SIMULATING AN ECOSYSTEM AND ITS BENEFITS

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Abstract: *The process of evolution leads to increases in complexity when complexity is beneficial to survival and reproduction. Many factors affect on the survival of species. Real study of factors' influence is particularly difficult due to the complex interaction between them. Ecosystem models aim to characterize the major dynamics of ecosystems, in order to synthesize the understanding of such systems, and to allow predictions of their behavior and testing hypothesis. An individual-based model (IBM) can assist in the analysis of effective factors. In this study, using an original IBM created in python, I have examined the impact of some factors like speed and size on the prediction of extinction and the importance of biodiversity. By applying some genetic algorithms for reproduction, I have shown that balance is the key for survival. Also, by emphasizing the ecological importance of diversity, I highlighted that both the prey and the predator are an important part of a healthy ecosystem.*

Classification: *AMS Mathematical Subject Classification - 68W50 - Evolutionary algorithms, genetic algorithms (computational aspects).*
ACM Computing Reviews Categories and Subject Descriptors - I.2.m - Computing Methodologies, ARTIFICIAL INTELLIGENCE, Miscellaneous

1 INTRODUCTION

Ecological modeling is a still growing field, at the crossroad between theoretical ecology, mathematics and computer science. One of the main interests of an ecosystem simulation is that it offers a global view of the evolution of the system, which is difficult to observe in nature.

Students, researchers or any passionate individual can use an ecosystem simulator to test their hypotheses about producer/consumer and predator/prey relationships. By understanding how different species and their habitats interact, conservationists can develop strategies for protecting and preserving biodiversity. Simulating an ecosystem can also be useful for practical purposes, such as predicting the impacts of extinction. The simulation includes vegetations, predators and preys interacting together in one ecosystem. The user can change any one of the individual components and watch the effect that the change has on the total ecosystem. Data is generated by the computer simulation in the form of a graph that shows population change over time.

Even though this simulation is proven to be helpful in the field of biology, few attempts have been made to simulate a complete and complex ecosystem. "An example of such a system is the platform Echo, which includes an evolutionary mechanism. However, the organisms in Echo are very simple, and are not provided with any behavior model. Another system studying long term evolution is the Avida. It nevertheless has some limitations such as: the individuals do not move and are quite limited in number, there is no explicit representation of species. Other models, such as PolyWorld, Bubbleworld.Evo or Framsticks, have been proposed including more complex agents and behavioral models. However, these approaches are highly computationally expensive and only allow the implementation of a small population (few hundred) of agents" (EcoSim). EcoSim is the current best choice for simulation, but it doesn't provide any 2D or 3D visualization.

In this research paper I formulated 2 hypotheses to test my simulation. The first one I already know the answer to is about how the extinction of a species or a natural disruption can throw off or even destroy the ecological balance of the entire ecosystem, and the second one who doesn't have an answer yet is about which has the better chance of survival through generations: the smallest and fastest or the biggest and slowest.

2 ORIGINAL APPROACH

The proposed approach is a simple virtual environment consisted of a 1200 x 600 2D screen, "bloops" as the creatures that are the representation of a living form and rectangles as food sources for the bloops. Compared to other works, my simulation targets a more simplified 2D view of the problem using Genetic Algorithms instead of machine learning techniques.

A. Correlation to the two hypotheses

I established that the first hypothesis is the answer to the question "Which has the better chance of survival through generations: the smallest and fastest or the biggest and slowest?", which I am responding with none, since I think the medium bloops will last. For this case, I am describing the virtual environment and the agents as it follows:

The *Bloops* – Have the form of a circle. The creatures' movements are generated using Perlin Noise and a speed from the interval [-x, x] where x is the maximum speed set by the user. The size is inversely proportional to the speed: the bigger the bloop, the slower it is. When a bloop eats a rectangle, it reduces its hunger and improves its fitness by 1. They have a starting health which is declining as time passes, and it can improve by eating. For the visual effect, the less health a bloop has, the whiter it turns until it disappears completely. If a bloop ate once, it survives the next generation. If a bloop ate at least 2 units of food, then it is capable of reproducing. If a bloop didn't eat at all, it dies.

The *Food* – Has the form of a rectangle. It gives health and fitness to the bloop. Every iteration, the food quantity is halved.

I established that the second hypothesis is: "the extinction of a species or a natural disruption can throw off or even destroy the ecological balance of the entire ecosystem", and for this I am testing what happens if I suddenly eliminate the predators. For this case, I am describing the virtual environment and the agents as it follows:

The *Bloops* – The new addition to them is the fact that they are now split in two categories: the predator (a red circle) and the prey (a yellow circle). The predator will suddenly go extinct at X iteration, where X is a number that is given by me.

