Nature Inspired Computing: Artificial Life

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Background

Artificial Life (A-Life)
A-Life is the act of using computers to simulate natural life. Known as the "bottom-up scientific study of the fundamental principles of life," computer scientists are able to build ecosystems from scratch and observe certain processes that come to occur. In many ways, A-life is attempting to answer the question "what is life?".

The complexities that have led to the evolution of organisms and biological processes today have made it difficult to extract data that pinpoints a particular process or organism without bias. As a result, it is nearly impossible to determine what processes originated as a necessity or an accident. One cannot simply turn back the evolutionary clock, or extract data from an independent ecosystem to compare. One way to combat this problem is through A-life, which looks to simulate natural processes within computers. Using A-life, one can attempt to build an ecosystem from the ground up on a computer, watching each process as they evolve and identifying essential characteristics of each organism.

A-Life is a broad field, encompassing evolutionary computing, neural networks and more. In this project, I am using artificial life to simulate a simple food chain — foxes eat rabbits eat grass — and look at what happens when certain conditions are altered. In addition, through generalizing this model, I was able to look at different food chains and get an idea of the origination of certain hunting and migration patterns in nature.

Technology
This project was done primarily in Python, specifically using the **matplotlib** and **seaborn** library to create an animation the migration of specific organisms over time. All of the data was stored in **numpy** arrays.

Methods

An object oriented design was used to describe an ecosystem. Each organism had a location (x and y) and a field tracking if they've eaten enough to survive and reproduce. These organisms can be put onto a field and are allowed to undergo certain actions every generation:

eat their prey, move and reproduce. At the end of each generation, the autotroph (if included) regenerates at a given rate and organisms are killed off if they have not eaten (death by starvation). The addition of specific organisms in certain ecosystems have been simulated: (a) just rabbits, (b) learning rabbits, (c) temperature gradient, (d) rabbits and foxes, (e) general model.

A. Just Rabbits

This is the simplest of the models. Each rabbit moves randomly (regardless of is there is grass growing in the next spot) and the grass grows back at a consistent rate.

B. Learning Rabbits

While this model is similar to the just rabbits (A) model, it allows the rabbit to move towards grass instead of a random direction.

C. Temperature Gradient

This model is similar to the Learning Rabbits model, but a temperature gradient is applied so that the grass rate is not uniform throughout the field. This is done to observe potential migration patterns.

D. Rabbits and Foxes

This model introduces a carnivore: foxes. This would alter the food chain to become fox as top of the food chain, followed by rabbits and then grass. Foxes and rabbits moved randomly. If a fox and a rabbit were on the same square, the fox ate the rabbit. In terms of visualization and animation, the organisms were shown based on their place on the food chain. For instance, if a fox were in the same spot as grass, the fox would be shown over the grass.

E. General Model

After creating a model with a carnivore, herbivore and autotroph, the idea of generalizing a model came to be. This model has two classes: an **organism class** and an **ecosystem class**. Every ecosystem automatically has some food source (usually grass or some autotroph) and then the user may add organisms to the model. Instead of only giving an organism a location, it is also given a name (what species it is), prey (a string of the name of its prey) and survival rate (how long an organism can go without eating until it dies of starvation). Organisms more randomly throughout the ecosystem and in each iteration, if an organism lands on the same tile as their prey, it kills and eats its prey. In the ecosystem class, organisms are tracked in a dictionary, so that as new species of organisms

F. Rabbits and Sexual Reproduction

This model is in progress. Each rabbit placed in the field is given a random position and genes (speed, mutation rate and color). In each generation, if two rabbits land on the same square, they reproduce a rabbit in the same location with a mix of the two rabbits traits (or a completely different trait if a mutation occurs).

1 Results

In addition to the animation, summary graphs were produced. A simple line graph comparing the proportion of rabbits to grass, a contour plot comparing number of rabbits to grass and a multiple line graph comparing proportions of rabbits to foxes to grass were created.

Just Rabbits

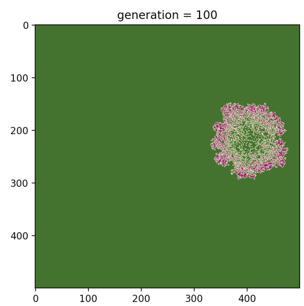

Figure 1: Just rabbits model animation after 100 generations.

