Starling Murmuration

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1 Introduction

(Flocking Behavior): Flocking is a behaviour belonging to a group of birds(2 or more) in which their movement is dependent/restricted by the behaviour of the other birds.It is parallel to the behavior of other things as well such as the shoaling behaviour of fishes or the swarming behaviour of insects.

Using the rules of flocking ,the birds can create a swaying form of motion which can be hard to create otherwise as the rules are fixed and same for each of the birds.Here we will learn and implement the flocking behaviour of starlings and of their murmuration.It will be somewhat based on Boids which was an artificial life program creat by Craig Reynolds which was used to simulate the behavior of flocking of birds.

Starling flocks, it turns out, are best described with equations of "critical transitions" — systems that are poised to tip, to be almost instantly and completely transformed, like metals becoming magnetized or liquid turning to gas. Each starling in a flock is connected to every other. When a flock turns in unison, it's a phase transition.At the individual level, the rules guiding this are relatively simple. When a neighbor moves, so do you. Depending on the flock's size and speed and its members' flight physiologies, the large-scale pattern changes. What's complicated, or at least unknown, is how criticality is created and maintained

2 Flocking

Flocking can be boiled down to 3 basic rules in which birds are seen to be flocking in:-
1)Separation - avoid crowding neighbors (short range repulsion)
2)Alignment - steer towards average heading of neighbors
3)Cohesion - steer towards average position(centre of mass) of neighbors(local flockmates) (long range attraction)

Measurements of bird flocking have been made using high-speed cameras, and a computer analysis has been made to test the simple rules of flocking mentioned above. It is found that they generally hold true in the case of bird flocking, but the long range attraction rule (cohesion) applies to the nearest

5-10 neighbors of the flocking bird and is independent of the distance of these neighbors from the bird. In addition, there is an anisotropy with regard to this cohesive tendency, with more cohesion being exhibited towards neighbors to the sides of the bird, rather than in front or behind. This is no doubt due to the field of vision of the flying bird being directed to the sides rather than directly forward or backward.

3 Dynamics of the Rules

"What does a bird actually see when it is part of a large flock?" Its view out from within a large flock likely would present the vast majority of individuals merely as silhouettes, moving too fast and at too great a distance to be tracked easily or even discriminated from one another. Here the basic visual input to each individual is assumed to be based simply on visual contrast: a dynamic pattern of dark (bird) and light (sky) across the field of vision (although it might be possible to extend this to other swarming species and environmental backgrounds, respectively). This has the appealing feature that it also is the projection that appears on the retina of the bird, which we assume to be its primary sensory input. A typical individual within a very dense flock would see other, overlapping individuals (dark) almost everywhere it looked. Conversely, an isolated individual, detached from the flock, would see only sky (light). The projected view gives direct information on the global state of the flock. It is a lower-dimensional projection of the full 6N degrees of freedom of the flock and therefore is more computationally manageable, both for the birds themselves and for the construction of simple mathematical models of swarm behavior.

The information required to specify the projection mathematically is linear in the number of boundaries. Our simplifying assumption is that the individual registers only such a black-and-white projection (in addition to nearest-neighbor orientation). This information, then, is all that would be available to an agent, regardless of the behavioral model that might be chosen. Individuals in a flock that is sparse enough for them to typically see a complex projected pattern of dark and light have more information about the global state of the flock. Such sparse flocks also allow an individual to see out in a significant fraction of all directions, which would allow the approach of a predator, or at least the response of distant individuals to the approach of a predator, to be registered. Conversely, a dense, completely opaque flock would offer little information about either the global state of the flock or the approach of predators.

In the remainder of this article, we focus on proposing a model for how bird flocks organize and specifically on how the global density is regulated, which remains an open question (1). We develop what we believe to be the simplest possible model that takes the projected view described above as sensory input while retaining co-alignment with (visible) nearest neighbors and allowing for some noise. We then compare the swarms generated by this model with data.

We define the opacity, Θ', of a flock to be the fraction of sky obscured by individuals from the viewpoint of a distant external observer. A closely related quantity is the average opacity seen by a typical individual located within the flock, written Θ. Crucially, the opacity and density are quite different quantities: flocks containing large numbers of individuals might be nearly opaque ($\Theta \sim 1$) even for very small densities, corresponding to well-separated birds. Below we present evidence that large bird flocks are marginally opaque, with opacities that are intermediate, neither very close to 0 nor 1 ($0.25 \lesssim \Theta' \lesssim 0.6$ in our data). Such a state corresponds to a complex projected pattern rich in information.

