Simulation of Distributed Behavioral Model: Aggregation Motion of School of Fish

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***Abstract*—Few things in nature are as impressive as how some animals seem to be able to organize themselves into larger groups so effortlessly: birds, sheep, fish, swarms- among others. If we can understand the mechanism of the emergent behaviour of these different organized species, we might be able to apply the same mechanism to our problems and achieve what we have not achieved so far. One of the first stepping stones to get to an understanding of flocking behavior is to be able to simulate it [1]. This paper explores one such algorithm that exhibits similar collective behaviour found in fish. Since the flocking algorithms are simulated by the designers having expertise in computer domain, it becomes difficult for non-programmers to change the parameters and observe the required behavior. This algorithm is simulated keeping in mind the user friendly interface. The complex interaction of simple behaviors of independent fish results in aggregate synchronized motion of fish. Each fish navigates following some simple rules that drives the motion. The rules are followed based on the perception from the immediate local neighbours within the school. There is no centralized control. The rules in the algorithm have been coded in C# and the simulation has been implemented in virtual environment on Unity platform.**

***Index Terms*—aggregate motion, simulation, school, Boids, algorithm, design, collective behavior**

I. Introduction

Animal behaviour has never failed to amaze mankind. In many areas, the abilities of the animals surpasses the abilities of us humans. Scientists are drawn to study animal behaviours for varied reasons, a major one being that the study sheds light on the evolution of human beings.

"The vision systems of the eagle and the snake outperform everything that we can make in the laboratory, but snakes and eagles cannot build an eyeglass or a telescope or a microscope." —Judea Pearl [33]

Ants cultivate fungus farms, crows make tools, bees co-operate on a large scale, other animals exhibit behaviours that demand different levels of cognition. Collective behaviors are found in the animal kingdom. These animals organise themselves in groups so effortlessly. Flocks of birds, schools of fish, herd of animals- among others exhibit some of nature's most beautiful phenomenon. Specifically, flocking is the term for this spectacular phenomenon,though schooling is the term that is often comes into play while describing the same phenomenon occurring in fish. The term flock would be applicable to any aggregation of homogeneous species in this paper, size or density factors not being taken into consideration. The term 'flock' is used interchangeably with 'schooling behavior', however, it's highly possible that every flocking species has developed specific strategies that are accustomed to its context. The behaviors may seem simple but it evolves with the complex interaction between the species.

We are all surrounded by collective behavior- Birds in the sky, a massive shimmer of fish swim in unison in the aquarium, army of ants, a cloud of bees move following their queen etc. The group of these entities exist in varied range of numbers- from tens to hundreds to thousands, yet the entities avoid collision and synchronize themselves in group at a fascinating speed. This behavior is depicted in Figure 1. In each of these cases, individuals move through their environment and respond to threats and opportunities almost simultaneously, forming an undulating enclave that seems to operate as a single entity [4]. Such coordinated behavior demands the rapid and efficient communication among individuals, but interpreting exactly how this information is transferred through the group has been no easy task for the scientists.

The why and how underlying these complex collective behaviors have perplexed scientists for so long. Figuring out the coordinated synchronized movement that basically relies on the unbelievable communication between the entities has been a challenging task. Since, the cues that drive the schooling behavior in fish occur at lightning speed and these cues come from different directions and that too underwater, studying this behavior in fish has been challenging to an incredible extent. But now scientists are getting some insight into collective behavior by studying the schooling of fish [3]. High speed video cameras and motion-tracking software are being used so as to get to the gist of happenings in the water. This new research is believed to reveal a lot about the evolution of the coordinated collective behavior in animals.

One of the first stepping stones to get to an understanding of flocking behavior is to be able to simulate it [1]. Computer animators seek both to invent wholly new types of abstract motion and to duplicate (or make variations on) the motions found in the real world [1]. Implementing collective behavior in animals has been made easier with the development of better approaches that are efficacious, streamlined, robust and

Fig. 1. A small [30] and large school [31] of fish

simulate life-like behavior.