The *Food* – Represents the vegetation and has the form of a rectangle. It gives health to the prey. This time, the food is not reduced. At every iteration, new units of food appear.

B. Genetic algorithms

Genetic algorithms apply a generalized evolutionary loop to optimize the fitness of an organism (Ashlock, 1998). In a genetic algorithm, every solution in a population is represented as a gene or data structure. This gene carries all of the relevant information that can be altered by the algorithms. The initial population of solutions may be random or pre-initialized with possible very "fit" solutions. The fitness evaluation is done according to a given fitness function which maps data structures onto some ordered set.

The process of natural selection starts with the selection of fittest individuals from a population. They produce offspring which inherit the characteristics of the parents and will be added to the next generation. If parents have better fitness, their offspring will be better than parents and have a better chance at surviving. This process keeps on iterating and at the end, a generation with the fittest individuals will be found.

This notion can be applied for a search problem. We consider a set of solutions for a problem and select the set of best ones out of them.

Five phases are considered in a genetic algorithm.

1. Initial population
2. Fitness function
3. Selection
4. Crossover
5. Mutation

C. Fitness Function

Fitness Function (also known as the Evaluation Function) evaluates how close a given solution is to the optimum solution of the desired problem. It determines how fit a solution is. Some individuals will compete and those with good fitness will reproduce. What we mean by having good fitness is having the objective function optimized:

$$f(x) = x, \text{ where } x \text{ is how much food units the Bloop ate}$$

We create the equivalent maximization problem as max(f(x)). Even though in genetic algorithms, each solution is generally represented as a string of binary numbers, known as a chromosome, for this experiment for the fitness score the chromosome will be an integer number representing the number of food units eaten.

D. Selection

The idea of selection phase is to select the fittest individuals and let them pass their genes to the next generation. Two pairs of individuals (parents) are selected based on their fitness scores. Individuals with high fitness have more chance to be selected for reproduction.

For this experiment, the Tournament Selection is used. Selection is done by taking a sample from the population in the t-th generation for t = 1, 2, …, then from that sample, one individual with the best fitness is selected to continue to enter the population in the (t+1)-st generation. Individuals in the t-th generation who are not selected will die off. This process is carried out multiple times so that the number of individuals in the population in each generation is the same.

E. Crossover

In genetic algorithms and evolutionary computation, crossover, also called recombination, is a genetic operator used to combine the genetic information of two parents to generate new offspring.

For this experiment, the Blend Crossover Operator is used. (the variant with $\alpha = 0$). Assuming p1 < p2, this crossover operator creates a random solution in the range [p1, p2].

p1 - first parent

p2 - second parent

u - random number in [0, 1]

offspring = (1 - u) * p1 + u * p2

The blend crossover operator has the interesting property that if the difference between parents is small, the difference between the child and parent solutions is also small. So the spread of current population dictates the spread of solutions in the resulting population (this is a form of adaptation).

F. Mutation

In certain new offspring formed, some of their genes can be subjected to a mutation with a low random probability. Mutation is a genetic operator used to maintain genetic diversity from one generation of a population of genetic algorithm chromosomes to the next.

In this case, the uniform mutation is adding or subtracting from the size the value 0.02 and the probability for an individual to mutate is 10%.

3 EXPERIMETAL VALIDATION

For the speed versus size experiment, I will provide a step-by-step approach, and for the elimination of a predator approach, I will compare the results of my program with a real event.

A. Eliminating a predator

Ecosystems are carefully balanced, with a hierarchy of prey and predators that keep populations in check. As species go extinct, they are taken out of the food chain. Animals that ate the newly-extinct species have to find new food sources or starve. This can damage the populations of other plants or animals. Furthermore, if a predator goes extinct, its prey's population can proliferate, unbalancing local ecosystems.

First, I simulated a balanced ecosystem where the preys and predators lived and their number was stable. Then, I eliminated all the predators at an iteration number of my choice, the consequences being that the number of prey animals did not remain stable. Instead of remaining the approximate same number, they started to reproduce more and more since there wasn't a predator to kill some of them. The vegetation decreased until it was non-existent. For my hypothesis, I was expecting an increasing number of prey animals and the decrease of food units, and after some iterations I expected this number to stabilize meaning that the prey would drastically decrease because of lack of food and the food increasing a little because a lot of prey animals died of hunger, stabilizing in the end. What I didn't expect was the disappearance of the vegetation completely, leading to the death of the remaining animals.

If a species has a unique function in its ecosystem, its loss can prompt cascading effects through the food chain (a "trophic cascade"), impacting other species and the ecosystem itself.

