University of Sheffield

Project title

Your name

Supervisor: Supervisor name

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3.1 Swarms

3.1.1 Swarms in Nature

A swarm is a group of small individuals that interact with one another and with their surroundings, with each entity playing a simple role[9]. However, the combined actions of these individuals result in complex behaviour. Swarms can exist on Earth's surface, beneath the ocean, and on other planets[9]. Swarms can be heterogeneous, which means that the group is made up of different types of entities with varying abilities and characteristics. It can also be homogeneous, which means that the group is made up of the same entities with the same abilities and characteristics[9].

3.1.2 Swarms Intelligence

The study of self-organized systems, such as animal swarms is called swarm intelligence which is based on the collective behaviour of all the entities.

The use of local rules to manage the behaviour of individual agents is a core principle of swarm intelligence[8]. These rules allow the entities to interact with their surroundings and with other entities in a way that results in complex, emergent group behaviours[8]. Individual ants in an ant colony, for example, employ simple principles to communicate and coordinate their actions, leading to the formation of complex behaviours such as food searching[13].

Many methods, including ant colony optimization, particle swarm optimization, and artificial bee colony optimization, have been implemented using swarm intelligence[13]. What makes these algorithms unique is that it has strengths such as flexibility and robustness. These algorithms may also be used to manage massive data and complicated situations since they can identify effective solutions fast and easily, making them useful in a broad range of applications[13]. There are three main components are used in all Swarm intelligence algorithms which are agents, communication, and coordination.

Agents: are basically the individuals of any swarm intelligence system. They are basic, independent and can interact with their surroundings and with each other. These agents can be biological or artificial entities such as ants, bees, and robots.

Communication: The process through which agents communicate information with one another is known as communication. Visual, aural, chemical, and electrical signals are all modes of communication. It is a necessary component of swarm intelligence because it enables agents to communicate information about their surroundings and coordinate their activities.

Coordination is when agents work together in order to achieve a goal. It is based on the communication and interaction between the agents, and it can be accomplished through a variety of techniques, including self-organization, feedback, and consensus-building.

3.1.3 Boids model

In 1987 Craig Reynolds developed a simulation model for the behaviour of the flocking birds which then was named as Boids model[10]. This model was implemented to study the emergent behaviours that result from agent interactions. Each agent represents a boid (or "bird") that follows a series of rules to control its behaviour such as moving with respect to its surrounding agents and the group as a whole[10]. The agent may be designed, for instance, to strive to keep a certain distance from its neighbours, to prevent collisions, or to move in the same direction as the group[5].

The Boids model is an example of self-organized and decentralized systems which are based on agent collective behaviour that arises from their interaction with their neighbours and the environment to produce a complex behaviour to generate global functional patterns[10]. The boids model has been used to implement several algorithms and simulations which were utilised to research a variety of phenomena, including flocking behaviour, traffic flow, and collective decision-making[5]. Boids models have three roles which are alignment, cohesion, and separation. These roles are responsible for making the agent work in groups and avoid any scattering or colliding between the agents[5].

The alignment rule ensures that the velocity of each agent is matched to the neighbours' velocity in order to simulate agents' tendency to coordinate their motions with those of their neighbors[10]. Alignment can be implemented by measuring the velocity average of the agent in a specific radius of the boid and then changing the agents' velocity in the radius to the calculated average[5]. A stronger alignment rule will produce more coordinated and cohesive behaviour, whereas a weaker alignment rule will create more autonomous and distributed behaviour[10].

The cohesion rule specifies how individual agents should move to maintain a specific distance from their neighbors[3]. This rule is intended to replicate the tendency of agents to cluster together and form a cohesive group. Cohesion can be implemented by calculating the average position of the agents in a specific radius of the boid and applying the calculated position to the agents in that specific radius[5]. Like the alignment rule, A greater cohesiveness rule produces more cohesive, concentrated behaviour, while a weaker cohesion rule produces more scattered behaviour [3].

