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Simulation of a Marine Ecosystem Using Swarm Intelligence

Dokyung Lee

Taejon Christian International School, Daejeon, Republic of Korea

Email address:
dokyunglee0101@gmail.com

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Abstract: The coexistence of multiple species and their interactions have been a topic of interest for hundreds of years. Humans have been taking advantage of species to maximize surplus or control our environment. Nowadays with the growing complexity of our effect on the Earth, it has become more difficult than ever to understand and plan how we are to use our environment. In this paper we attempt to simulate a marine ecosystem and investigate the factors Based on the boids algorithm and the population growth equation that are important for a sustainable system. This simulation will help us understand how marine populations grow and reach an equilibrium, how sudden spurts in one species affect the others and how even in the most devastating scenarios nature exhibits its incredible ability to replenish itself. We observed some interesting emergent behaviors and how the two species interacted with each other. Then with the use of such simulations, we plotted a population graph by collecting data of the number of sharks and fishes for each frame, and an equilibrium was created. As long as the predator relies on the prey, this equilibrium may have its ups and downs but will always stay in a stable range. This however becomes a different story when humans interfere with the food chain.

Keywords: Ecosystem, Swarm, Intelligence, Simulation, Boids Algorithm

1. Introduction

In nature, it is common to observe the cooperative behavior of multiple agents. Often these agents are following a set of simple rules that as a whole become a complex system. Flocks of birds, schools of fish, and herds of sheep are some examples of swarm intelligence seen in nature. I am interested in how these simple rules form feedback loops to create complex and unpredictable behavior. I am also interested in how different species interact with each other.

Marine ecologies comprise of many different entities with their own patterns and rules. Understanding marine life and how to sustain it has become a vital part of human civilization. There have been many studies of how we treat our oceans can affect us and the land we live on [3, 4].

In this paper first I will discuss the material and methods used for our simulation, largely inspired by the boids algorithm that was introduced in 1987 by Craig Reynolds [1, 2]. I will give a brief summary of the algorithm and then move on to the core part of the simulation: the brain of the fish.

In this section I will explain how I used the boids algorithm to sculpt the brain of the fish and how sharks and fish interact with each other as predator and prey.

Finally I will review marine ecology 101, mostly focusing on population dynamics. Using this knowledge I will explain how I applied the population model to our simulation.

In discussions, I will talk about the components of the simulation that I found were most interesting. I will show the results of the simulation in regards to both the population graph and the emergent behaviors of the agents.

At the end of this paper I will give the conclusions made based on our findings and the process of building the simulation.

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2. Material and Methods

2.1. Boids

Boids is a swarm intelligence algorithm that is aimed to model the coordinated behavior of birds or fish. In the basic model of boids, there are three types of steering behaviors: *separation*, *alignment*, and *cohesion*. These steering behaviors are modeled as vectors. Each fish has its own local crowd or neighborhood that models the fish's viewing range.

Separation steers the fish away from its local crowds. This models the fish's individual need for space.

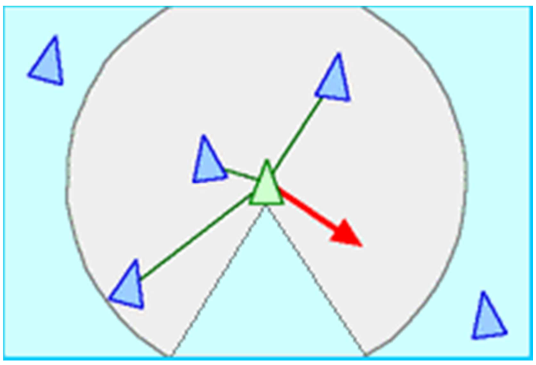

Figure 1. *Separation diagram.*

Alignment is a behavior of steering towards the average heading of local crowds. This models the tendency of fish to follow the direction of its neighbors.