We might be able to apply the knowledge from learning more about the fascinating behavior of the animals to find many new and interesting solutions to our problems, often with great results. Some literature have been proposed and simulated in the past describing these complex collective behaviors.

One of the successful simulation was done by Craig Reynolds in 1986, on developing a computer program with the name- "Boids" that exhibited flock-like behaviour. The word "Boid" is the shortened form of "Bird - oid -object", meaning bird like object. The approach assumed that collective behavior is simply the outcome of the complex interaction between individual birds. It is still considered as one of the most popular models for simulating flocking behaviour.

The algorithm in this paper is an elaboration of the algorithm by Craig Reynolds [1]. Each fish in the school is an independent actor or entity and the resulting aggregate motion is the result of complex interaction between the entities. The decision of each entity is based on its perception of group through their immediate neighbours [2]. There is no centralized control and each fish exhibits its own behavioral model comprising of few simple rules: maintaining specified distance from other fish in the school so as to avoid collision, aligning towards the average heading of local schoolmates, steering towards the average position of the local schoolmates, navigating towards the target and avoiding obstacles. To the astonishment, a complex school behavior arises from these simple rules.

This paper is organised as follows. In section II, related work of different era is discussed and the advent of high speed GPUs leading to high quality animation is discussed. Reynold's work on Boid models has been explained in detail in Section III. Section IV discusses the approach used for simulation of collective behavior. It includes the pseudo code for the rules of the algorithm. Section V outlines the analysis of results. The behavior obtained on changing different parameters is analysed in this section. Section VI mentions some of the applications of the flocking algorithm, while section VII describes the scope of the future work. Finally, section VIII presents the conclusion drawn of the project.

II. Related Work

A. 16th Century Literature

"Birds of a feather flock together"- a famous proverb, dates back to the mid-16th century. In 1945, the version of this proverb "Byrdes of on kynde and color flok and flye allwayes together", has been used by William Turner in his papist satire- "The Rescuing of Romish Fox" [5]. It is the evidence of attraction of researchers of the early era towards the collective behavior in animals.

B. Early 20th Century Literature

In the beginning of the early 20th century, many researchers began to speculate the movement of birds from the perspective of gregariousness. John Emlen, Jr. in 1952, while describing their movement from the aspect of gregariousness, proposed that form and density characteristics of bird flocks are determined by the interplay of positive and negative forces associated with gregariousness on the one hand and intolerance and independence on the other [6]. There are two opposing forces, a positive force of mutual attraction and a negative force of mutual repulsion, interacting in the formation of bird flocks. The positive force initiates the process and acts centripetally in drawing membership; the negative force serves a regulatory role, limiting the size of the flock and preventing close crowding through its centrifugal action [6]. Flocking reaches its highest development when gregariousness is given free rein, unrestricted by conflicting demands of reproduction and self-maintenance [6]. Trotter in his work [7] described gregariousness as an impulse in individuals to be in and remain with the flock and to resist anything which tended to separate them from it [6]. Craig's work [8] in 1918 classified it as an appetite, which he defined as "a state of agitation which continues so long as a certain stimulus–is absent," and which is resolved as soon as the appeted stimulus is received [6]. Ten years later, in 1928, Wheeler [9] compared it with the appetites of hunger and sex and noted its persistent nature and its striking effects on segregated individuals [6]. It is not difficult to find the illustrations of the gregarious behavior of animals. Nearly each of us has watched crows responding to their own flock on the ground. Besides these, there is a significant effect of group of decoys on the quarry of geese or ducks.