The separation rule describes how individual agents should modify their positions in order to avoid colliding with their neighbours [6]. Separation can be implemented by measuring the distance between one agent to each neighbour in a specific radius and then creating a constant distance to be applied between all agents[5]. A greater separation rule results in more widely spread, decentralised behaviour, whereas a weaker separation rule results in more crowded, centralised activity[6].

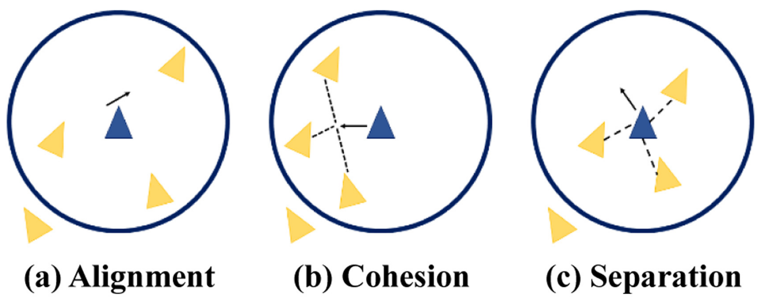


Figure 3.1: The main rules of Boids model

These laws, as illustrated in Figure3.1, may be represented as a three-dimensional differential equation with a periodic boundary condition in order to replicate the velocity of the entities by employing emergent behaviours that are complex and resemble swarming, schooling, and other types of collective behaviour[11].

$$\Delta V = W_{coh}\left(x_i - \frac{\sum_{j\in S_{coh}} x_j}{n_{coh}}\right) + W_{sep}\left(\sum_{j\in S_{sep}} \frac{x_i - x_j}{|x_i - x_j|}\right) + W_{ali}\left(v_i - \frac{\sum_{j\in S_{ali}} v_j}{n_{ali}}\right) \quad (3.1)$$

Based on the equation 3.1 each boid velocity v_i control and update it position. The cohesion, separation and alignment rules are represented by the first, second and third terms, respectively. The ranges of neighbors for each rule are indicated by S_{coh}, S_{sep} and S_{ali}, respectively. The amplitudes of those interactions in the rules are provided by the terms W_{coh}, W_{sep}, and W_{ali}, respectively.

W_{coh}, W_{sep}, and W_{ali} weights may be altered to regulate the strength of each behaviour, while the size and form of the sets S_{coh}, S_{sep}, and S_{ali} can be changed to control the range of effect of each behaviour.

3.2 Bubble net feeding behaviour

Bubble net feeding behaviour (BNF) is a complex foraging behaviour used by humpback whales to feed on dense concentrations of fishes such as fish swarms [7]. In BNF, humpback whales uses a unique technique known as bubble-net capture, which involves blowing bubbles under water in cylinder-ring shapes to trap and contain the swarm[4]. While the swarm is trapped in the bubble net, the whale pods will swim together beneath the bubble net before swimming vertically towards the swarm. When the whales get close to the swarm, they open their mouths and swallow a significant amount of water that contains the swarm[7].

The first eyewitness of bubble net feeding behavior was in 1905 [12]. Since then, this behavior has been seen in a several groups of humpback whales in distant parts of the world, including Southeast Alaska, the Gulf of Maine and the Western Antarctic Peninsula [12]. It was With all studies that have been done of this behaviour, there is still very little is known about some part of it such as the mechanisms by which the whales use to create bubbles[4] and how do whales coordinate together through the hunting process.

Humpback whale pods

Humpback whales are baleen whales that are known for their size. A whale's length at 6 months is approximately 8.5 meters, and it reaches 14.3 meters at the age of 17 years [7]. Despite being bigger than the majority of baleen whales, humpback whales have shown to be more maneuverable than the others [4]. Additionally, humpback whales are able to swim with agility and make rapid, short turns. this is because they have flippers that are longer, more slender, and have a larger aspect ratio [7].