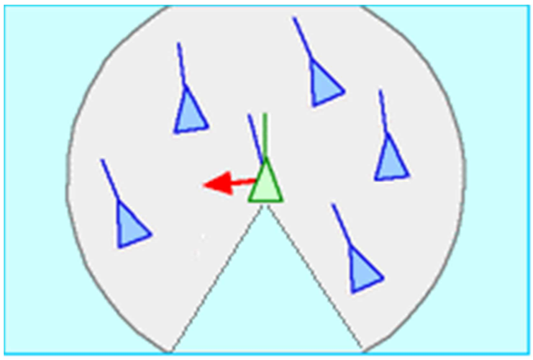

Figure 2. *Alignment diagram.*

Cohesion is a behavior of steering into the average position of crowds, steering into the center. This models the tendency of fish not wanting to be on the outlines of the school.

All of these behaviors of the school of fish are designed and structured using the angle and distance of the neighbor fish. The angle is calculated using the dot product between the center fish's steering vector and the position vector of the neighboring fish.

$$d=|u-v| \tag{1}$$

Eq. 1 Obtaining the angle and distance
where u is the center fish's steering vector
and v is the neighbor fish's position vector

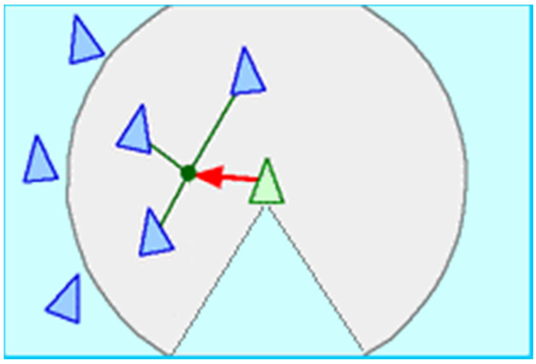

Figure 3. *Cohesion diagram.*

2.2. Fish Brain

The fish that exist in the simulations were divided into the two groups of *schooling fish* and *shark*. Such divisions were made in order to represent and show the simple system of prey and predator.

Schooling fish are given behaviors of *avoidance shark*, *avoidance wall*, *avoidance* (*seperation*), *alignment*, and *cohesion*. On the other hand, sharks only consist of *chase fish* and *avoidance wall*.

$$v=v+s+s_w+s_s+a+c \tag{2}$$

Eq. 2 Algorithm for calculating steering vector of *schooling fish*

Avoidance wall (S_W) or *avoidance shark* (S_S) is basically the same as *separation (S)*, but used for different purposes. While the normal *avoidance* (*seperation*) is used to separate each fish from one another, *avoidance shark* is used to imitate the behavior of fishes swimming away from their predator, and *avoidance wall* was used to prevent fish and shark from going out of the frame for an extended amount of time where we are unable to observe them. This also emulates the boundaries of a natural environment.

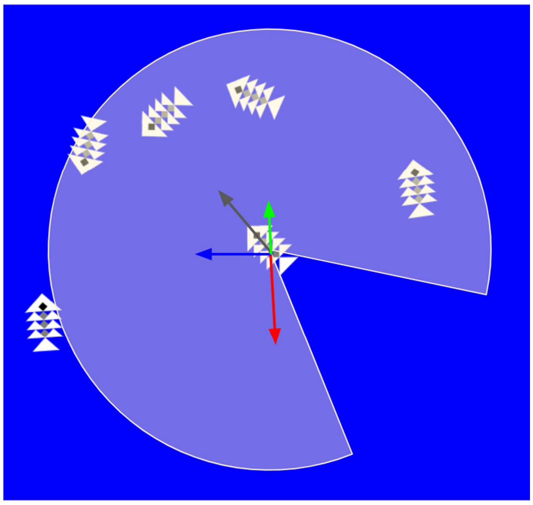

Figure 4. *Avoidance, Alignment and Separation vectors for schooling fish.*

The figure above represents the vectors that determine the fish behavior. Original velocity (black), *avoidance* (red), *alignment* (blue), and *cohesion* (green) vectors are added to get a new velocity vector as in Eq. 2.