C. Mid and Late 20th Century Literature

In 1958, Beer's [11] defined flock as "...two or more birds which associate with each other due to innate gregarious tendencies" [10]. This definition breaks down in the face of more recent flocking studies, like Reynolds' (1987), which suggest that coordinated flocking may be the product not simply of 'gregariousness', but extremely simple behavioural rules followed by each bird in the group [10]. Wynne-Edwards in 1962 proposed that instead that the movements that enable each member of the flock to estimate the density and numbers of population as a whole represented 'epideictic' displays. This information might be useful to direct the breeding process of these flocks. This suggestion was part of a larger concept that is called today 'naïve group selection' [10]. Major and Dill in 1978 came up with the idea of turning and rotating movements as 'protean' so as to puzzle the predators. It was only in the early 2000s that studies revealed the underlying concept behind these movements. These help pigeons direct towards their nests.

Many researchers in the 1970s came up with the concept of leader of the flock. The concept was studied and a hypothesis was put forward. It suggested that leader orienting in different direction of heading of the flock causes twisting and spinning motion in the flock. When the leader turns, immediate neighbours trigger to orient their direction with that of the leader, which in turn drives the entire flock to swirl. In 1984, W.K Potts, with the analysis of the film of dunlin, depicted that the manoeuvre that spreads like a wave within the flock may be initiated by a single bird. The propagation of this 'manoeuvre wave' begins relatively slowly but reaches mean speeds three times higher than would be possible if birds were simply reacting to their immediate neighbours [12].

1) Computer Simulated Flocks of the Era: It was also the era of technology. Information processing systems and programming languages formulated in the era. Many scientists then took the challenge of simulating the flock in the form of animation. They started with the idea of scripting flock members as they hypothesized that the rules followed by individual birds leads to the complex behavior of flocking. The Electronic Theater at SIGGRAPH '85 presented a piece labeled "motion studies for a work in progress entitled 'Eurythmy'" [13] by Susan Amkraut, Michael Girard, and George Karl from the Computer Graphics Research Group of Ohio State University [1]. In the film, a flock of birds flies up out of a minaret and, passing between a series of columns, flies down into a lazy spiral around a courtyard [1]. The behavior of bird is seen as flapping their wings during their flight and avoiding collision with the flock members in the flock.

Akira Okubo in 1986 [12], Craig Reynolds in 1987 [1], and Frank H. Heppner in 2009 [10] were the ones to succeed in the development of mathematical computer simulated models of flocking behavior.The successful simulation was done by Craig Reynolds in 1986, on developing a computer program with the name- "Boids" that exhibited flock-like behaviour.The word "Boid" is the shortened form of "Bird - oid -object", meaning bird like object. The approach assumed that collective behavior is simply the outcome of the complex interaction between individual birds. Surprisingly, he was able to simulate life-like behavior using just three simple rules of separation, alignment and cohesion. It is still considered as one of the most popular models for simulating flocking behaviour. Later, Heppner and Grenander achieved success in simulating a model where the birds flew with different regulators of velocity but with approximately the same speed. They moved closer to other members when they were far from the group or distant themselves if they found themselves too close to the members in the flock. With the use of Poisson Stochastic Process, winds, dynamic obstacles and other natural impacts were also enclosed in the model.

Few years later after the Craig Reynolds paper was published in 1987, in 1993 Lorek and White performed simulations that had the advantage of changing the parameters in play mode and at the same time observing the changes in simulation. They used Meiko Transputer System that had upto 50 processors for executing simulations. However, the simulation consisted of 100 slow moving birds but they achieved the interactive rates of 6 frames/second.

D. 21st Century Literature

In 2002, Couzin and his team presented a self-organizing model of group formation in 3-Dimensional. This work was completely different from the works of Reynolds and Heppner. They were the first one to present the evidence for collective memory in the process of transition from one collective behavior to another in animal groups like schools. He represented the model with the three zones- zor: zone of repulsion, zoo: zone of orientation and zoa: zone of attraction.The model is then used to show how differences among individuals influence group structure, and how individuals employing simple, local rules of thumb, can accurately change their spatial position within a group (e.g. to move to the centre, the front, or the periphery) in the absence of information on their current position within the group as a whole [14].

Fine and Shell in 2013 [18] identified that there are at least five critical aspects of the flocking problem. These five aspects are: sensing; flock member detection; neighbour selection; motion computation; and physical motion, or, in this case, virtual motion [16].

