

# Animation of Flocks Flying in Line Formations

Marina Klotsman & Ayellet Tal  
Technion

## Abstract

The coordinated flight of bird flocks is a pleasant and attractive sight. While most previous approaches have focused on animating cluster formations, this paper introduces a technique for animating flocks that fly in certain patterns (so-called line formations). We distinguish between the behavior of such flocks during initiation and their behavior during steady flight. We provide a biologically-motivated technique for animating bird flocks, which produces plausible and realistic-looking flock animations.

## 1 Introduction

Researchers in computer graphics have long been intrigued by the challenge of realistically animating groups of animals. One such example is the synchronized motion of flocks of birds, which is a delightful and fascinating sight. Flying flocks can be classified by their formation – *cluster formations* or *line formations* [1]. In cluster formations, typical of small birds as well as fish and herds, the animals are organized in irregular shapes. Conversely, in line formations the flocks are organized in a characteristic pattern, such as a line, 'V', or 'U'. These formations are typically two-dimensional and exhibit a high degree of regularity in spacing and alignment. They are common in flocks of large birds, such as waterfowls, cranes, and pelicans.

In his ground-breaking paper, Reynolds proposed animating groups by simulating the behavior of each bird independently [2]. The results are pretty animations of cluster flocks. Others have also addressed the animation of cluster formations [3, 4]. This paper introduces a technique for realistically animating flocks of birds flying in line formations (Figure 1).

In nature, these flocks undergo two stages: flock *initiation* (also termed *formation*) and *steady flight*. Initiation occurs during takeoff, with many rapid changes in the locations of the birds within the flock. During steady flight the flock flies over



Figure 1: Animation of a flock of barnacle geese (snapshots)

large distances in more stable shapes. Previous approaches have not distinguished between these stages and applied the same rules to the whole animation. While this strategy suffices for clusters, it does not suit the long, steady flights of flocks flying in line formations. We propose modeling these stages differently.

Why flocks fly long distances in specific patterns is still a puzzle [5]. While it is often believed that the central rationale is to save energy [6], no model exists that can precisely predict the birds' positions. This lack of knowledge directed us into choosing a data-driven approach, utilizing real examples of flying flocks, for animating the steady-flight stage. Since existing examples are typically very short, while the flight is extremely long, we augment these examples with calculations of potential energy-savings. This combination is shown to produce not only feasible, but also eye-pleasing animations of flying bird flocks.

Inspired by previous work, our approach for animating the initiation stage is rule-based, where the behavior of each individual bird governs the motion of the whole flock. We introduce a new set of rules that better suits line formations. These rules are based on two novel drives, target-reaching, and separation.

Our contribution is hence threefold. First, we propose to distinguish between the initiation and the steady flight. Second, we show how steady flight patterns can be produced by combining

a data-driven approach with an energy-savings model. Finally, we suggest a novel set of rules for the initiation stage of line-formation flocks. See [7] for a full version of the paper.

## 2 General Approach

In nature, during initiation and takeoff the positions and the velocities of the birds change rapidly. In contrast, smaller changes occur during the almost two-dimensional steady flight [1]. Our goal is to animate these different behaviors, so that the generated animations resemble flocks in nature.

Since no model exists that accurately predicts the behavior of a flock, we turn to a data-driven approach – learning from examples. Given an example movie, the challenges are to determine the major variables that characterize a given flock, extract the parameters that are relevant for computing them, compute these variables, and utilize them in the creation of plausible flock shapes.

While data-driven methods have been used successfully in crowd simulation [8, 9], they cannot be used in a straightforward manner in our case. This is because, unlike human pedestrians who have their own individual trajectories, a bird flock has a common global goal – migrating together. Thus, while pedestrian behavior can be learned from various scenes in different movies, the trajectories of birds must maintain the sequential ordering of the original movie. Using the shapes in a single movie is unsatisfactory as well, since movies are typically very short and contain a limited number of possible flock shapes.

Hence, our solution combines the data-driven approach with an energy-savings model. The key idea is to learn from examples – but to learn the energy-savings values – not the trajectories, since these variable are generally believed to be the primary reason for flying in a pattern. A bird flying alone at steady speed demands more flight power than a bird flying in a flock, where drag reduction helps the bird save energy. *Power reduction* is defined as the ratio between this difference in flight power – that of a single bird minus that of a bird in a flock – and the flight power of a single bird.

