Modeling Collective Motion in Starlings

Pratyush Maini and Pranav Baurasia
Department of Computer Science and Engineering
Indian Institute of Technology, Delhi

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Abstract

The aggregate motion of Starlings *(Sturnus vulgaris)* in the sky is one of the most beautiful and impressive examples of collective awareness. It is considered as a means of protection from predators and making the flight more efficient in terms of energy utilization.

We will computationally simulate the phenomenon by modeling each bird as an independent agent communicating and cooperating with other neighbouring agents. Our objective will be to measure from a realistic simulation the average energy spend by each bird, the angular momentum and the force that each bird has to withstand in a typical flight ritual.

But this type of complex motion is rarely seen in computer animation. The simulated flock is an elaboration of a particle system, with the simulated birds being the autonomous agents. The term autonomous agent generally refers to an entity that makes its own choices about how to act in its environment without any influence from a leader or global plan. The aggregate motion of the simulated flock is the result of the dense interaction of the relatively simple behaviors of the individual simulated birds.

Key Words and Phrases: flock, bird, starling, collective motion, particle system, actor, flight, constraints, path planning, autonomous agents, swarming, self-organisation.

1 Introduction

The motion of a flock of Starlings *(Sturnus vulgaris)* is one of the nature's delights. The synchronised motion of a flock of starlings leads to the formation of magnificent patterns in the sky. Some interesting contrasts in the behaviour of Starlings are:

1. Even though each actor of the flock is an autonomous agent, the over all motion is fluid and well synchronized.

2. The motion of each individual actor is simple, but that of the over all flock is highly complex.

3. The motion of each bird appears to be completely random, but all of them together end up making a very synchronized appearance.

To simulate the motion of hundreds of thousands of Starlings, we assume that a flock is the aggregate of the behaviour between individual birds. If one single instance of the bird follows the correct perceptual mechanisms and aspects of aerodynamic flight, then we just need to create multiple randomized copies of the same.

2 Starling murmuration

Starlings are small to medium-sized passerine birds in the family Sturnidae. The starlings are generally a highly social family. Most species associate in flocks of varying sizes throughout the year. A flock of starlings is called a murmuration.

The paper "On The Normal Flight Speeds Of Birds. by T.H. Harrisson" tells the maximum velocity of a starling to be 30.5 miles per hour.

3 Aspects of Flight Control

3.1 Autonomous Agents

For the simulation of starling murmuration, we will be using autonomous agents for single starling. We use the term *Autonomous Agents* to signify an individual that decides its behaviour in a given situation without the guidance from a leader or a pre-defined objective that each member of the swarm needs to comply with. Some of the important characteristics of an autonomous agent can be summarized as:

1. **Processing environment to determine action:** This is the more acceptable part. As discussed in preceding sections, autonomous agents take information of other actors from the environment to calculate the force that they need to apply internally to be able to modify their state of motion. They do not act in accordance with any one final end goal.

2. **Limited Perception of the environment:** Any autonomous agent simulated in a real-world environment is driven by the behaviour of other actors in the environment. However, an important consideration is : *How much can an autonomous agent perceive?* Given that there is a limit to which any Starling can learn from its surroundings, it is inappropriate to include information of every actor in the environment, to determine the motion of an autonomous agent. There are various techniques, such as most proximal seven, or 150 °radar with limited viewing distance. The approach is discussed in further sections.

3. **No Single Leader:** Flocking in Starlings stems from the principles of collective awareness and intelligence. No single actor determines the motion of the others, yet all the Starlings seem to be flocking in a highly synchronised fashion.

In the late 1980s, computer scientist Craig Reynolds developed algorithmic steering behaviors for animated characters. These behaviors allowed individual elements to navigate their digital environments in a "lifelike" manner with strategies for fleeing, wandering, arriving, pursuing, evading, etc. Used in the case of a single autonomous agent, these behaviors are fairly simple to understand and implement. In addition, by building a system of multiple characters that steer themselves according to simple, locally based rules, surprising levels of complexity emerge. The most famous example is Reynolds's "boids" model for "flocking/swarming" behavior.

3.2 Implementation of autonomous agent

The implementation of autonomous agents is based on Reynold's original paper of reference. The entire flock can be represented by a set of n agents,

$$B = \{b_i, i = 0, 1, ..., n-1\}$$

Each autonomous agent has the following characteristics: position p_i, velocity v_i, the up-vector u_i and and three steering forces which are separation, cohesion, and alignment.
The important thing is that agents have limited vision beyond which what other agents are doing it will not be able to see. This vision in terms of radius can be approximated to five times the size of the agent. This parameter is equal for all boids. The set of agents inside the sphere of visibility of the ith boid can be given by :-

$$V_i = \{b_j \in B : |b_i - b_j| < e, j = 0, 1, ..., m-1\}$$

where m is the number of the boids visible by the i-th boid.