In the 2000s, with the advent of multicore technology (Gschwind et al 2006) and hardware dedicated to computer graphics like NVIDIA 2007, the barriers to slow speed execution and real time execution have been overcome. In 2006, Reynolds with the reward of Cell processor of Sony Playstation 3, came up with the multicore solution. It could run 10,000 animated fish in simulation at high quality and interactive rates reported were 60 frames/sec. At the SIGGRAPH 2008 conference, the Game Computing Applications Group of AMD, Inc. was showing a cinematic quality technology demo titled 'March of the Froblins' (AMD 2008; Shopf et al. 2008), a graphics processing unit (GPU) based crowd simulation of 65,000 agents at 30 frames/s [10]. However, it was only at the expense of real life-like behavior that the techniques achieved high frame rates.

III. Boids

Since this work is an elaboration of Craig Reynolds work on ‘Boids’, this section discusses boids in detail. No such evidence had been provided that shows the complexity of the flock bounded in some way. Flocks do not become ”full” or ”overloaded” as new birds join [1]. Migration of herring to their spawning grounds takes place in schools that consist of millions of fish. The schools stretch as long as 17 miles in distance. It does not seem that an individual bird can be paying much attention to each and every one of its flockmates [1]. In case of huge flock size, each flock member must have the ability to perceive the rest of the flock. A bird might be aware of three categories: itself, its two or three nearest neighbors, and the rest of the flock [15].

The above speculations show that the there should be some time-constant algorithms, independent of the size of the flock. But there is an upper bound on Boids. It is dependent on the population size. Since the complexity of the algorithm is $O(N^2)$, the computational cost of the algorithm increases square times with the number of the flock members.

Boid model of Reynold is the extension of the generalization of earlier work of Reeve’a on particle systems [17]. There were some significant differences involved:

- Replacement of ‘dot-like particles’ with a complete geometric object [16].
- The geometric objects (boids) have orientation [16].
- Generally, particles do not interact with each other. In contrast, boids dynamics depend on both boids internal state and interaction with other boids in their external environment [16].

Reynold started with a boid model in which geometric flight was being supported. Set of behaviors were added to the model which consisted of tendency to avoid collision and impulsive behavior to join the flock. The distributed behaviors of flocking, defined as rules, are listed below in order of decreasing precedence.

- Collision Avoidance: steer to avoid collisions with nearby flockmates [1].
- Velocity Matching and alignment: attempt to match velocity with nearby flockmates [1] and align with the average heading of the direction of the flock. Velocity is represented as a vector quantity.
- Flock Centering or cohesion: attempt to stay close to nearby flockmates [1] and so steer towards the average position of the flock.

The following flowchart [28] in Figure 2 gives an overall view of the Reynold’s Boid model.

The establishing of minimum required distance between flock members is accomplished through Collision Avoidance and maintaining of this minimum distance is accomplished through Velocity Matching. It is due to the flock centering that there is an urge in boids to be always near to the centre

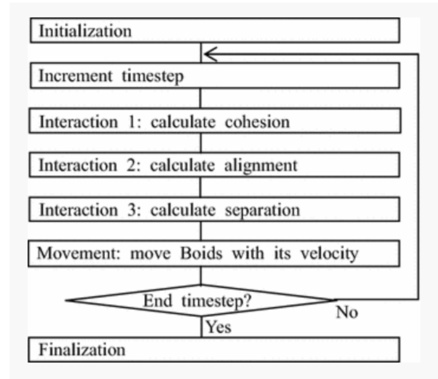

Fig. 2. Flowchart of Reynold’s Boids model

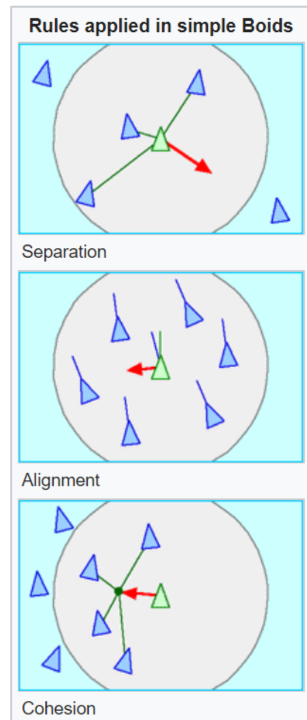

Fig. 3. Graphical depiction of rules in Reynold’s model [29]