We aim at generating shapes that preserve similar power-reduction values as those obtained in the example shapes, thus guaranteeing plausible shapes. Another benefit of our scheme is that it does not constrain us to the existing example shapes, in terms of the number of birds in the flock, the relative location of the leader bird, and the variations in birds' positions.

Alternative simpler methods, such as interpolation, not only limit the number of possible shapes, but might also generate shapes that do not com-

ply with feasible energy-savings values, and thus could not occur in nature.

Below we describe the three components of our method: parameter extraction, steady flight, and flock initiation.

**Parameter extraction:** Most existing movies show small portions of the flight in a formation (steady flight). We aim at extracting the parameters that can help us compute the power-reduction values of the birds, which are essential in creating plausible flock shapes. These parameters are the flock's optimal shapes and the outliers.

The algorithm consists of two steps. First, the position parameters are extracted for each movie frame. Then, the optimal geometric shape of the flock and the outliers are computed for each frame. The latter is performed using the RANSAC (Random Sample Consensus) algorithm [10]. RANSAC allows a model to be fit to a data set that contains outliers and these outliers to be detected. In our case, the input to RANSAC is the positions and the possible models. These models are either a parabola for  $\{U, J\}$ -shapes and a linear function for  $\{V, line\}$ -shapes. The output is:

1. The optimal geometric shape that best fits the current formation, as well as the outliers.
2. Position deviations: The inliers' mean of the y-positions and the standard deviation.
3. Special roles: Being either a leader or an outlier bird is considered a special role.

**Steady flight:** The input consists of the parameters extracted, the physical characteristic of the bird in terms of the wing-span  $b$ , the required number of birds in the animation  $N$ , and the required number of frames in the animation  $F$ . The goal is to construct an animation of a steady flight of a flock.

Our proposed solution combines an energy-savings model with a data-driven approach. It does not constrain us to the existing example shapes, in terms of the number of birds, the relative location of the leader bird, and the variations in birds' positions.

The key idea is to learn the flock's energy-savings patterns and generate shapes that respect them, thus creating plausible shapes. An important and novel aspect of our scheme is showing how the positions of the birds can be computed by solving a system of non-linear equations that take the power reduction values into account.

The algorithm, which is outlined below, proceeds in four steps. We first create some initial shapes whose geometry is similar to the shapes in the example movie, but whose number of birds is  $N$ . These shapes are used to extract the range of power reduction values for each bird. These values allow us to generate a wider variety of plau-

sible shapes that comply with the energy-savings pattern. Once these plausible shapes are produced, they are interpolated to generate the final animation.

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**Algorithm 1** Steady flight animation

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**Input:**

The extracted parameters (shapes, deviations, special roles);

$b$  – the wing-span;

$N$  – #birds in the animation;

$F$  – #frames in the animation.

**Output:** An animation ( $F$  frames) of an  $N$ -bird flock.

**Algorithm:**

1. Construct initial shapes of an  $N$ -bird flock, which maintain the general shapes and deviations of the movie.
  2. Calculate the power-reduction values of each bird, for each shape constructed in Step 1. We use the model of [11].
  3. Construct new key shapes that satisfy the power-reduction values calculated in Step 2.
  4. Create an  $F$ -frame animation of a steady flight, by interpolating between the shapes generated in Steps 1 and 3.
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Step 3 is the key step of the algorithm. Constructing a variety of feasible key shapes is performed by first associating every animated bird with a range of “typical” power-reduction values (obtained at Step 2) and then generating new shapes that comply with this range. We show that the positions of the birds can be calculated by solving an  $N$  non-linear equations system.

**Flock initiation:** The goal is to produce an animation that begins with a given (e.g., random) distribution of the birds and ends when the flock converges to the first shape in the steady-flight animation.

As in previous *artificial bird* models, our animated bird lives in a *world* and *perceives* its state through its senses. The bird’s *actions* are governed by its interpreted perception and attempt to satisfy its *drives*.

We propose a new set of drives, suitable for flocks flying in line formations:

1. **Target-reaching:** The tendency of a bird to reach a specific distance from a chosen reference bird.
2. **Separation:** The tendency of a bird to have a unique reference bird to follow.

The target-reaching drive accounts for the main distinction between line-formation flocks

and cluster-formation flocks. Rather than attempting to fly “close” to their flockmates (by attraction) to form a cluster, the birds try to converge to a certain shape. Since no global decisions are made, this target shape should be attained through the actions of each individual bird. The drive of each bird (excluding the leader) is, hence, to reach a position at a certain *target distance* on a certain *side* (left/right) relative to its reference bird (which can change at every time step).