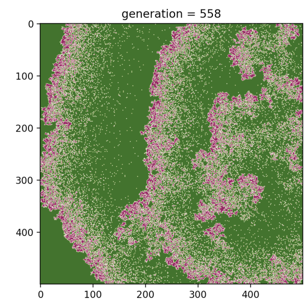

Figure 2: Just rabbits model animation after 558 generations.

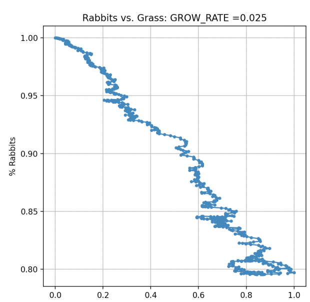

Figure 3: Proportional line graph comparing rabbits and grass.

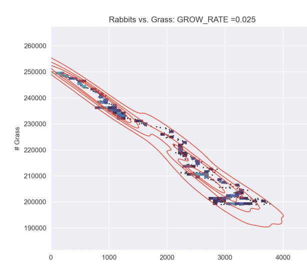

Figure 4: Contour plot comparing rabbits and grass.

The Just Rabbits model showed regular and expected rabbit movement as shown in Figure 1 and 2, where the green represents grass, white represents the absence of grass and red represents rabbits. Starting with a singular rabbit, it eats grass and reproduces. Initial movement after reproduction is shown to spread outward (Figure 1). This is logical as there is more available food if going outwards. It is important to keep in mind that rabbits move randomly, not in the direction of grass. Hence, the overall movement of rabbits outwards is because the rabbits that move randomly inwards are unable to eat grass so they die of starvation.

An indirect relationship is shown in both Figure 3 and 4 where the proportion of rabbits increase, the proportion of grass decreases. This makes sense as when there are more rabbits, there is an increased likelihood that more grass will be eaten. At the bottom of the graph in Figure 3, you can see a small circle. This circle occurred when the rabbits initial movement (outwards) was interrupted by the bounds of the field. After the rabbits reach the outer bounds, they are forced to move back in while the grass on the edges grow back. Through this process, some rabbits die off and a dynamic equilibrium is reached.

Learning Rabbits

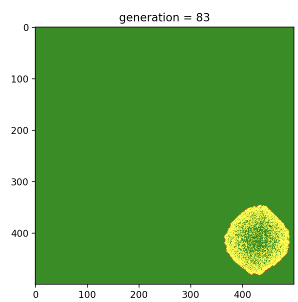

Figure 5: Learning rabbits model animation after 83 generations.

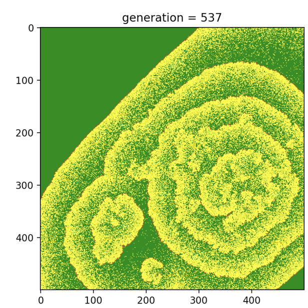

Figure 6: Learning rabbits model animation after 537 generations.

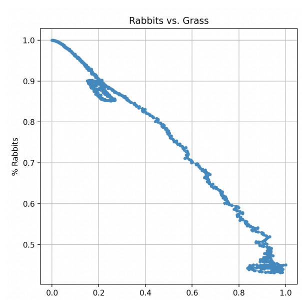

Figure 7: Proportional line graph comparing rabbits and grass.

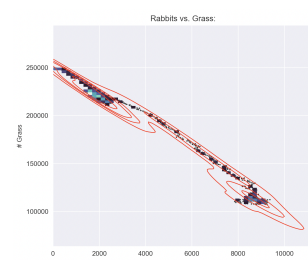

Figure 8: Contour plot comparing rabbits and grass.

The Learning Rabbits model implemented a custom color scheme with rabbits in red, grass in green and the absence of grass in yellow. Rabbits are directed to move towards grass if possible. Similar to the Just Rabbits model, the rabbits ate grass, reproduced and initially spread outward (Figure 5). Even before the rabbits made it to the edge of the field, new pockets of rabbits were generated as the grass grew back (Figure 6).

An indirect relationship can be shown between grass and rabbits. A small circle at the bottom of the line graph can be seen (Figure 7) and on the contour plot it is more dense towards the very top and bottom (Figure 8). The dense top of Figure 8 is due to the rapid increase in rabbits and the dense bottom of Figure 8 is due to the rabbits hitting the edge of the field.