of the flock, so this causes the movement in boids that makes them fly closer in the direction of centroid of its neighbours. Because each boid has a localized perception of the world. ”center of the flock” actually means the center of the nearby flockmates [1].

The acceleration requests are processed on priority basis. However, ordering is subject to change in order to suit dynamic conditions.The acceleration requests are added in accumulator by considering them in priority order. The magnitude of each request is measured and added into another accumulator [1]. The process is repeated until the sum of accumulated magnitudes becomes greater than the parameter of each boid which is the maximum acceleration value. For compensating the excess accumulated magnitude, there is trimming of last acceleration request.The point is that a fixed amount of acceleration is under the control of the navigation module; this acceleration is parceled out to satisfy the acceleration request of the various behaviors in order of priority [1].

The selection of initial velocity and initial location of each boid is done from uniform distribution. In order to repeat the experiments and compare the results, a known seed is used for random number generator. All other aspects of the boids model are deterministic [16]. There is no need for Randomization. The boids could start from locations chosen on regular pattern also. Released boids at different locations begin to flock together and force their way at positions.The boids stay near one another (flock centering) but always maintain prudent separation from their neighbors' (collision avoidance), and the flock quickly becomes "polarized"-its members heading in approximately the same direction at approximately the same speed (velocity marching); when they change direction they do it in synchronization [1]. Solitary boids and smaller flocks join to become larger flocks, and in the presence of external obstacles, larger flocks can split into smaller flocks [1].

One of the most interesting behaviors of the simulated flock arises with the interaction of flock with other objects in the environment that may be dynamic in nature. Reynold's work implements two different shapes of environmental collision avoidance- Force field concept and steer-to-avoid. Steer-to-avoid is more robust in nature.

When the simulation is executed, reacting to the initial conditions is the first action of the flock. There is an initial expansion in the flock if the boids started out with the positions too close to one another. There is a natural tendency to avoid collision, which drives the boids to move radially outward away from the overpressured zone. If released in a spherical shell with a radius smaller than the "neighborhood" radius, the boids contract toward the sphere's center; otherwise they begin to coalesce into small flockettes that might themselves begin to join together [1]. Smaller flocks coalesce to form a single flock if the boids are confined within a region and left to wander for long enough time.

IV. Proposed Framework

The algorithm described in this section is an elaboration of Reynold's work on Boids as described in the previous section. Simulation of flock behavior has been implemented in virtual environment on Unity platform. User friendly interface has been developed with simulation that can allow non-programmer biologists to change some parameters such as individual speed at their will and observe the required behavior. There are 25 different fish models that can be used for simulation in the project. The fish models that have been used in the project have been downloaded from the Unity Asset store [19]. These fish models have basic animation of body and two fins. However, other fish models can also be created by customising properties and adding the code for animation for the purpose of simulation.

Environmental Obstacles have also been implemented in the simulated environment. For the purpose of adding obstacles, rocks and boulders have been used. Rocks, stones and boulders, used as project assets have also been downloaded from the Unity asset store [20]. The package consists of 24 different varieties(called prefabs) of rocks and boulders.

In addition to the set of behaviors implemented by boids model- collision avoidance, velocity matching and flock centering, other set of behaviors have also been added in this proposed framework. Apart from avoiding obstacles, school implement another rule of goal seeking. The goal has been shown as a 3-D sphere in the simulated virtual environment. The position of the goal changes randomly at irregular intervals between the dimensions specified. Fish moves towards the target while following other rules.