The separation drive has two goals. First, it ensures that at the end of the initiation, each bird is followed by at most one bird (with the exception of the leader). In addition, it aids in avoiding collisions between the birds.

The resulting actions of these drives are changes in the bird’s speed and direction.

### 3 Results

Figure 2 shows an example where the number of birds in the example movie and the animation is the same. The animated birds are super-imposed on the real barnacle geese, so that they could be compared. While the shapes are not identical, they bear similarity and look as natural as those of the real flock.

Figures 3–4 show snapshots from an animation that uses the same example movie (of 9 birds), yet creates an animation of 14 birds. Figure 4 demonstrates initiation from random locations, whereas Figure 3 shows the steady flight stage. It can be seen that the general shapes are maintained, creating realistic-looking flocks. For instance, the two rear birds on the right side are very close (in  $x$ -coordinates) to each other. This happens in the original movie for the rear birds to the left. Moreover, it is interesting to note that the flock changes from a U-shape to a V-shape. This occurs both in the original 9-bird flock and in the animated 14-bird flock.

### 4 Conclusion

This paper has introduced an approach for animating flocks of birds flying in line-formation patterns. We distinguish between the behavior of such flocks during initiation and their behavior during the steady flight and propose different techniques for animating each of these stages. A data-driven approach that utilizes an energy-savings model is proposed for animating the steady flight. We show that this problem can be formulated as a system of non-linear equations and solved. Rules are used to govern the behavior of the birds during initiation. These rules differ from those of previous

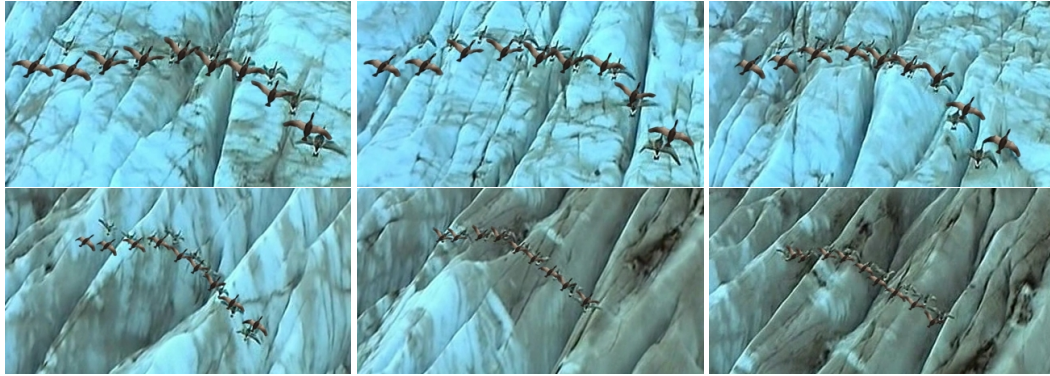


Figure 2: Snapshots from a steady flight of 9 barnacle geese – the brown (higher) birds are the animated ones, whereas the gray ones belong to the original movie (along with the original background). Snapshots from the initiation of this flock are presented in Figure 1, using a different background



Figure 3: Snapshots from a steady flight animation of a 14-bird flock, whose behavior was learned from the movie of the 9-bird flock in Figure 2.

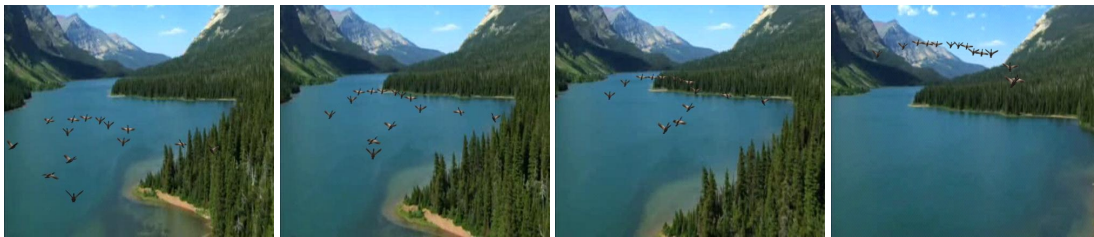


Figure 4: Snapshots from the initiation of a 14-bird flock, whose steady flight is shown in Figure 3.

work, which have focused on cluster flocks.

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