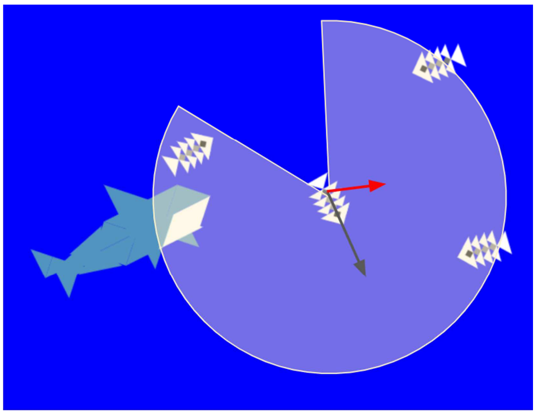

Figure 5. *Avoidance shark for schooling fish.*

Different from the previous figure, this specific figure shows two arrows that represent the fish's original velocity (black) and *avoidance shark* (red) to show how the direction of the fish would be determined by interacting with a different species.

Sharks will not cooperate with each other. Rather they are rivals trying to catch the schooling fish. When this happens, the eaten schooling fish is taken out of the simulation and the population is decreased.

2.3. Population

We now have that the population of fish can be decreased by the interaction of sharks. In order or equilibrium to be reached in our ecosystem, we must implement population growth. This is done with Vurhulst's equation which is a variation of the following recursion equation [5].

$$Nt+1=Nt + rNt \tag{3}$$

Eq. 3 Exponential growth equation

This equation was used as a simple basis in finding the population's growth over time, "r" being the rate of growth and "N_t" as the population of fishes after "t" time. If population growth were to follow this equation, it would rise exponentially.

However, this is not the case in most ecosystems. Species are regulated by an invisible environmental factor. Because of this Vurhulst defines a constant K, which is the carrying capacity or the maximum population that the ecosystem can support for that species.

$$\frac{dN}{dt} = rN(1 - N/K) \tag{4}$$

Eq. 4 Logistic growth equation

This is similar to the exponential growth equation but in a differential equation form and with an additional factor multiplied (1-N/K) to it. This additional factor is what slows down the growth of a population once it comes close to the carrying capacity.

We implement this equation into our simulation and now the population is able to reach an equilibrium. The fish and shark population grow logistically while they each can drop when fish are eaten or sharks starve.

3. Discussion

3.1. Emergent Behavior

I would like to talk about some interesting behaviors found in the simulation.

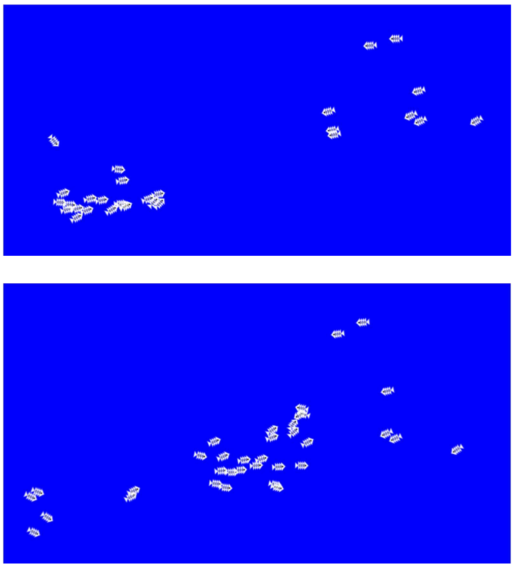

Figure 6. *Two fish schools merging together.*

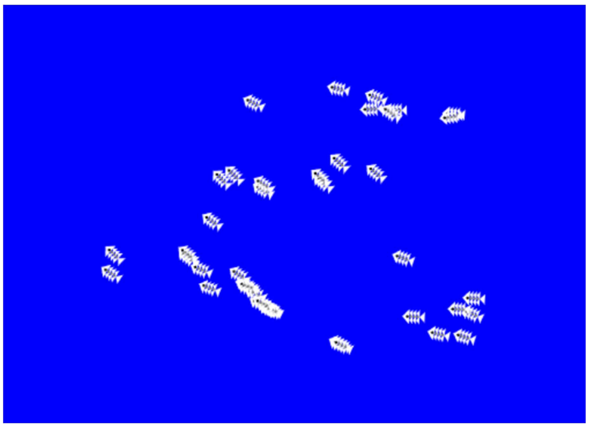

Figure 7. *Two fish schools have merged together to become one big school.*

In the figures above, we can observe that the fish display a complex behavior of merging into and detaching from groups. This behavior occurs in a fluid and natural motion with each fish having what looks like a mind of its own. Even though we have defined a set of simple rules the fish can be unpredictable according to its environment. This is called emergent behavior.