In order to increase the effectiveness of their hunting and assault big flocks of prey, humpback whales tend to hunt in a group foraging behavior, which is based on a combination of individual behaviors or actions [1]. The most well-known foraging behavior of humpback whales is known as BNF behavior because of traits like possessing ventral pleats that aid in feeding by separating the prey from the water when they consume a large amount of water [12], the ability to blow bubbles via their blowholes to contain and confuse the prey [7], and the capacity for cooperation between whale pods when hunting prey.

Bubble net

Figure 3.2: BNF sequences images [12]

Bubbles creation is the main factor in the BNF behaviour where is capture the pray from escaping. Humpback whales blow bubbles by expels air from their blowholes which create a small bubbles that form a cylindrical ring of bubbles [2]. As shown in 3.2, bubbles will rise to the sea surface with the pray trapped inside it. The bubble net act as a boundary that the pray can not swim through it. the diameter of the net can vary depending on the several factors such as the size of the pray, size of whales and number of whales [2].

3.3 Previews implementation

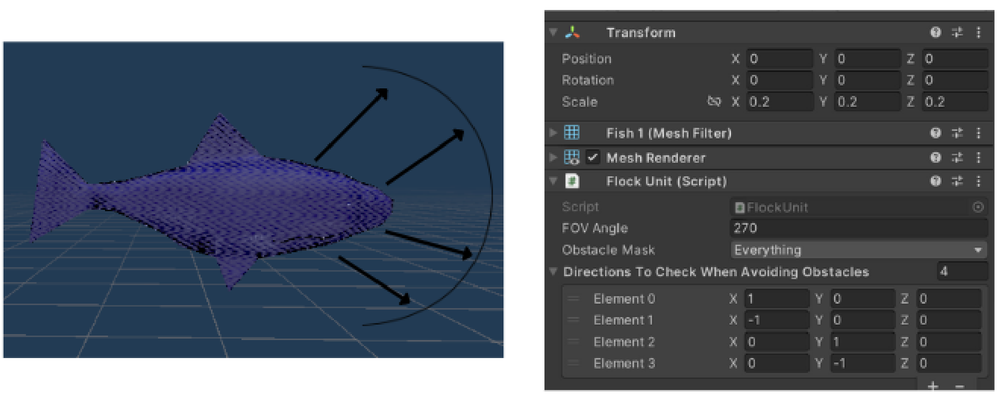
3.4 Editors engines

Chapter 4

Design and implementation

4.1 Fish Model

The fish model was imported from the unity asset store because it is necessary to obtain a realistic Swarm model. The fish's size can be changed, and any movement, such as swimming animation, can be added. The fish will therefore be able to move in a realistic manner when they are added to the swarm.



(a) Fish Shape

(b) Fish setting inspector

Figure 4.1: Fish Model Design

Figure 4.1 is showing the fish form that will be used to create the fish swarm. The initial fish size will be 20cm. In addition, the fish will have 270 degrees of vision, as indicated in figure 4.2 as well as a detection radius in the range of 1 to 10 meters to identify any nearby object. **??** demonstrates the fish model's unity inspector field, which may be used to modify all fish-related settings. Scale field indicate the size of the fish, mesh filter and mesh render are responsble for

4.2 Whale model

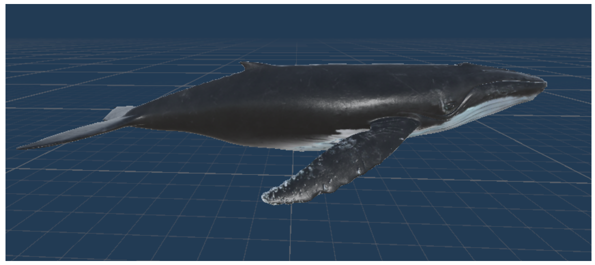


Figure 4.2: Whale Model Design

4.3 Bubble net Model

4.4 Water Environment

Chapter 5

Implementation

5.1 Swarm Model

5.1.1 Fish Behaviors

To imitate the movement of the fish model in the swarm, the fish model will exhibit diverse behavior. The fish will exhibit cohesion, alignment, and separation behaviors as shown in the equation 3.1. Also, the fish will have another behavior to detect the best direction to take in order to avoid any obstacles or predators.

