COP290 - Starlings Simulation

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2015EE10534

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2015EE10735

April 23, 2018

Abstract

Here we develop the mathematical formulation of the starlings simulation problem and present algorithms for it. We want to model the birds as independent agents which can communicate with neighboring agents to fly in coordination and calculate the average energy spent by each bird and the angular momentum and force each bird has to withstand during the flight.

Contents

1 Introduction

Starlings are a type of migratory birds that travel from cooler northern temperate climates every to warmer southern equatorial regions every winter and migrate back during the summer months. They exhibit a unique behavior known as murmurations. These are complex aerial displays of aerial roosts of birds in which thousands of individuals form multiple flocks which are continually changing shape and density, while splitting and merging, a snapshot of which is shown in figure 1.

Figure 1: Starling Murmurations (Source: http://ww2.rspb.org.uk)

These complex formations can be explained and modeled using self-organization principles involving movement and local coordination. We subsequently describe a physical model describing the various forces of interactions between birds in a specific region of interaction and can be used to accurately simulate starling murmurations.

2 Model of the bird

Each individual bird is modeled as a separate entity.Each individual is characterized by its mass m, speed v, and its location (position vector) $\vec{r}$. Its orientation is specified by a local coordinate system (e_x, e_y, e_z). e_x indicates the forward direction, e_y indicates the sideways (lateral) and e_z indicates the upwards (vertical) direction. Subsequently, rotation about the x-axis of the bird is defined as roll, rotation about the y-axis of the bird is known as pitch and rotation about the z-axis is known as yaw.

3 Interacting forces

The interaction forces between starlings in a flock can be classified into three types of forces - Social Forces, Steering Forces and Flight Forces

3.1 Social forces

The interaction forces between starlings in a flock, for each bird are bounded within a region known as the topological range.The range is adaptive and different for each bird and changes between iterations. The interaction range and neighborhood of a starling are defined in 3.1

$$R_i(t + \Delta u) = (1 - s)R_i(t) + s\left(R_{max} - R_{max}\frac{|N_i|}{n_c}\right)$$

$$N_i = \{j \epsilon N; d_{ij} \leq R_i\}$$

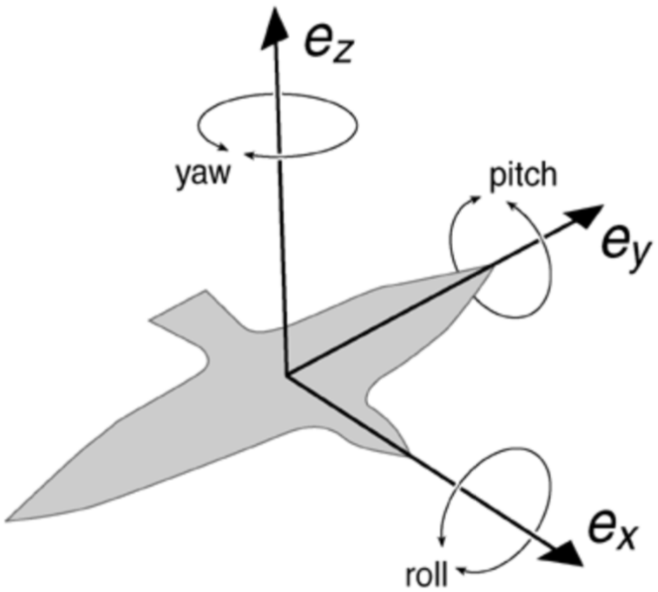

Figure 2: Local Coordinate System

Where, Δu is the reaction time, s is an interpolation factor and R_{max} is the maximal interaction range,N_i is the neighborhood of the individual i, i.e. the set of neighbors of an individual i which is composed of $|N_i|$ neighbors, n_c is the fixed number of topological interaction partners it strives to have and d_{ij} is the distance between individual i and j. The radius of interaction therefore increases if the number of interaction partners $|N_i|$ is smaller than the targeted fixed number n_c, decreases if it is larger and remains constant if it is equal. This fluctuation of $|N_i|$ about n_c, results in an individual i perceiving a force F_{s_i} to move in a direction opposite to the average direction of the locations of N_i others in its neighborhood. This results in a separation force inside a sphere r_{sep}. Outside this sphere the force declines following a halved Gaussian with standard deviation such that at the border of the separation zone the force is almost zero.