4 Behavioral Rules

Basic models of flocking behavior are controlled by three simple rules:

4.1 Cohesion

Cohesion is the force that encourages starlings to move closer to their neighbors, creating a clustering effect. In this simplified system, each starling wants to move to a weighted average of the other starling's positions with the weighting depending on the distance to the neighbor. Thus, if a starling is within another starling's perceptual range, its position will be considered in the cohesion force. This force can be understood biologically as a desire for starling to remain close to avoid being picked off by predators. Starling can be modeled by having each individual consider all neighbors, with the weighting of the social forces inversely proportional to the distance of the neighbor.

The cohesion force only considers birds within the neighborhood described as sphere of radius of R_i centered on bird i.

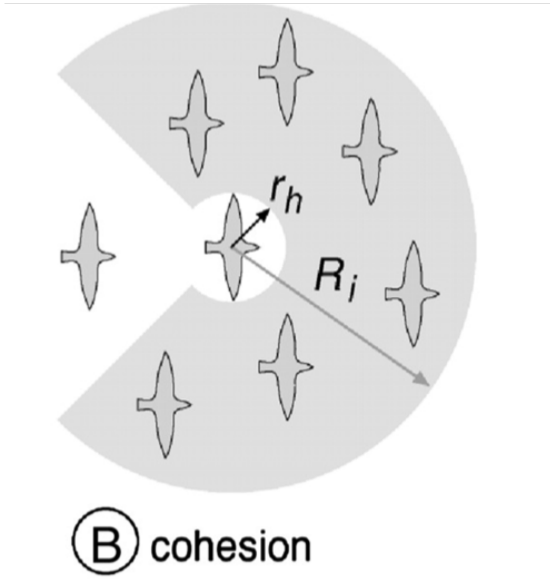

Figure 1: Adapted from Self-organized aerial displays of thousands of starlings

Cohesion of the boid b_i is denoted by k_i and is calculated in two steps. First, the center of the directly visible set V_i is calculated. This center is denoted by c_i and corresponds to the center of density of all visible boids:

$$c_i = \sum_{\forall b_j \epsilon V_i} \frac{p_j}{m}$$

The tendency of the boid b_i to navigate toward the center of density of the visible flock V_i is calculated as the cohesion displacement vector k_i

$$k_i = c_i - p_i$$

There is a special case when no boid is around the b_i and $m = 0$. In this case the Equation is not defined; no cohesion is applied; and, its result is the zero vector $k_i = 0$.

4.2 Alignment

The alignment neighborhood is almost identical to the cohesion neighborhood, but without the inner sphere where the force is zero. It is also the simplest force to describe and steers the bird towards the average forward direction of its interaction neighbors. It is calculated by giving it a force in the direction of the difference between its direction and its interaction neighbors. This is calculated by looking at the normalised forward vectors for the birds.

Boids tend to align with the velocity of their flockmates. This steer is denoted by m_i and is calculated as the average velocity of the visible flockmates

$$m_i = \sum_{\forall b_j \epsilon V_i} \frac{v_j}{m}$$

The velocity speed is the size of the vector. Therefore, the boids will automatically slow down or speed up de- pending on their flockmates. If a boid accelerates too much it can jump out of the visibility sphere of the flock- mates and eventually escape. If there is no boid directly visible, the cardinality of V_i is equal to zero and $m_i = 0$.

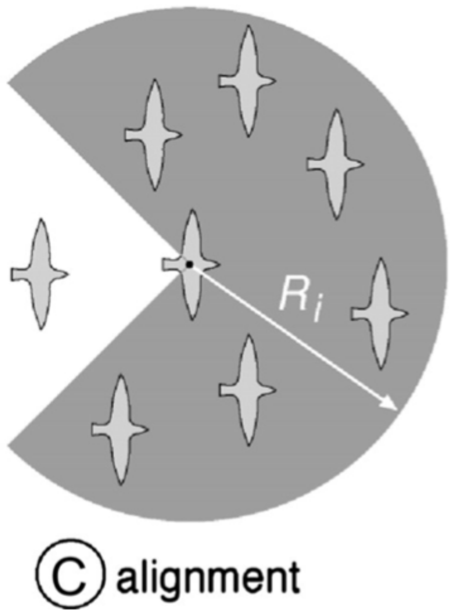

Figure 2: Adapted from Self-organized aerial displays of thousands of starlings

4.3 Separation

Separation counters this and makes starling avoid other starling. In our simple model, this is shorter range force than cohesion to recognise the fact that its main purpose is to stop starling crashing into each other. Meanwhile, alignment steers starling so that they are pointing in the same direction. Again this is a short range force. The separation is force is best understood by its effects within three different areas. If the neighbor is closer than $r_h = 0.2m$, there is a very strong force encouraging it to separate so this neighbor contributes significantly to the separation force. Biologically, this is to avoid a crash.

