FUZZY MODEL OF BIRD FLOCK FORAGING BEHAVIOR

Miha Moškon[1], Frank H. Heppner[2], Miha Mraz[1], Nikolaj Zimic[1], Iztok Lebar Bajec[1]

[1]University of Ljubljana, Faculty of Computer and Information Science
1000 Ljubljana, Tržaška 25, Slovenia
[2]University of Rhode Island, Department of Biological Sciences, Kingston, RI 02881 USA

miha.moskon@fri.uni-lj.si (Miha Moškon)

Abstract

We present a fuzzy logic based model for the simulation of bird foraging behavior. The core of the model is based on the fuzzy model for the computer simulation of bird flocking presented by Lebar Bajec et al. The later was extended in such way that allows the simulation of bird foraging. In order to upgrade the original model it was necessary to advance the artificial world and the synthetic bird (synbird). The former was expanded with the introduction of feeding areas - circular regions containing food. Similar to the synbirds they were implemented as animats, i.e. by means of a three stage transition function. The first stage of this function is responsible for the selection of information about the synbirds that are currently within the area, the second for computing the change of the available food and the third for computing the new state of the feeding area. In addition to the introduction of feeding areas we upgraded the synbirds with the notion of hunger. In order to do this two drives were added to the model's basic drives and the synbird's internal state was changed as well. To support the attraction of the feeding areas a new perception function was added and the action selection was upgraded so as to take into account the influences of the newly introduced drives. The behavior of the synbirds is governed by their behavior type, which can be feeding, take off, flying or landing. While the behavior type drive is responsible for the transition between behavior types, the feeding drive, with respect to the current behavior type, influences hunger, flight altitude, speed and flight direction. With the extensions made we moved the model a step closer to a more naturalistic simulation of bird behavior.

Keywords: fuzzy logic, animat, boid, foraging, flock.

Presenting Author's Biography

Miha Moškon received a BSc degree in Computer Science from the Faculty of Computer and Information Science, University of Ljubljana in 2007, where he is currently working as a researcher in the Computer Structures and Systems Laboratory. His research interests include fuzzy logic, artificial life and communication protocols.

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1 Introduction

Many species of birds fly in highly organized and coordinated flocks. These have been characterized [1] as either *line flocks*, represented by large birds like geese that fly in extended lines often joined together to form V's, or *cluster flocks* that are frequently formed by small birds like pigeons, starlings, and small shorebirds. These flocks may be very large, in the tens of thousands of birds, and show coordinated turning and wheeling movements. Often, cluster flying species also demonstrate *roosting* behavior, where large numbers of birds will gather overnight in trees or buildings to sleep, then depart the roost at dawn to go to foraging areas. Typically, these flocks will fly some distance from the roost, then drop down to a feeding area, like an agricultural field. They will then forage in the feeding area, then depart to go to another feeding area, or at the end of the day will return to the roost. Arrivals and departures from foraging areas may also display coordination, the birds leaving *as if* by signal. These coordinated movements of small birds have fascinated observers for millennia, but it was not until the mid-80's that successful attempts to produce a simulated flock with the aid of a computer were reported [2, 3]. Initial models were followed by studies of the evolution of flocking behavior [4, 5, 6, 7, 8], flock take off and landing [9], models concentrating on the stability analysis of organized flocks [10, 11] and models concerned with leadership and decision making in animal groups on the move [12]. Nevertheless most of these models did not differ substantially from those of the early days. Indeed all of them originate from the premise that flocking might be an emergent property arising from individuals following simple rules of movement. In this view all models develop mathematical equations that dictate the movement of individual synthetic birds (*synbirds* or *boids*) in order to produce a visually credible flocking behavior. It is only recently that the behavior of these synthetic flocks (*synflocks*) has been refined with the use of fuzzy logic [13, 14, 15, 16]. Although these models produce behavior that superficially resembles natural cluster flocks as represented in 2D, natural flocks are undoubtedly more complex. The ultimate test for a synflock is that it be able to predict natural behavior under defined conditions. For example, "Based on the behavior of the starling synflock, if there be 30 birds in a natural starling flock, it will turn every 37 sec and forage on a field for no more than 4 min." To achieve this goal, synflocks must include naturalistic parameters, in addition to the basic engine that produces flocking behavior in the model. We here report the next step in producing a more naturalistic synflock; the addition of feeding behavior, satiation, and its effects on flock organization and behavior through modification of a fuzzy logic model.