$$f_{s_i} = -\frac{w_s}{|N_i|} \sum_{i \epsilon N_i} g(d_{ij}) d_{ij}$$

$$g(x) = \begin{cases} 1 & x \leq r_h \\ exp\big(-\frac{(x-_h)^2}{\sigma^2}\big) & x > r_h \end{cases}$$

Similarly, $|N_i|$ here represents the total number starlings in a neighborhood. the distance between starlings d_{ij} is given by $||p_i - p_j||$ and w_s represents the weighting factor indicting the separation. For cohesion forces an individual i is attracted by a force f_{c_i} to the direction of the centre of mass (i.e. the average x, y, z position) of the group of N_i^* individuals located in its topological interaction neighborhood. Cohesion forces, as mentioned previously are ignored within a sphere of influence of radius r_h. The outer borders of flocks of starlings are denser than the interior of the flock. Therefore, we make individuals cohere more strongly at the border than in the interior by multiplying by the degree to which an individual is peripheral. To measure the location of an individual, we use the degree of its "centrality" the group, C_i. It is calculated as the length of the mean vector of the direction towards its neighboring individuals N_G. We use an arbitrarily fixed value in this simulation.

$$f_{c_i} = C_i \frac{w_c}{|N_i^*|} \sum_{j \epsilon N_i^*} \delta_{ij} d_{ij}$$

$$\delta_{ij} = \begin{cases} 0 & x \leq r_h \\ 1 & x > r_h \end{cases}$$

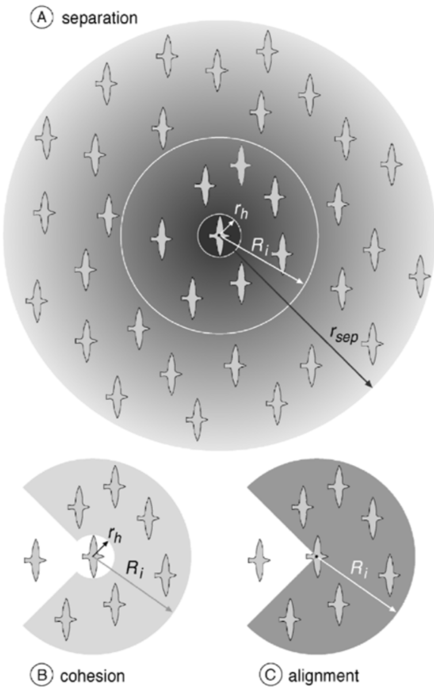

Figure 3: Social Forces

Where $N_i^* = j\epsilon N : jnotin'blindangle'ofi$ and C_i is a hyper parameter indicating the centrality of an individual in the flock.
The Alignment behavior is controlled by the tendency of the starling to align with the average forward direction of its N_i^* interaction neighbors. This alignment force is described by

$$f_{a_i} = w_a \left(\sum_{j\epsilon_i^*} e_{x_j} - e_{x_i} \right) \Big/ \left\| \sum_{j\epsilon_i^*} e_{x_j} - e_{x_i} \right\|$$

The net social force can therefore be described as

$$F_{social} = f_{s_i} + f_{a_i} + f_{c_i}$$

3.2 Steering Forces

Starling also show the murmuration behavior only close to their roosting area. Therefore to limit the three dimensional movement to the flight area above the roosting site, a the starlings perceive an attraction force f_{Roost} to this roosting site. This roosting force has two components - vertical and horizontal and is described as follows

$$f_{roost_i} = f_{roost_{H\,i}} + f_{roost_{V\,i}}$$
$$f_{roost_{H\,i}} = \pm w_{roost_H} \left(\frac{1}{2} + \frac{1}{2}(e_{x_i}.n) \right).e_{y_i}$$
$$f_{roost_{V\,i}} = -w_{roost}(Projection\ of\ vertical\ distance\ on\ z - axis)$$