An often-cited example is the impact of the wolves in Yellowstone Park, which were hunted to near extinction by 1930. Without them, the elk and deer they had preyed upon thrived, and their grazing decimated streamside willows and aspens, which had provided habitat for songbirds. This left the stream banks susceptible to erosion, and a decline in songbirds allowed mosquitoes and other insects the birds would have eaten to multiply. When the wolves were reintroduced to the park in 1995, they once again preyed on the elk; plant life returned to the stream banks and along with it, birds, beavers, fish and other animals.

B. Speed versus size

I selected a population of 20 bloops and 100 food units. Every iteration lasts 7 seconds, and the number of iterations is 3-5 depending on how much the bloops survive, the maximum number of iterations being 5. The probability for selection, crossover and mutation are 10%, 20% and 100%. Every 40 milliseconds, the bloop is losing health and its maximum health is 255. In the first iteration, the bloops are placed randomly, and after that at each iteration the population starts competing for food from the right bottom corner. The food quantity is halved each iteration.

The question that I am trying to answer is: "Which has the better chance of survival through generations? The *smallest and fastest* or the *biggest and slowest*"? Both have their advantages and disadvantages which will be discussed below.

A. First try

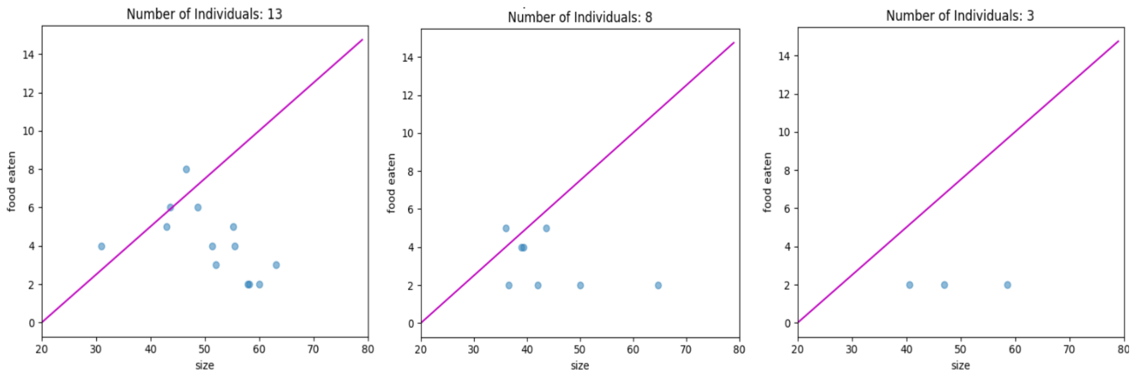
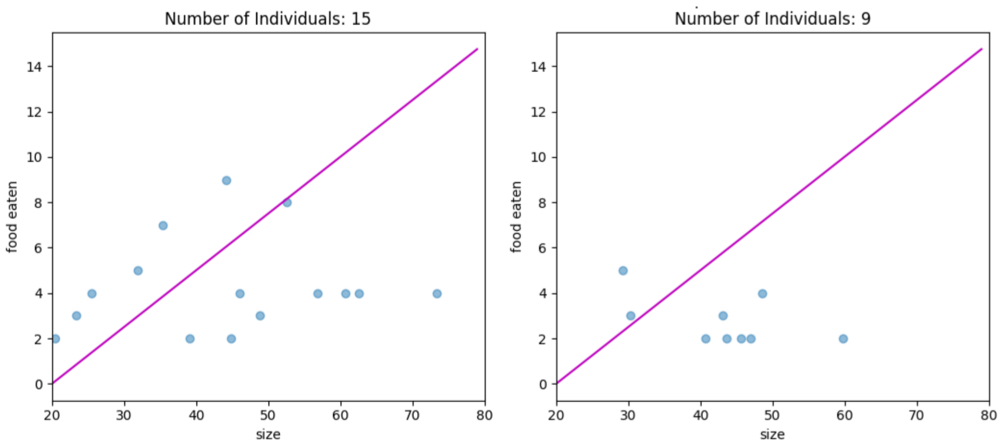


Figure 1. First trial results

The graphics generated by the plotlib package show statistics for bloops that reproduce at the end of an iteration. The size of the surviving interval on the initial iteration is [30,70], indicating that neither the smallest nor the largest bloops were able to persist or procreate in the initial generation. Even though the smallest bloop is the fastest among them all, due to its size, the bloop was passing by nearly every food unit, as it can also be seen from the 2D simulation, despite the fact that its speed helped it to be the first one to have a chance to take the food. The bigger bloops, on the other hand, have a better chance of grabbing the food nearby, but because they move too slowly, other bloops reached the food before them.

The bloops that ate the most are in the interval [40, 50] and the bloops that had a greater chance of survival had the size in the interval [40, 60], which is precisely the middle of our original interval: [20, 80]. This shows that, for the first try, balance is the answer to survival, since both speed and size is important.