2 Methods

The core model [15, 16] presumes that each animal exists in time and space and is surrounded by inanimate and animate objects (i.e. *the universe*). It also presumes that each animal *perceives* the current state of relevant parts of the universe through senses. Regarding the animal's current internal state only certain inputs from the universe are important, and the animal's *drive* is to optimize the rate of their occurrence, e.g., maximize "pleasure" and reduce "pain." The animal is capable of influencing its internal state and the state of the universe through actions. It selects actions that satisfy its drives. Finally the animal performs a sequence of movements that will accomplish a combination of these actions (*action selection*). An animal model that takes into account the above characteristics is referred to as an *animat* [17].

The core model's universe comprises only synbirds. A synbird's state in a certain time instant is given by its current position in space, flight direction, flight speed and internal state (i.e. the range of visual perception, maximal achievable flight speed, maximal available force, etc.). Its next state is derived through a three-stage transition function that comprises *perception of the universe*, *drives* and *action selection*. Perception of the universe is limited by the field of vision and perception distance. When selecting the actions it needs to take, it arbitrates among three drives that simulate flocking behavior [3], namely:

- *separation*: avoid collisions with nearby flockmates,
- *alignment*: attempt to match flight speed and flight direction with nearby flockmates,
- *cohesion*: attempt to stay close to nearby flockmates.

For a more detailed description of the core model see [13, 14, 15, 16].

As a first approximation of a more naturalistic model, the following sections present the modeling of feeding areas and their inclusion into the artificial world, followed by the improvement of the synbird with the notion of satiable hunger and behavior type.

2.1 Properties of feeding areas

Feeding areas like agricultural fields can be approximated as inanimate stationary objects. More precisely we approximate them as circular regions within the artificial world, where synbirds can satiate their hunger. Thus they can be defined by stating their position within the model's universe, their radius and the amount of food that is situated within them.

As the core model is based around the animat framework [18] and the latter can be used to model both animate and inanimate entities [16] we model feeding areas as simplistic animats (i.e. animats with a straightforward transition function). They employ only one perception function, one drive function and a simple update action selection function. The perception function determines how many synbirds are currently feeding in the area and their state of hunger, which in turn determines how quickly they remove food from the area. From this information, the drive function determines how much food has been consumed. It increases linearly with the hunger of synbirds that are currently feeding within the area. Based on the computed amount of consumed food the update function updates the state of the feeding area (i.e. subtracts it from the amount of food that is currently available within the feeding area).

2.2 Properties of synbirds

To be able to model naturalistic behavior the synbird had to be upgraded with satiable *hunger* as well as *types of behavioral actions* (*flying*, *landing*, *feeding*, *taking off*) [19, 20]. In other words three dynamic properties named hunger, behavior type and flight altitude were added to the synbird's internal state. To support the new functionalities the synbird was advanced with an additional perception function, which gives it the ability to obtain information (i.e. location and amount of available food) about the feeding areas (*feeding areas perception function*). The later is required by two newly introduced fuzzy logic based drives, namely the *feeding drive* and *behavior type drive*.

The feeding drive implements the synbird's tendency to fly toward a feeding area, land within it and satiate its hunger. When the synbird is no longer hungry or when there is no more food left within the feeding area, the drive ceases its influence and the synbird takes off. These functionalities are achieved through the feeding drive's influence on the synbird's flight direction, speed and altitude. For reasons of simplicity the feeding drive also computes the modification of the level of hunger. If the synbird is situated within a feeding area and its behavior type is feeding, hunger is decreased. Otherwise it is increased.

The drive's influence on flight direction, speed and altitude is derived through the evaluation of a set of fuzzy rules. These are evaluated per every perceived feeding area, algebraically summed together and finally defuzzified to obtain the vector that represents the required change in direction, speed and altitude. The influence on hunger is on the other hand computed by means of a simple equation:

$$h_{\mathrm{f}} = \begin{cases} e_{\downarrow} h & ;\text{if feeding} \\ e_{\uparrow}(1-h) & ;\text{otherwise,} \end{cases} \quad (1)$$

where $e_{\downarrow} \in [-1, 0]$ is the hunger decrease factor, $e_{\uparrow} \in [0, 1]$ is the hunger increase factor, and $h \in [0, 1]$ is the current hunger value.

Each synbird in the improved model can work in four different types of behavior: flying, landing, feeding and taking off. They dictate the degree of influence of the feeding drive and also the degree of influence of the core model's drives. The latter are most of the time left untouched, except for when the synbird is feeding, when they are disregarded.