Temperature Gradient

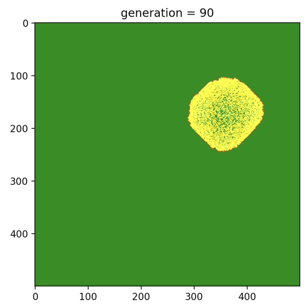

Figure 9: Temperature Gradient model animation after 90 generations.

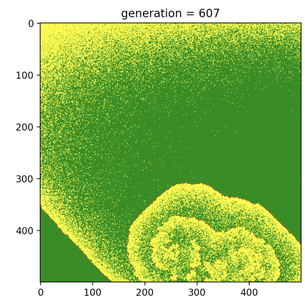

Figure 10: Temperature Gradient model animation after 607 generations.

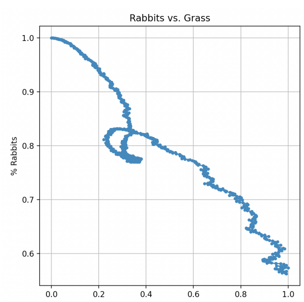

Figure 11: Proportional line graph comparing rabbits and grass.

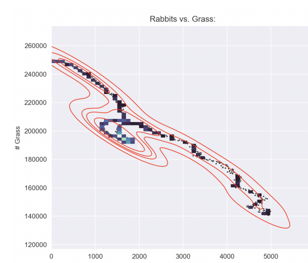

Figure 12: Contour plot comparing rabbits and grass.

This model had the same color scheme as the Learning Rabbits model. The initial movement of the rabbits were similar to the Learning Rabbits model (Figure 9). This makes sense because at first, the field is full of grass, so nothing impeded rabbit movement. When the first group of rabbits makes it to the top of the field, the growth rate of the grass affects the survival rate of the rabbits. The gradient in the field resulted in the top of the field having a slower growth rate than the bottom of the field. As a result, it is seen that more rabbit colonies are formed at the bottom of the field as the top of the field does not have as much grass.

The circle in the line graph (Figure 11) is shown higher than in previous models, indicating that equilibrium takes place when there is a higher ratio of grass to rabbits. This can also be reflected in the contour plot.

Rabbits and Foxes

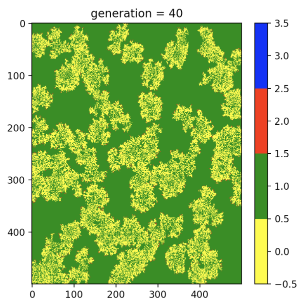

Figure 13: Rabbits and foxes model animation after 40 generations.

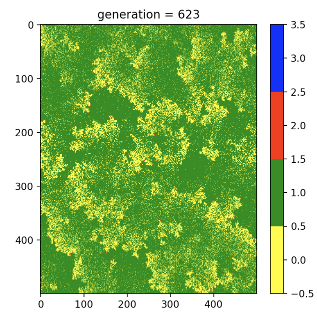

Figure 14: Rabbits and foxes model animation after 623 generations.

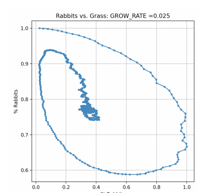

Figure 15: Proportional line graph comparing rabbits and grass.

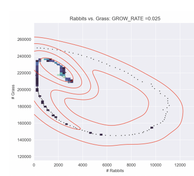

Figure 16: Contour plot comparing rabbits and grass.

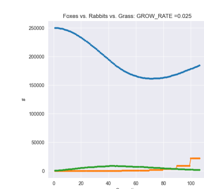

Figure 17: Contour plot comparing rabbits and grass.

This model had a similar color scheme as the Learning Rabbits model, but with the added color of blue for foxes. Multiple rabbits and foxes are spawned in the beginning, so there is not a regular outward spread since different rabbit pockets run into each other and are eaten by foxes.

There is not a clear relationship between rabbits and grass, but there is still a small circle in the middle of Figure 15, where the rabbits reach an equilibrium. The equilibrium can also be seen in the dense part of the contour plot in Figure 16. Figure 17 shows the grass in blue, rabbits in green and foxes in orange. In this visual, we see that as the amount of rabbits increase, grass decreases but foxes increase. Alternatively, when the amount of rabbits decrease, the grass has time to grow back and increase, but the foxes don't have as large of a food source so they also decrease.

General Model

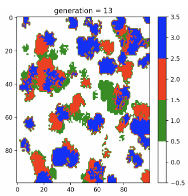

Figure 18: Three way circular relationship at generation 13.

