect of Food Count on Emergent Speed

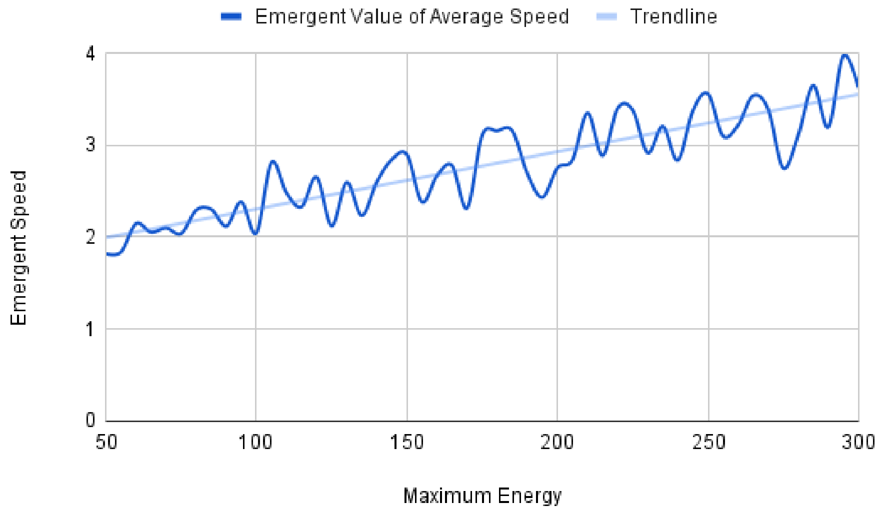

Figure 3: Effect of Maximum Energy on Emergent Speed

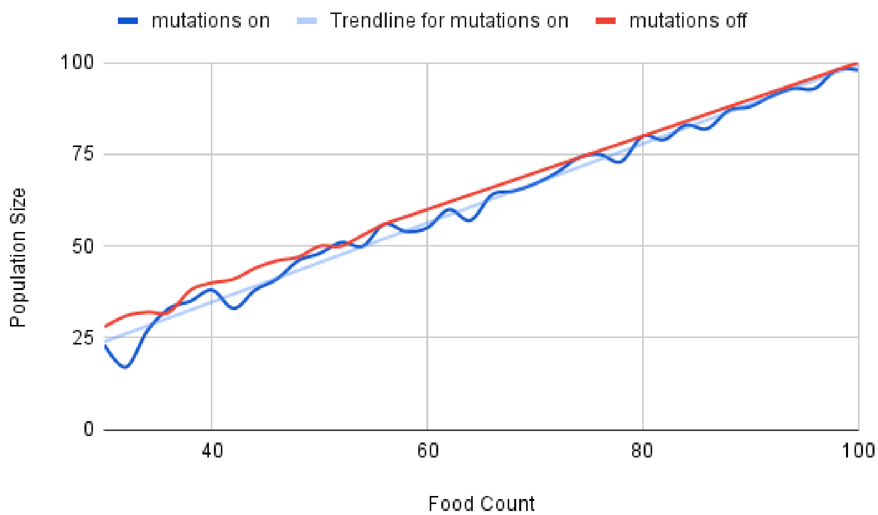

Figure 4: Effect of Mutations on Population Size

4 Discussion

It is extremely hard to theoretically estimate the outcome of natural selection. To the best of my knowledge, there has been no work that theoretically estimates the emergent value of average `speed` for such a simple model of natural selection. `initial-speed` has no effect on the emergent value of average `speed`, while as `food-count` or `max-energy` increases, the emergent value of average `speed` also increases. The dependence on `max-energy` can be reasoned as follows: if animals start with more `energy`, they can afford a higher `cost`, and can hence can have higher `speeds`, while they cannot if they start with less `energy`. The dependence on `food-count` is harder to explain. One could reason it to be because higher `speed` only becomes viable when there are a large number of food available so that the animal doesn't use up its `energy` before finding food. Even though we do not know what value of average `speed` would emerge, the agents themselves interact with each other and attain this `speed`. The fact that the population when `mutations?` is on is lesser than the population when `mutations?` is off shows that natural selection may not always act for the good of a species. A trait that is advantageous to an individual (e.g., being fast) could become more and more frequent and end up driving the population to extinction [2] (or in our case a smaller population size).

5 Conclusion

The evolution of the trait 'speed' through natural selection was studied in a population of animals living in a simple environment with finite food resources. The emergence of a value for the average speed of the population was studied and `max-energy` and `food-count` were found to be factors that influence it. The fact that natural selection may not always act for the good of a species was verified by comparing the population sizes with and without mutations.

This was a simple model based on very few factors. Future improvements can include adding more factors that make the model more reliable. For example, the cost of movement is known to also depend on the turns(change of direction) an animal makes [8] and not just on the distance moved. In this model turns are considered to be free of energy costs. Future extensions of the model may include introducing mutations based on size, ability to sense food etc. Size can lead to more complex interactions between animals since we could allow bigger animals to eat smaller animals if the size difference between them is significant. This opens up a new food source for animals and leads to direct interaction between animals instead of the indirect interactions in this model(which are based on competition for food). We could balance this by making bigger animals move slower and use up energy faster(higher cost). Thus, there are several exciting ideas to explore further based on this model.

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