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| Optimizing Behavioral Genetics in a Simulated Microbial Life-Form |

**Abstract**

Evolution through natural selection is an optimization problem, with the environment as the problem set. While genetics is based almost entirely on the structural, structure dictates what is the optimal behavior for a species, and behavior is likewise controlled genetically (Dawkins, 2009). This project was intended to create a simple simulation of an environment (consisting of the microbe, a predator for the microbe, and a prey species for the microbe), a simple genetic structure (made up of an array of Boolean values that serve as flags for simple functions that can combine in various ways), and a mutation factor.

After a successful implementation of the model (using Java as the programming language), the model was run in multiple iterations. Speciation was looked for, and the results were surprising and interesting.

The model was created in a scalable manner that allows for new circumstances and changes or improvements in the genetic algorithm.

**Problem Statement**

Much has been observed about the evolution of behavior of various already-established species in the study of evolutionary biology, but it is difficult to observe the formation of fundamental behavior that evolved in the deep past when very basic behavior first developed. Examples include fleeing from predators or determining how much effort to put into the pursuit of prey species. The ability to model and simulate virtual analogs of simple life forms that are customized to the needs of the problem being examined would be a useful tool for observing such behavior. This project was created with the intention of producing a simple such tool, capable of being scaled towards increased complexity.

**Methodology**

After examining several resources for inspiration and understanding of the genetic algorithm (sources listed in the bibliography), as well as examining a resource that gave insight to the evolutionary process and how it related to behavior, particularly between predator and prey (Dawkins, 2009), the shape of the implementation began to take hold. The work of Vose (Vose, 1999) was particularly insightful, and provided guidance for this work.

It was imperative that the model make use of the processes that evolution uses to optimize the genetics of a species. Speciation comes from a range of values in genes, since there is variation within a species itself. For example, rabbits tend to have ears within a certain long range, but rabbits to vary in ear length.

The most important processes that needed to be used in the model were mutation, reproduction, and death.

The program was written in Java due to its modular nature and the ease of implementation of some of the algorithms. The first step was the creation of the most basic object to be a direct part of the simulation: the prey species.

The Prey class was created with only one method: a function for wandering aimlessly. Aimless wandering was intended to be the default behavior of later classes (the Microbe and the Predator classes), so the creation of the Prey with only this method allowed for basic testing. An environment made up of cells was created, with dimensions of 40 X 100 cells chosen for display purposes.

Once the Prey was tested and wandering, the Microbe class was then created. It was given the aimless wandering function, but was also given the ability to chase down Prey. This same method was to be given to the Predator to allow it to chase the Microbe.

After this was tested successfully, the next step was to create the Predator. It, too, was given the chase function. Once this was finished, the Microbe was programmed to flee from the Predator. It was also programmed with a slight tendency to go away from one’s own kind (in one of five decisions). Once tested successfully, the Microbe was programmed to prioritized its behavior in this manner:

* Flee the Predator,
* Chase the Prey,
* Go away from other Microbes if so inclined, and
* Otherwise wander aimlessly.

Once these behaviors were established, the Microbe was then programmed to keep track of its energy. Energy was expended by movement, gained by consuming a Prey, and if the energy reached a certain threshold (called RepCost), then the Microbe would flag itself for reproduction. If the energy reached zero, it would flag itself for destruction (death).

Reproduction was then defined thusly: If a Microbe was flagged for reproduction, a new Microbe would be instantiated in the same location. Each gene on the chromosome (to be defined next) would have a 5% chance of mutation. Mutation resulted in the Boolean value being flipped for that gene. The parent’s energy would then be set to 30% of its energy at the moment of reproduction (reproduction being a very exhausting process in nature). The child Microbe would enjoy the benefit of 45% of its parent’s energy from the same moment. The remaining 25% of the energy would be lost in the process.

After reproduction was tested, it was time to create the genetics themselves. A total of eighteen genes were defined in an array called “chromosome” in the following manner:

* chromosome[0]: Slight increase in speed approaching Prey (a value stored in a variable called preyAppr), moderate increase in energy cost for pursuit (called chaseCost)
* chromosome[1]: Slight increase in preyAppr, slight increase in chaseCost
* chromosome[2]: Slight reduction in preyAppr, but moderate decrease in chaseCost
* chromosome[3]: Slight reduction of preyAppr, slight reduction of chaseCost
* chromosome[4]: Moderate increase in preyAppr, very large increase in chaseCost
* chromosome[5]: Moderate decrease in preyAppr, very large decrease in chaseCost
* chromosome[6]: Slight increase in speed fleeing a Predator (a value stored in a variable called predFlee), moderate increase in energy cost for flight (called fleeCost)
* chromosome[7]: Slight increase in predFlee, slight increase in fleeCost
* chromosome[8]: Slight reduction in predFlee, but moderate decrease in fleeCost
* chromosome[9]: Slight reduction of predFlee, slight reduction of fleeCost
* chromosome[10]: Moderate increase in predFlee, very large increase in fleeCost
* chromosome[11]: Moderate decrease in predFlee, very large decrease in fleeCost
* chromosome[12]: Slight increase in perception range, no change in replication cost
* chromosome[13]: Slight increase in perception range, increase of replication cost of 120%
* chromosome[14]: Slight increase in perception range, replication cost doubled.
* chromosome[15]: Increase in tendency to move away from one’s own kind
* chromosome[16]: Increase in tendency to avoid one’s own kind
* chromosome[17]: Transform the tendency to avoid one’s own kind into a tendency to go towards one’s own kind

Each of these Boolean values was a simple flag that had a simple effect. They could combine in interesting ways, even creating opposite effects. For example, a specific configuration of chromosome[6] through chromosome[11] could result in a negative “flee speed”, resulting in a Microbe that actually moved toward a Predator instead of fleeing! On the surface, this seems to be a genetic result that would be bred out of the Microbes as the model runs, due to it being a negative trait, but as shall be seen, it did not exactly turn out that way.