School of fish while chasing the goal and implementing other set of behaviors may run out of screen. The camera is static and cannot adapt to the motion of the school, because this implementation would require obstacles to be placed at different locations at infinite distance. For the purpose of limiting the fish behavior in specified screen format, sea dimensions have been specified. The position of the goal also changes within these dimensions specified, so fish seek the goal within the dimensions specified and never run out of screen.

Two C# scripts have been coded for the implementation. One of the script, called IndividualFish.cs is used for specifying the behavior of the individual fish. This is the script that assigns random velocity to the individual fish of the school in the beginning. This script contains parameters like group centre, group velocity, rotation speed and minimum distance between two fish to avoid collision. The set of behavior or rules have also been coded in this script. The other script, called School.cs is the one that is used to define the behavior of the complete school. The task of assigning random positions to the individual fish in the beginning of the simulation has been given to this script. Parameter of number of fish in the school has also been defined in this script. The global school script also contains the code to change the position of the goal or target randomly.

The function in which the rules have been coded is named ApplyRules(). ApplyRules() function can also be applied randomly depending upon the size of the school. The rules are not applied frequently because it will lead to arbitrary behavior given the size of the school. These are the few lines from code that calls the function randomly.

```
if(Random.Range(0,4)≤1)          //Creating randomness
    ApplyRules();
```

However, there is no need of randomness if the size of the school is small.

The pseudocode of the ApplyRules() function has the following structure:

```
FOR EACH FISH f

        IF Distance with Neighbour Fish ≤ Minimum
```

Distance to become part of School THEN
Make that fish member of the group
Add up the centres of fish again

IF Distance with Neighbour Fish $\leq$
Minimum Distance for Collision THEN
Change the orientation of the vector to face in another direction to avoid collision
END IF

Add the speed of the neighbouring fish to the group
Calculate the new group speed by adding the speed of the neighbouring fish
END IF

END

There are two functions which are common to both scripts-start() and update(). Start is called before the first frame update and is basically used for instantiation. It basically instantiates the Prefab at the beginning. A prefab is a template for creating new instances of objects in the scene. In IndividualFish.cs script, random velocities of fish have been defined in start function, where as the random positions of fish in School.cs have been defined in this function. The other function of update() is called once per frame. The rest of the code has been written in this section.

V. Analysis of Results

There is no formal definition that defines the intended behavior of the flock. For the interest of comparison, flocking of bodies in aggregation is defined as:

- Are close to each other [23].
- Move with approximately the same speed [23].
- Move in approximately the same direction [23].

And "good" flocking behaviour can be defined as: Bodies that meet should form a flock[23].

- The flock member should not collide with each other [23].
- The flock should not spontaneously lose members [23].
- The flock should not spontaneously split off into new flocks [23].

For comparing the results, different parameters are modified in the scripts and the results are noted. Each rule is implemented with the use of parameters, for instance, the distance between the fish and the nearest fish in the school is defined in DistanceOfNeighbour variable. Altering this parameter changes the behavior of the school drastically. Changing the constant parameters proves to make the behavior of the school more realistic, while another change can change the behavior of the school to behave like a flock of birds. The rest of this section describes the effect of different parameters on the behavior of the school.

A. Effect of size of school

The 'good' flocking behavior changes with the size of school. Since the camera is static, increase in size of the school cannot accommodate all the fish on the screen. The behavior of large school can also be observed by zooming out the camera specifications, but at the expense of the high quality animation of the fish. The size of the school should be chosen wisely so as to observe the proper behavior of the school within specified screen. Figure 4 and 5 shows the simulation of the school behavior with different school sizes.

Another change has to be made to ApplyRules() function. This function should be called randomly if the size of the school is increased. If this function is not called randomly, it will lead to arbitrary behavior in large group of fish within the specified screen size. The frequency of calling the function can be increased or decreased in the random function.