Vectors defined by the position of the boid b_i and each visible boid b_j are summed and the separation steer, denoted by s_i, is calculated as the negative sum of these vectors:

$$s_i = -\sum_{\forall b_j \epsilon V_i}(p_i - p_j)$$

4.4 Roosting

Another notable property is that birds want to remain close to their roost. To achieve this, we have introduced a social force that acts in the direction of a fixed point above the roost. This is split into two equations: the vertical roost force and the horizontal roost force.

$$f_{Roost_i} = f_{roost_{H_i}} + f_{roost_{V_i}}$$
$$f_{Roost_{H_i}} = w_{Roost_H}(\tfrac{1}{2} + \tfrac{1}{2} * e_{x_i} * n))e_{y_i}$$
$$f_{Roost_{V_i}} = (z_{point} - p_i.z)w_{Roost_V}, where z_{point} = (0,0,1)$$

The vertical roost force is very simple. By setting the preferred vertical height as 0, According to the paper "Aerial flocking patterns of wintering starlings" a

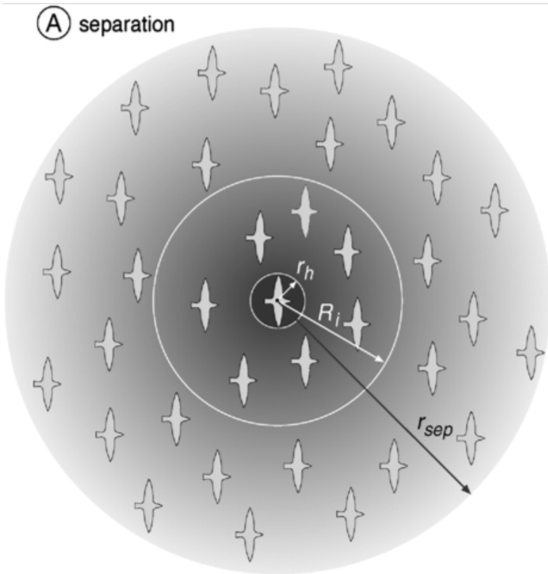

Figure 3: Adapted from Self-organized aerial displays of thousands of starlings

force is introduced that is linearly proportional to any deviation from this force, that always acts vertically. The horizontal roost force is slightly more complicated and is stronger if the bird is flying away from the roost than if it is flying back to it. It acts in a lateral direction relative to the bird, encouraging it to bank and turn back towards the roost. The sign is chosen so that this force reduces the distance the bird is traveling away from the roost. Using the simulation of boids we previously developed, we added the roost force and some wings. Whereas the fish had to be enforced to stay within a fixed area, by adding forces that made it like there were solid walls to avoid, such as in a pond, this was no longer necessary with the introduction of the roost force as birds tend to return to a central position. The introduction of this roost force already started to generate the more complex behaviour associated with birds.

5 Algorithmic Considerations

5.1 Complexity Analysis

The algorithm for collective motion of an individual actor in a swarm requires it to know about the parameters of every other actor in the swarm. Even though its actions are governed only by those agents that are within the required spatial configuration, it still requires to analyze the status of every agent in the environment, even if we have to at then end ignore it.

This implies that the algorithm would grow in complexity as the order of the square of the flock's population ($O(N^2)$). This does not say the algorithm is slow or fast, merely that as the size of the problem (total population of the flock) increases, the complexity increases even faster. Doubling the number of birds, quadruples the amount of time taken.

5.2 Distributed Processing

The reason for the evident slowing down of the processing is that we are using a single processor to run the entire flocking of every agent in the environment. However, consider the real scenario, where each bird is acting like an independent agent, capable of processing its actions independently.

The natural solution is to use distributed processing, as the real flock does. If we distribute each actor among separate processes through multi-threading, we end up having an algorithm that is O(N) per process.

5.3 Spatial Filtering

The aim of the algorithm to be efficient enough, such that it stays unaffected by the number of birds in the flock. Therefore, we can move forward with an N^2 algorithm, given that we are able to keep N small enough to yield a constant time algorithm.

The problem can be solved by dynamic spatial partitioning of the flock. In this approach,we place the actors in a lattice of *bins* based on their position in space. Ant navigating agent needs to only access other agents that are located in *bins* that are close by in the lattice.

5.4 Incremental Collision Detection

Another approach is to do incremental collision detection (x‘nearness testing"). General collision detection is another N^2 algorithm, but if one does collision detection incrementally, based on a partial solution that described the situation just a moment before, then the algorithm need worry only about the changes and so can run much faster, assuming that the incremental changes are small. The incremental collision detection algorithm used in Girard's PODA system [8] apparently achieves constant time performance in the typical case.

6 Conclusion

To summarise, the paper is a notable contribution to a growing area of complexity science, synthesising new empirical data with a range of important recent theoretical developments in complexity science. Having analysed and recreated parts of the model StarDisplay, we recognise its ability to simulate the complexity of the collective behaviour of starling flocking. We also offer an improved implementation of topological interaction which could provide notable qualitative and quantitative differences in the accuracy of the model.

7 References

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