“Perception” was defined as the maximum Manhatten distance between the Microbe and the things in its environment that it could perceive. If the distance between the Microbe and an object was further than the Microbe’s perception statistic, it could not see an object.

The only thing remaining was to engage the model and see what resulted.

**Results**

The results of the project were exciting and surprising, which was precisely what had been hoped for.

The project was run in five iterations. Each iteration started with a Microbe that had a “false” value set for each “gene” in the chromosome[] array. A lone Microbe was placed into an environment containing twenty Prey and two Predators.

For each iteration of the project, the Microbes would not be very successful for quite some time. Various genetic states would be tested. Each time the last Microbe would perish, a copy of the most recent to have successfully reproduced would be placed randomly into the environment. Eventually there would be a few Microbes that had some modest success. These mild successes always picked one of three possible strategies: fast pursuit of Prey, fast and efficient flight from Predators, or very long perceptions. Of these, perception seemed to be the most successful. For example, the first “population explosion” in the first iteration had all three of these genetic strategies, but eventually the only survivors were the ones with long perception. A Microbe with the ability to see a Predator coming from a distance did not have to move quickly to get away, since its detection had a longer range than that of the Predator. Slower movement meant more energy-efficient survival of Predators. On the other hand, fast-moving Microbes with shorter perceptions sometimes ran themselves to exhaustion to escape the Predator.

Swift pursuit of Prey was useful, as well. Even though one might have a greater chance of being eaten by a Predator, the excess energy from capturing Prey meant that reproduction came more quickly, and thus death by Predator often came after several successful reproduction cycles.

For single Microbes that avoided one another in an environment where the Microbe had modest success, the most successful was one with both long perceptions and fast pursuit of Prey. Flight from a Predator helped in some individual circumstances, but successful microbes put less emphasis on it.

It was surprising to discover, however, that this was only a temporary solution. As behavior refined and these relationships between genes optimized, a new successful trait came to the fore-front.

At some point, seeming to be around a population of about fifty of the optimized species, things took a swift change. Up to this point, avoidance of other Microbes was a moderately selected trait (though not too important). Other Microbes represented competition, and sometimes attracted Predators.

However, when populations grew high enough, an interesting thing occurred: the Microbes began to select not for avoidance of one another, but attraction towards one another!

At first, this was puzzling. More Microbes meant less Prey to be available and a greater chance of drawing Predators. However, it eventually became apparent why this behavior was changing. What was happening?

It turned out that cooperative behavior was occurring! The Microbes were swift to move towards Prey. However, the model did not care if Microbes occupied the same cell as one another. Therefore, multiple Microbes could capture the same Prey and gain its energy. While many would not reach the Prey in time (and die out), many others would succeed and reproduce, keeping the population large and stable. Long perceptions and a tendency to move towards one another meant that Microbes often reacted to another Microbe’s sudden pursuit of a Prey outside of the first Microbe’s range of perception.

However, there was still one puzzling part of the mystery of the change: Predators were still attracted to clusters of Microbes, and Predators never got “full”. Even a large colony of Microbes should result in a holocaust of death if discovered by even a single Predator!

If one recalls, there was a configuration of chromosome values that would, on the surface, seem to be useless, if not disastrous, for a Microbe to have (an imperative to run *towards* the Predator instead of flee). And individually, this is still a terrible strategy. Few individuals within a colony of Microbes would manifest this configuration, as well. However, in a large enough group, there would be a few Microbes with this suicidal death-wish.

So when a Predator would happen upon a colony of Microbes, most of the Microbes would flee from the Predator. However, a few mutated Microbes would gleefully throw themselves towards the Predator (often from multiple angles if the colony was large enough)! This would result in a Predator staying behind to consume the nearest, suicidal Microbes while the rest of the colony fled to safety!

These surprising results led to a new speciation: a Microbe that tended toward one another, had swift pursuit of Prey, *low* flight speed (to allow for more mutants who would run toward the Predators), and moderately long perceptions. Occasionally, mutants without the tendency to cluster would wander away, and be reasonably successful, but the clustering Microbes clearly dominated the virtual landscape. Each iteration of the model’s operation had slight variations in the speciation, but the most successful species followed the same model.

**Conclusion**

Success of a species is a part of the problem set. This became quite clear when the optimal speciation changed each time the model was run at a moderately large population. The surprising exploitation of a seemingly negative trait by the final versions, and the Microbe’s selecting for just the right genetic configuration to exploit it, was a delightful surprise.

Further expansion of the model is needed. The real world is not a static environment, such as is presented in this model. The ability to change the circumstances of the environment itself during runtime is necessary to make a more complete model. Other changes and genetic opportunities would create even more surprising results.

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