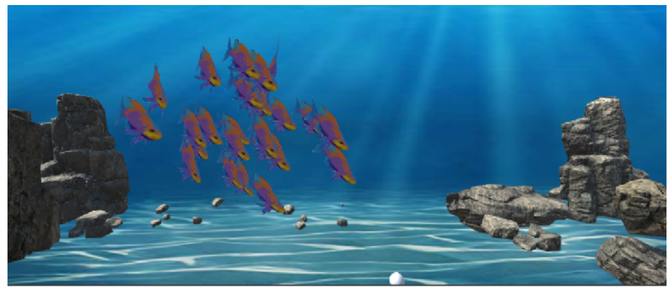

Fig. 4. Simulation with school size = 25

Fig. 5. Simulation with school size = 55

B. Effect of Turning Speed

Turning speed is the rotation speed of the fish. In other words, turning speed of fish is the speed with which the fish turns the other way or orient to different direction so as to avoid collision with other fish in the school or environmental obstacles. Turning speed also comes into play when the position of fish has to be confined within the dimensions of the camera's view. The fish must turn back to be in camera's view.

On increasing the turn speed of the individual fish, school behavior becomes absurd. The fish bounces back with much velocity that it by-pass the school and override the sets of behavior. For implementing the algorithm effectively, turn speed should be altered so as to keep the behavior life-like.

C. Effect of Distance between Neighbours

Distance between neighbours is the distance between the fish that is not a member of the school and the fish that is closest to it, but is a member of the school. This parameter decides the minimum distance between these fish in order to be considered into school. If the distance is too large, the fish does not merge with the school and schooling behavior is not observed, since the fish are far away from each other. However, on decreasing the distance to some optimal value, schooling behavior becomes real-life like. The change in behavior on altering the minimum distance to merge with school is depicted in Figure 6 and 7.

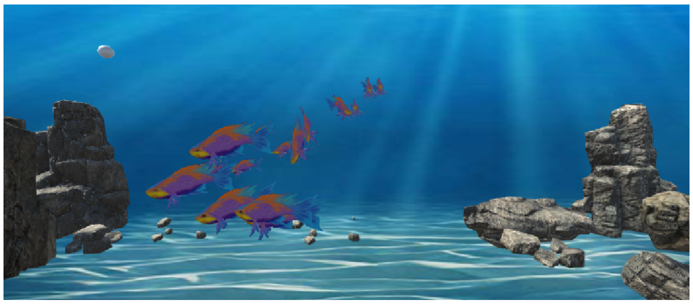

Fig. 6. Simulation with minimum distance to merge with school = 3.0f units

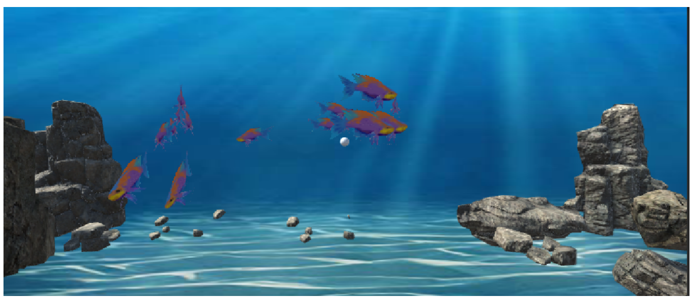

Fig. 7. Simulation with minimum distance to merge with school = 6.0f units

D. Effect of distance to avoid collision

Distance to avoid collision is the minimum distance that should be maintained between the fish in order to avoid the collision. Once this distance is reached, fish must orient its direction to avoid collision. If this distance is set too high, fish never actually form a school, because they always stay at a larger distance from one another. This distance should be chosen in a way that fish don't seem to collide with one another or environmental obstacles, but forms a school in simulation. Figure 8 and 9 shows different behaviors of simulation on modifying the minimum distance to avoid collision.