B. Second try



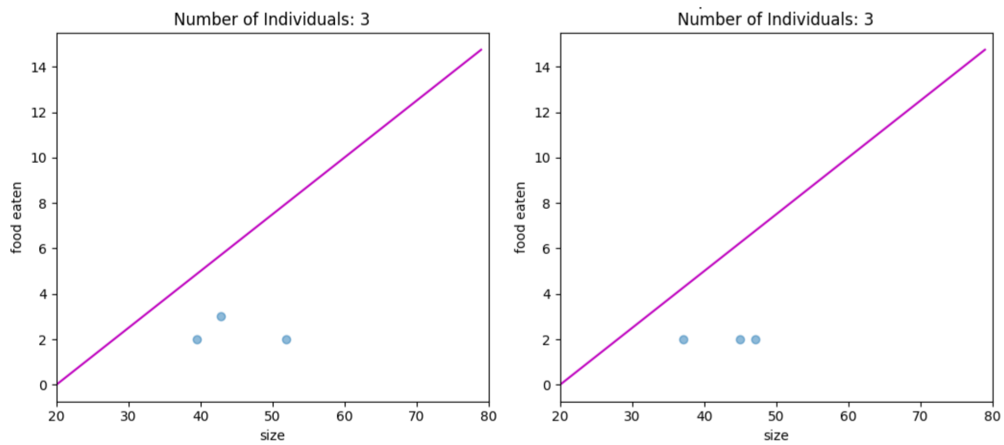


Figure 2. Second trial results

From the second try we can conclude that the smallest to medium bloops survived, the range being [35, 50]. From other trials, the natural selection favored either the medium bloops or the small-to-medium bloops. Also, the number of food units eaten were almost equal in every trial for each size, the bloops being scattered the same and as proof you can compare the images from Figure 2 and Figure 3. This concludes that our hypothesis and validations are correct: you need to have a balance of both speed and size to survive the natural selection.

The first similar research found was written by Sterling's Team Speed which is a leader in sports performance training, who compared speed and size in the athletic domain, and concluded that "athletes need both strength and speed to be competitive in their given sport".

The article "Only small animals might stand a chance in a manmade world" by Daniel T Cross highlighted the idea that small creatures will be favored by natural selection. The difference between this research and his is that Daniel T cross included humans as a factor. A lot of other articles found on the internet talked about the intervention of humans and other external factors, while the presented research case strictly focuses on creatures' growth in their environment over time, without any interventions.

A very similar experiment and research is done by a youtuber which goes by the name "Prism" in his "Simulating Natural Selection" video, where he sees how his "blobs" evolve over time. His experiment has a different disadvantage for the bigger creatures: the bigger creatures consume twice as much energy (so they die faster), while the bigger bloops move slower. His conclusion is the same as mine, which is that creatures of the sizes medium-to-small survive on the long term.

Personally, I expected the conclusion to be on the side of the medium ones, so the fact that the smaller-to-medium ones also survived was an unexpected yet pleasant surprise.

4 RESULTS AND CONCLUSION

Simulating an ecosystem is interesting from a biological and technical point of view. From a biological point of view, simulating an accurate ecosystem could potentially be used to model how species might develop in the future. It could also predict how changes in the environment could affect different species.

In this study, we used a python simulation, an IBM with the purpose to create a visual simulation of natural processes within a small ecosystem, such as evolution and natural selection. Based on this model we set up two hypotheses followed by experiments to compare the results to real-life events. Results confirmed the hypotheses hence the accuracy of the simulation is good, given its simplicity compared to other existent simulations.

From the results we can conclude that the simulation showed how important biodiversity is, since for both hypotheses it could be observed its benefits. First of all, it gives an ecological stability by helping to maintain the balance of ecosystems, ensuring that they can continue to function properly. This is because different species and ecosystems play different roles in the environment, and the loss of one species (like a predator) can have knock-on effects on other species and the ecosystem as a whole. Also, it helps to maintain the genetic diversity of species, which is important for the long-term survival and evolution of those species. This could be seen in selecting what is more important: the size or the speed.

For the next step, I want to focus on the development of the code, since the more features the simulation has, the more hypotheses can be proven and more behaviors can be observed. I would like to move the simulation in a 3D environment and add more factors like different types of animals, water, more methods of GA to choose from, the human factor, and so on.

5. BIBLIOGRAPHY

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5. GitHub

Here is the link of the history of commits:

https://github.com/AliceHincu/Simulation-of-Ecosystem/commits/main

Here is the link of the project:

https://github.com/AliceHincu/Simulation-of-Ecosystem

This is the code for this research