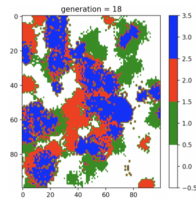

Figure 19: Three way circular relationship at generation 18.

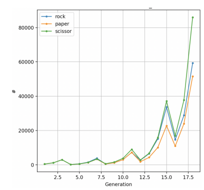

Figure 20: Line graph of three way circular relationship.

The General Model was used to test different food chain structures. One food chain structure was called rock paper scissors. There are three organisms (A, B and C). A eats B, B eats C and C eats A. The circular direction of this food chain makes it similar to the game of rock paper scissors (rock beats scissors, scissors beats paper and paper beats rock). When testing this model, I expected one organism to dominate the others and then die out. For instant I expected organism B to eat all of organism C and then A to eat all of B, leaving A as the only organism left. Then without a food source, A would die out. However, when looking at the resulting figures (Figure 18, 19 and 20), it can be seen that when the same amount of each organisms is spawned (Figure 18), they spread out irregularly (Figure 19) and have direct relationships with each other (Figure 20).

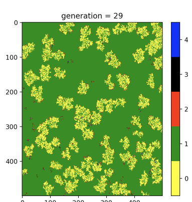

Figure 21: Three way circular relationship at generation 13.

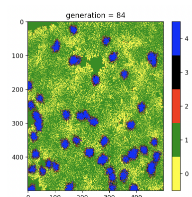

Figure 22: Three way circular relationship at generation 18.

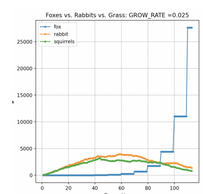

Figure 23: Line graph of three way circular relationship.

The second food chain tested was called Two Prey. In this food chain, there is grass, two herbivores that eat grass and one carnivore that eat both herbivores. In addition, one herbivore prioritizes moving towards grass and the other herbivore prioritizes moving away from its predator. This food chain involves competition between the two herbivores since they have the same food source, and and two different survival techniques. The color scheme in Figure 21 and 22 is similar to the rabbits and foxes model but with the added color of black for the second herbivore. With more potential prey, the fox population was able to flourish (Figure 23). However, it is surprising to see that the green line (herbivore that prioritized moving away from predators) decreased more than the orange line (herbivore that prioritized moving towards food). This may be due to the fact that both herbivores were required to eat in each generation, so they were more likely to die from starvation than being eaten by a fox.

2 Conclusion

Each of the model showed the expected trends in the ecosystem it represented. The Just Rabbits model showed that even when the rabbits move randomly through a field, they find a similar solution as the Learning Rabbits model. In the Learning Rabbits model, the rabbits were more successful in finding food and they were able to sort themselves into colony like orientations easily. When a temperature gradient was applied to the Learning Rabbits model, the rabbits reproduced more in the regions that had high grass growth rates.

When foxes were introduced in the Rabbits and Foxes model, it was difficult to find an optimal starting population for foxes and rabbits. There needed to be enough rabbits for the foxes to eat and there could not be too many foxes that they eat all of the rabbits. It was found that there should be at least 75 foxes and 100 rabbits for the model to be successful. Through this model, the relationship between grass, rabbits and foxes developed as expected.

Using the General model, different food chain structures were explored in the Rock Paper Scissors food chain and the Two Prey food chain. All the organisms in both food chains moved randomly, but both output logical results. The Rock Paper Scissors food chain resulted in the direct relationship between all three organisms. The Two Prey food chain resulted in an indirect relationship between herbivores and their predators. The use of this model can extend to a variety of food chains.

One of the problems that arose with the General model was run time. A variety of different organisms and relationships required a longer run time and if one were to include more than 5 organisms interacting in the same ecosystem, it would result in a very slow run time. Some ways to fix this issue would be to change the way data is stored, create a smaller field, or animating on every n-th iteration rather than every iteration.

One model that is still being worked on is the sexual reproduction model. This model is envisioned to encompass grass, rabbits and foxes. When an organism is on the same tile as another organism of the same type, sexual reproduction can occur where their genes (relating to speed, color and other attributes) could be mixed. In addition, mutations can occur where the offspring may not inherit genes from either parent. The importance of color in rabbits in nature is to camouflage and blend into its environment. With that, foxes can be "colorblind" to a certain color of rabbit, where if the fox lands on the same square as a rabbit but it is colorblind to that particular color of rabbit, it has a smaller chance of successfully hunting it.

Sources

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