E. Effect of Group Speed

The group speed of the school also has an impact on the schooling behavior. Group speed is calculated by getting the average speeds of the fish in school. Group speed is initially set at the beginning of the simulation. If the group speed is high, schooling behavior is still observed, but it doesn't seem realistic. Fish move with so much speed that it becomes difficult to observe where the school breaks or forms or when the solitary fish joins the school.

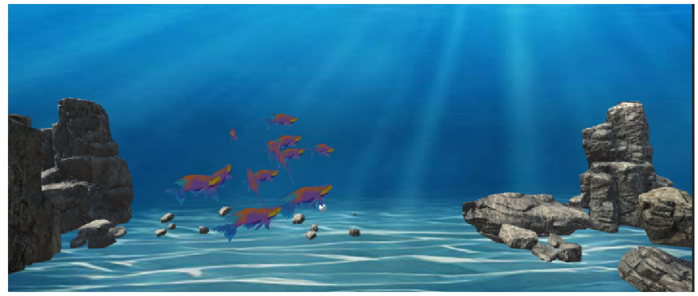

Fig. 8. Simulation with minimum distance to avoid collision set to 1.5f units

Fig. 9. Simulation with minimum distance to avoid collision set to 6.5f units

VI. Applications

Flocking algorithms are implemented is in the field of animated movies. When Reynold came up with the proposal of his approach, it was a big stride in comparison to other traditional techniques being used in motion pictures for animation. The first animation created with the model was Stanley and Stella in: Breaking the Ice (1987), followed by a feature film debut in Tim Burton's film Batman Returns (1992) with computer generated bat swarms and armies of penguins marching through the streets of Gotham City [10]. Flocking algorithm was actually used for the 'Lion King' movie to animate automatically all of the herd scenes in the movie. Flocking algorithms are commonly used in animated screensavers.

There are other interesting applications of boids model. It has been applied to automatically program Internet multi-channel radio stations [24]. It has also been used for visualizing information [25] and for optimization tasks [26].

Another application domain where this algorithm is being used is in video games. This algorithm gives really good movements of the fish, where food is dropped into the tank. One application of this is in some sort of aquarium type games where the food is dropped into the tank and school of fish implement the algorithm stated above.

Flocking algorithms are also used to control the behavior of Unmanned Air Vehicles (UAVs). The concept of drone swarms is becoming popular. The collective behavior of drone swarms is being fully controlled and improved. It is being developed at a rapid pace in the coming years. Fabian Schilling, Julien Lecoeur, Fabrizio Schiano, and Dario Floreano used machine learning and flocking algorithms in their work on flight drones.

Their paper presented a machine learning approach to the problem of collision-free and coherent motion of a dense swarm of quadcopters [27]. The agents learn to coordinate themselves only via visual inputs in 3D space by mimicking a flocking algorithm [27].

VII. Future work

The work cited above has been the composition of homogeneous entities. However, this is not the case in reality. There are different fish species that differ in age, gender, response to danger and have some other unique features that impact schooling behavior. More work can be performed in these areas to make the behavior life-like. More cameras can be used to observe the behavior in a wide range of areas. High quality cameras and high speed GPU can be used to achieve high frame rates and simulate the environment in high quality.

Since the flocking algorithms are simulated by the designers having expertise in computer domain, it becomes difficult for non-programmers to change the parameters and observe the required behavior. More User friendly interface than the one implemented in this framework can be developed that will allow biologists to change parameters at their will and observe the required behavior. Certain parameters can also be quantified like, turning speed in order to make the simulations predictable to the natural behavior. These metrics can be used for testing the efficiency and accuracy of flocking behavior by comparing it with real collective behavior exhibited across the animal kingdom.

VIII. Conclusion

There are many fascinating applications of the flocking algorithms. Few of them have been described in section VI above. Despite these, there are many domains where the algorithm usage has been left unexplored. Depending upon the application areas, it is now possible to custom these algorithms to fit into the domain. With the assistance from knowledge domain experts, the implementation of these algorithms can be achieved at the next level, at times by just varying the parameters of the flocking algorithm so as to accustom it to the demands.

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