The drive responsible for transitions among different behavior types is the behavior type drive. The transition depends on the synbird's current level of hunger, current behavior type and the distance from the perceived feeding areas in conjunction with the amount of food situated within them. The conditions that define each behavior type and their descriptions are as follows:

- the synbird transits to or remains feeding if its hunger is high, its altitude is zero and its position is within a feeding area with a sufficient amount of food; in this behavior type the synbird's velocity is small and its level of hunger is decreasing (in all other behavior types the level of hunger is always increasing);
- the feeding behavior type is usually followed by taking off; the transition occurs when the synbird satiated its hunger or when there is no more food left within the feeding area; in this behavior type the synbird's velocity and altitude are rapidly increasing;
- when the synbird's level of hunger is low and its altitude is high enough its behavior type transits to flying; in this behavior type the feeding drive's influences are disregarded and the synbird's behavior is the same as in the core model;
- as time passes the synbird's hunger increases; when it is high enough and a feeding area with a sufficient amount of food is nearby, its behavior type transits to landing; in this behavior type the feeding drive causes the synbird to change its direction toward the feeding area; reaching it the synbird begins circling around it while diminishing its altitude; landing is usually followed by feeding.

The behavior type drive is again implemented by means of a fuzzy rule set. The sequence of transitions among behavior types is presented in Figure 1.

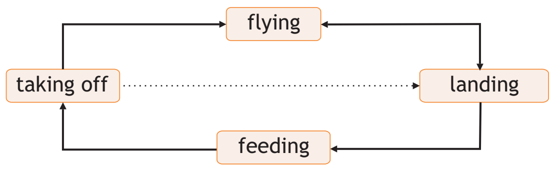

Fig. 1 Transitions among behavior types. The dotted line indicates a synbird taking off and immediately landing, a behavior often seen in natural flocks.

To take into account the newly introduced drives as well as the new synbird's properties the core model's action selection had to be changed. Now it combines the actions resulting from the core drives and the actions resulting from the feeding and behavior type drives. It computes a weighted sum of all drives' outputs where each drive's priority is represented by its weight. It has to be noted that unless the synbird is feeding, the basic functionality of the core model (i.e. flocking behavior) has been preserved.

3 Results and discussion

Because there are no real world data readily available for testing bird flocking behavior models and obtaining them is an extremely difficult, if at all possible, task [9] actual truth testing is a major problem. At this stage in time, we thus decided to test our model using a series of controlled experiments and compare the displayed behavior against our knowledge about the typical behavior of bird flocks while foraging.

In nature, in the morning, birds usually wake up at their roosting area and as time passes their hunger increases. To satisfy it the birds start to leave the roosting area in search of food. Once in the air they start forming flocks and circle around the roosting area. However, as they arrive in the proximity of a feeding area and notice it, they direct toward it. After descending in a circular motion and landing on it they start to feed and their hunger diminishes. When they satiate their hunger or when there is no food left, they leave the feeding area and fly around forming flocks until their hunger increases again. They spend their whole day alternating between feeding areas, while in the evening they return back to the roosting area where they overnight.

We can therefore sum up the expectations from our model in the following list:

- if there is not a feeding area nearby, the synbirds fly at high speed at a high altitude,
- while hunger is small, nearby feeding areas do not affect the behavior of the synbirds,
- when hunger increases and the distance between the synbirds and a perceived feeding area with a sufficient amount of food diminishes, the influence on their behavior increases,
- if the synbirds reach a feeding area while flying at a high altitude, they start circling around it while gradually decreasing their altitude,
- if altitude is small enough the synbirds enter the feeding area, land within it and start feeding,
- when hunger is small enough or when there is no more food left, the synbirds leave the feeding area,
- throughout the course of the whole simulation with the exception of the synbirds' feeding collision avoidance and organized flocking behavior are preserved.

The goal of our first experiment was to demonstrate that the configuration where all of the fuzzy values on which the feeding and behavior type drive are based (i.e. hunger, behavior type, altitude and distance from the feeding area) have approximately the same values, gives results that are in accordance with our expectations. It was carried out with a flock of 11 synbirds and a single feeding area with a sufficient amount of food to enable all landing synbirds to satiate their hunger. In the initial configuration all of the synbirds had the same configuration. Their hunger level was set to zero (satiated), behavior type to flying and altitude to high. The initial distance between the synflock and the feeding area was large enough not to have an initial effect on the synbirds' behavior.