The sum of the social force, the forces that control speed and ranging and a random force (indicating unspecified stochastic influences) is labeled as the 'steering force'

$$f_{\Im_i} = w_{\Im}.\Im$$
$$F_{Steering_i} = F_{Social_i} + f_{\tau_i} + f_{Roost_i} + f_{\Im_i}$$

3.3 Flying Forces

The standard equations of fixed wing aerodynamics apply to describe the flight of the bird. During horizontal flight with constant cruising speed v_0 the lift L_0 balances the weight mg of the bird and the bird generates thrust T_0 that balances the drag D_0.

$$L_0 = \frac{1}{2}\rho S v_0^2 C_L = mg$$
$$L_i = \frac{v_i^2}{v_0^2} L_0 = \frac{v_i^2}{v_0^2} mg$$
$$D_0 = \frac{1}{2}\rho S v_0^2 C_D = T_0$$
$$D_i = \frac{C_D}{C_L} L$$
$$F_{flight_i} = (L_i + D_i + T_0 + mg)$$

Here, g is the standard gravity, v is the speed, ρ is the air density, S is the wing area, C_L and C_D are the dimensionless lift and drag coefficients; T_0, L_0 , and D_0, respectively represent the default thrust, lift and drag at cruise speed v_0.

When flying along a curve, birds usually roll their wings into the direction of the turn until they are at a certain angle to the horizontal plane, known as the banking angle.This causes the lift to bank also, so that its horizontal component acts as centripetal force which helps to maintain the curved flight path. This is calculated as

$$a_{l_i} = \left(\frac{F_{steering_i}.e_{y_i}}{m}\right).e_{y_i}$$
$$tan(\beta_{in_i}) = w_{\beta_{in}} ||a_{l_i}|| \Delta t$$
$$tan(\beta_{in_i}) = w_{\beta_{out}} sin(\beta_i) \Delta t$$
$$\beta_i(t + \Delta t) = \beta_i(t) + \beta_{in_i} - \beta_{out_i}$$

where β_i is the actual banking angle, $w_{\beta_{in}}$ and $w_{\beta_{out}}$, respectively are the weights for rolling in and out the curve of turning, Δt is the update time and β_{in} and β_{out} are the angles over which an individual intends to move inwards and outwards.

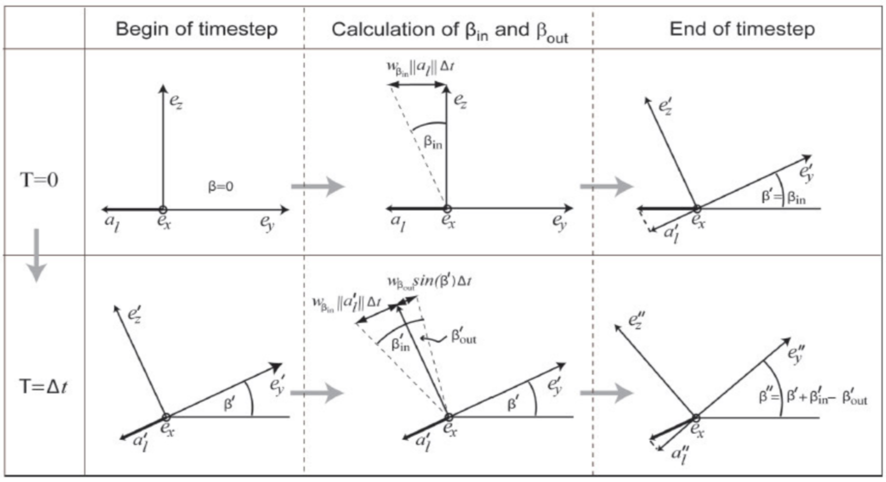

Figure 4: Flying Forces

4 Calculations of Required Quantities

For each iteration of calculating the net force on each starling, the net steering and flight forces are summed vectorially and summed using Euler's method of integration, to calculate the position and velocity at the end of each time-step Δt

$$v_i t + \Delta t = v_i(t) + \frac{1}{m}\left(F_{steering_i}(t) + F_{flight_i}(t)\right)\Delta t$$
$$r_i t + \Delta t = r_i(t) + v_i t + \Delta t.\Delta t$$

Here, v_i is the speed of individual i, m its mass, r_i its location, and Δt is the update time.

5 Multi-Threading

References