4 Hybrid Projection Model

We propose a hybrid projection model in which each individual responds to the projection through the swarm it observes. We first identify those (dark) angular regions in which a line of sight traced from an individual to infinity intersects one or more other members of the swarm. These are separated by (light) domains (Fig. 1)

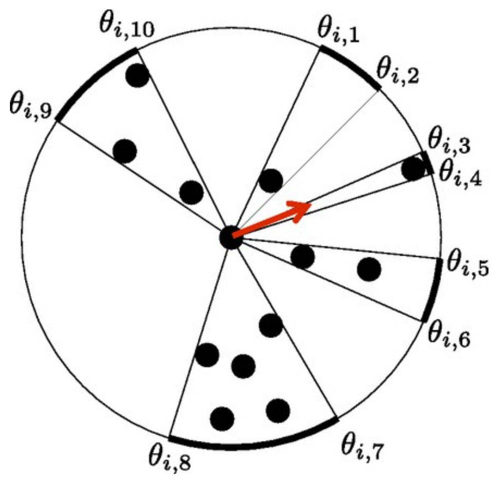

Figure 1: 2-D Swarm

Sketch showing the construction of the projection through a 2D swarm seen by the i^{th} individual, which here happens to be one near the center of the swarm. The thick dark arcs around the exterior circle (shown for clarity; there is no such boundary around the swarm) correspond to the angular regions where one or more others block the line of sight of the i^{th} individual to infinity. The sum of unit vectors pointing to each of these domain boundaries, at the angles shown, gives the resolved vector $\underline{\delta}_i$, shown in red, that enters our equation of motion. See *SI Appendix* for the extension to 3D.

Each individual is assumed to be isotropic and has a size $b = 1$, which then defines our units of length. Anisotropic bodies give rise to a projected size that depends on orientation and are explored further in *SI Appendix*. In two dimensions, the domain boundaries seen by the i^{th} individual define a set of angles θ_{ij}, measured from an arbitrary reference (x) axis, where the index j runs over all the $\mathcal{N}_i$ light–dark (or dark–light) domain boundaries seen by the i^{th} individual, equal to 10 for the central individual shown in **Fig. 1**. These θ_{ij} are a reasonable choice for input to a behavioral model: edge detection such as this is known to be performed in the neural hardware of the visual cortex in higher animals (**21**). In particular, behavioral models based on motional bias toward either the most dark or light regions tend to be unstable with respect to collapse or expansion, respectively. The simplest candidate model that might support physically reasonable solutions therefore is one that responds to the domain boundaries. We seek a model that takes as input the angles specifying the domain boundaries and produces a characteristic direction for the birds, acknowledging that their actual motion also should include their known tendency to coalign with neighbors and also the effect of some noise. A natural choice for this characteristic direction is simply the average direction to all boundaries $\underline{\delta}_i$:

$$\underline{\delta}_i = \frac{1}{\mathcal{N}_i} \sum_{j=1}^{\mathcal{N}_i} \begin{pmatrix} \cos\theta_{ij} \\ \sin\theta_{ij} \end{pmatrix}.$$

Figure 2: Formula1

This easily can be extended to 3D flocks, in which the light–dark boundaries now may be represented as curves on the surface of a sphere and δ becomes the normalized integral of radial unit vectors traced along these curves; see *SI Appendix* for details.

Our model involves $\underline{\delta}_i$ in such a way as to correspond to birds being equally attracted to all the light–dark domain boundaries. In addition, they coalign with visible local neighbors, assigned in a topological fashion (**6**, **9**). We define visible neighbors to be those for which there is an unbroken line of sight between the two individuals (see *SI Appendix* for details). We incorporate these two preferred directions, arising from the projection and the motion of neighbors, into an otherwise standard agent-based model for a swarm of *N* particles moving off-lattice with constant speed v_0 ($v_0 = 1$ in all our simulations). For simplicity, we treat the individuals as “phantoms,” having no direct steric interactions (the effect of introducing steric interactions is explored further in *SI Appendix*). The equation of motion for the position $\underline{r}_i^t$ of the i^{th} individual at discrete time *t* is

$$\underline{r}_i^{t+1} = \underline{r}_i^t + v_0 \hat{\underline{v}}_i^t$$

Figure 3: Formula2

with a velocity parallel to

$$\underline{v}_i^{t+1} = \phi_p \underline{\delta}_i^t + \phi_a \widehat{\left\langle \underline{v}_k^t \right\rangle_{n.n.}} + \phi_n \underline{\eta}_i^t,$$

Figure 4: Formula3

where $\langle \ldots \rangle_{n.n.}$ is an average over the $k \in [1, \sigma]$ nearest neighbors to the i^{th} individual (σ = 4 in all simulations); a hat (^) denotes a normalized vector; and $\underline{\eta}_i^t$ is a noise term of unit magnitude having a different (uncorrelated) random orientation for each individual at each timestep. This equation involves only three primary control parameters, ϕ_p, ϕ_a, and ϕ_n, the weights of the projection, alignment, and noise terms, respectively. We further simplify by considering only the relative magnitudes (ratios) of these control parameters, which then are taken to obey

$$\phi_p + \phi_a + \phi_n = 1.$$

Figure 5: Formula4

In conclusion,by the following rules of flocking and the following properties and mathematical restriction of the starlings with each other,we will be able to represent and implement the dynamics and movement of starling murmuring with respect to each other.