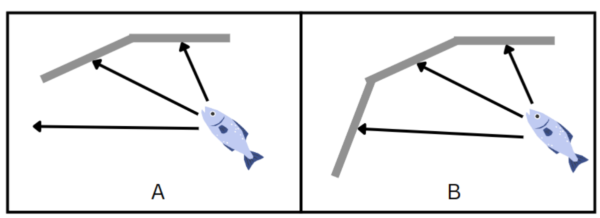


Figure 5.1: Fish Obstacle avoidance Behavior

As shown in Figure 5.2 with a given radius, the distance between the fish and any nearby objects in the radius will be calculated. If there is a direction without any nearby objects, the fish will swim in that direction; otherwise, if there is no obvious direction, the fish will swim toward the farthest object. All of These behaviors will be examined to evaluate the behavior of the swarm and see how each behavior affects the swarm's shape.

5.1.2 Fish Movement

As previously stated, the fish will have 4 main behavior cohesion, alignment, separation, and Obstacle avoidance. thus the movement formula of the fish will be similar to the Boids formula - equation 3.1- but with adding the avoidance vector.

$$\Delta V = (W_{coh} * Coh_{vector}) + (W_{sep} * Sep_{vector}) + (W_{ali} * Ali_{vector}) + (W_{avoid} * Avoid_{vector}) \tag{5.1}$$

The equation 5.1 represents the motion used to model the behavior of the fish in the swarm. Each vector in the equation is multiplied by weight to adjust the strength of the behavior across the fish's whole motion. The cohesion vector will be measured by getting the average position of the 3 dimensions (x,y,z) of all fishes that are located in a given radius.

5.1.3 Fish Script and Calculations

```
var currentUnit = allUnits[i];
            if (currentUnit != this)
            {
                float currentNeighbourDistanceSqr = Vector3.SqrMagnitude(currentUnit.myTransform.position - myTransform.position);

                if (currentNeighbourDistanceSqr <= assignedFlock.cohesionDistance * assignedFlock.cohesionDistance)
                {
                    cohesionNeighbours.Add(currentUnit);
                }
                if (currentNeighbourDistanceSqr <= assignedFlock.avoidanceDistance * assignedFlock.avoidanceDistance)
                {
                    avoidanceNeighbours.Add(currentUnit);
                }
                if (currentNeighbourDistanceSqr <= assignedFlock.aligementDistance * assignedFlock.aligementDistance)
                {
                    aligementNeighbours.Add(currentUnit);
                }
            }
```

Figure 5.2: Calculate the number of neighbors for each vector

5.2 Project specification

Model	parameter name	size
Swarm size	flockSize	300 fish
Fish size	None	100mm to 300mm
Cohesion weight	cohesionWeight	3
Alignment weight	aligementWeight	1
Separation weight	avoidanceWeight	4
Obstacle avoidance weight	obstacleWeight	5
Cohesion radius	cohesionDistance	10
Alignment radius	aligementDistance	4
Separation radius	avoidanceDistance	10
Obstacle avoidance radius	obstacleDistance	5
Bubbles radius	None	1mm
Bubble net radius	None	7 - 10m [**?**]
Bubble net depth	None	3m - 5m [7]
Whale size	None	(8.5m - 14.3m) [7]

Table 5.1: Project specification

5.3 Project Requirements

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5.4 Another Section

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5.5 Ethical, Professional and Legal Issues

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Chapter 6

Results and Discussion

Chapter 7

Conclusions

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Appendices

Appendix A

An Appendix of Some Kind

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Appendix B

Another Appendix

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