CS250 Final Project: Boids - A Swarm Intelligence Model

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1 Flocking: The Boids Distributed Behavior Model

1.a Motivation for the model

My final project aims to implement the boids model of swarming, created by Craig Reynolds to generate graphics of a flock of birds for animation in motion pictures. Instead of specifying the path of individual agents, the modeler specifies the behavior of each agent. Each bird has a specific set of behaviors when interacting with the

2 Follow the Leader

2.a Assumptions

As the first attempt at a flocking model, I present the following simplifying assumptions.

1. 2D geometric flight. Although Craig Reynolds' ACM SIGGRAPH paper proposed 3D geometric flight, his model is intended to produce 3D graphics instead of researching swarming behaviors. Meanwhile, although visually impressive, 3D flight necessitates motions roll and pitch, in addition to yaw, which is equivalent to turn in 2D flight. In addition, 3D flight requires a local frame of reference because of its complexity, which in turn requires translation from local frames of reference to the global frame of reference. With these additional implementation complexities, however, an extra dimension does not enable the model to answer more questions on intra-flock or flock-environment interactions. Thus, the choice of 2D flight in place of 3D flight in boids model is an easy one. As a result, we use a global frame of reference and geometric flight.

2. Global perception. Each bird can perceive all variables in this model, including other birds and the environment. When we consider the alter-

native - localized perception, where birds have a sphere of perception (particularly vision), global perception seems unrealistic, although it simplifies our base model and serves a basis for comparison. In subsequent models, we implement localized perception and explore how changes in the range of perception impacts both intra-flock dynamics and flock-environment interactions.

3. Position-oriented perception. Each bird has access to other birds' current and last position. This implies that each bird does not have access to others' current velocities but calculates their velocities in the last iteration based on the difference between their current positions and their positions in the last iteration. In other words, birds has a memory containing two frames - the current iteration and the last. The birds' latent velocity perception also makes it difficult to predict the next position of other birds. Subsequent models will change the size of memory, enabling them to average past velocities, and thus make a smoothed prediction. We then explore how different memory sizes affect flocking efficiency. Lastly, to simplify our model, we assume birds do not perceive or calculate accelerations of others, even though reality suggests otherwise.

4. A flock leader. Different flocking strategies can result in different flocking outcomes. Two possibilities are leader-following and density-following. Global perception enables leader-following because each bird can identify the leader among the other birds, retrieve its position, calculate the velocity needed to go to the leader, and actuate to adopt that velocity. In subsequent models, birds will attempt to navigate to a predicted future position of the leader in an attempt to speed up the process of flocking. I will compare these two different navigation strategies in terms of flocking speed and other dynamics.

5. Flock leader rotation. The environment will reassign flock leaders in order to make the model dynamic. In the absense of external stimulus such as environment obstacles and food sources, a change in leadership is the only source of reordering the flock. It also serves as a convenient tool for testing.

6. Velocity matching. Once a bird is in a flock, its goal is to match the velocity of its flockmates. Consistent with the global perception assumption in this base model, we define this goal as matching the average velocity of the flock. In future models with localized perception, we will modify this goal to matching velocity with known adjacent flockmates.

7. Flock centering. If a bird is not in a flock, its goal is to move closer to the leader of the flock (or a center mass in subsequent models).

8. Collision avoidance. In its pursuit of velocity matching and flock centering, a bird must not collide with another bird (which is likely a flockmate). Velocity matching already contributes to the fulfillment of this goal. Additionally, in future models, I attempt to include environment obstacles as well in this endeavor.

9. The order of priority for these three agent goals is collision avoidance, velocity matching, and flock centering. Collision avoidance is a prerequisite for velocity matching and flock centering (or any planned motion).

10. Goal-oriented behavior. If we treat these three behaviors as discrete goals?

2.b Implementation

1. Based on considerations from the previous section, we first specify the bird object and the flock object. As the basic agent of this model, birds have properties including position and velocity. In order to determine state and flock membership, we also associate each bird with an id.

2. Intertwined and conflicting goals. How to adjudicate conflict? 1. Abandon lower priority goal 2. Graded goal with composition and fitness

3. step-by-step: 1. $P_{leader} - P_{self}$ 2. $v_i = max|v|$ with new direction parallel to $P_{leader} - P_{self}$ 3. see if v_i also satisfies velocity matching

4. A bird first attempts to fulfill its goal - if ($goal_1$ and $goal_2$ and $goal_3$) then do all three elseif ($goal_1$ and $goal_2$) then do 1 and 2 else then do 1

   $$composite_{goal} = composite_{g1} + composite_{g2} + composite_{g3}$$

   max fitness over actuation variables =

   $$root((composite_g 1 - goal_1)^2$$
   $$+(composite_g 1 - goal_2)^2$$
   $$+(composite_g 1 - goal_3)^2)$$

5. We define the physical space a bird occupies as a square.

6. Each bird at iteration i has only its position and velocity.

   $$Bird_{i,b} = [P_{i,b}, v_{i,b}]$$

   .

7. The update in each iteration is

   $$dBird_{i,b} = [dP_{i,b}, dv_{i,b}]$$

   .

8. where $dv = a$.

9. So the invariant for each bird is

   $$Bird_{i+1,b} = Bird_{i,b} + dBird_{i,b}$$

   , or

   $$Bird_{i,b} = Bird_{i-1,b} + dBird_{i-1,b}$$

10. We consider implementing the three behaviors in order of precedence.
11. Collision detection.
12. Steering. Turning $-\frac{\pi}{2}$ (90 degrees to the right from $(1,0)$ to $(0,-1)$ is $dv = (-1,-1)$).

    Turning $\frac{\pi}{2}$ (90 degrees to the left from $(1,0)$ to $(0,1)$ is $dv = (-1,1)$).

2.c Questions

Corresponding to our basic assumptions for this simplistic model, we want to change them to extend our model.

1. (Question) Variable speed.
2. (Question) Localized Perception. I expect localized perception to slow down the speed of flocking because the subroutine of steering towards the center mass or the flock leader would no longer be possible without being able to perceive them. Instead, a process of identifying the relative density of neighboring agents would result in localized flocking. Based on the phenomenon of localized flocking, I am also interested in exploring the mechanism of local flocks into a bigger flock.
3. (Question) Localized Collision Detection.
4. (Question) Center Mass instead of flock leader
5. ?? (Question) Dynamic Steering. Can turn a range of degrees each step.
6. (Question) Change order of behaviors: (permutations of order).
7. (Question) Position perception instead of velocity perception.
8. Environment-flock/-bird interactions: Obstacles?
9. What am I measuring: flock size? Num of iterations it takes to achieve a full flock?
10. What is a flock: flock membership based on distance proximity between birds? velocity proximity between birds?
11. Affecting flocking behavior (speed to achieve full flock): 1. changing flocking strategy - center mass vs leader 2. interactions with the environment (obstacle, food)

References

[1] Flocks, herds and schools: A distributed behavioral model,
`http://dl.acm.org/citation.cfm?id=37406`