3.2. Population Graph

In order to understand how the equilibrium forms between the sharks and fish, I plotted a population graph with the current number of fish and sharks as the y axis and the number of frames (time) as the x axis.

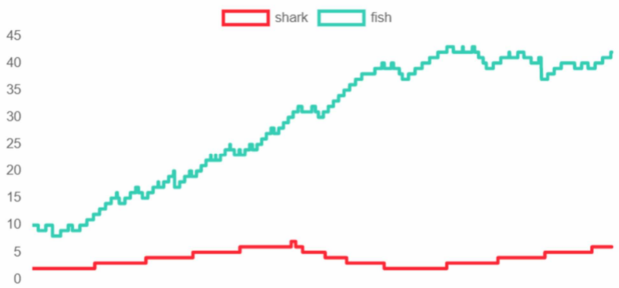

Figure 8. *Population graph for 10,000 frames.*

This graph above was collected for 10,000 frames. This shows the early stage of the simulation where the population of fishes are increasing over time. This is similar to the logistic growth curve that I am targeting.

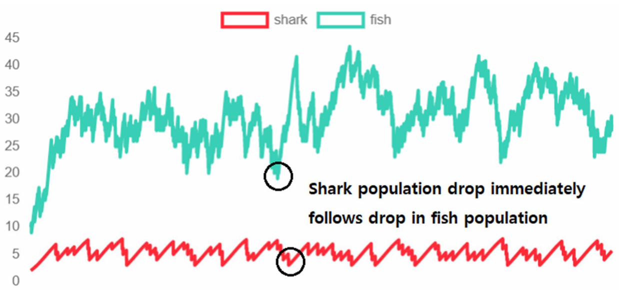

Figure 9. *Population graph for 100,000 frames.*

From the data collected in 100,000 frames we start to see an equilibrium. The populations of fishes stayed around 30~40, while the sharks' population tends to fluctuate around 4. This number is unique to the size of the environment. I would also like to note that whenever there was a drop in fish population, the shark population would also follow. There is also a pattern where the bigger the drop, the recovery is also greater and more remarkable.

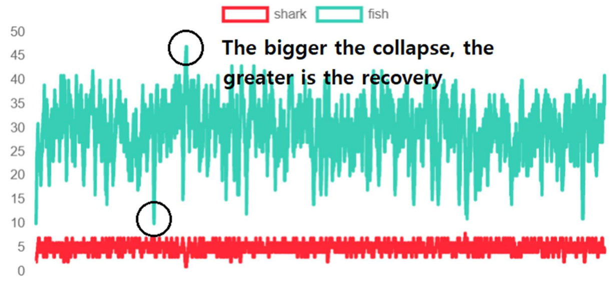

Figure 10. *Population graph for 1,000,000 frames.*

Finally, from this specific graph consisting of 1,000,000 frames we can see that the graph resembles that of two resonating springs. With one population triggering a bounce in the other. An equilibrium is formed until the environment causes the population to suddenly collapse. However this is never permanent and the population always bounces back stronger than ever.

4. Conclusion

Based on the boids algorithm and the population growth equation, the simulation was created. We observed some interesting emergent behaviors and how the two species interacted with each other. Then with the use of such simulations, we plotted a population graph by collecting data of the number of sharks and fishes for each frame, and an equilibrium was created. As long as the predator relies on the prey, this equilibrium may have its ups and downs but will always stay in a stable range. This however becomes a different story when humans interfere with the food chain.

In future works I would like to simulate more complex systems with various species. I would also like to introduce the human factor and our impact on the ecosystem.

Our simulation can be viewed in the following link: telos-j.github.io/aquarium.

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