A sequence of equidistant frames from the first experiment is presented in Figure 2. In the beginning of the simulation the feeding area does not have any influence on the behavior of the synbirds. Their behavior is equivalent to the one displayed by the core model. The added functionalities of the extended model can be seen from time step 1258 onwards, when the synbirds' level of hunger increases enough and the synbirds approach the feeding area. Initially the synflock changes its direction toward the area and as it reaches it, it begins circling around it while decreasing the altitude. When flying low enough the synbirds change their direction toward the center of the feeding area, land within it and begin with the process of feeding (note frame 3774 where their wings are folded up). Once satiated they take off and leave the feeding area (frame 4400).

The purpose of the other experiments was to test the model using several configurations with different hunger values and two feeding areas with different amounts of food. Only these parameters were modified, the rest were constant. More precisely:

- hunger was either zero (*satiated synbird*) or maximal (*hungry synbird*),
- the initial configuration of one of the two feeding areas was always sufficient available food, while the other was either 10%, 50% or 90% sufficient available food,
- the initial behavior type was set to flying,
- the initial altitude was set to high,
- the initial synflock's distance from the feeding area was the same for both areas and also small enough for the areas to have negligible influence on the synbirds (see Figure 3).

We observed the experiments by means of the following metrics:

- average number of frames from the beginning of the simulation to the moment when hungry synbirds reach a feeding area and begin circling around it (t_c),
- average number of frames from the beginning of the simulation to the moment when hungry synbirds begin feeding (t_f),
- proportion of hungry synbirds that have chosen to satiate their hunger within the feeding area with a higher amount of food (p_h),
- average number of synflocks formed when hungry synbirds begin feeding (n_f),

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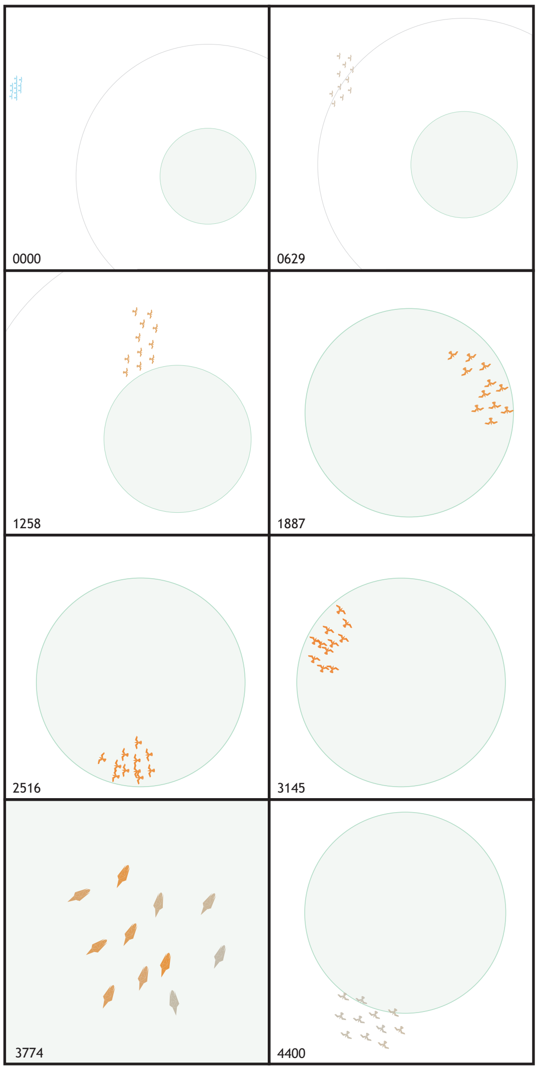

Fig. 2 A sequence of frames from the first experiment. The color of the synbirds indicates their level of hunger (blue minimal hunger, orange maximal hunger), the inner circle represents the border of the feeding area and the outer circle the extent of its influence.

- average number of stragglers when hungry synbirds begin feeding (n_s).

We carried out four sets of experiments, where each differed from the others in the number of hungry synbirds. In the first set all of the synbirds were hungry (see Tab. 1), in the second 90% were hungry (see Tab. 2), in the third 50% (see Tab. 3) and in the fourth 10% (see Tab. 4).

We can sum up the experiments with the following observations. The increase of food within the feeding area with the lower amount of it resulted in the increase of its influence on the behavior of the synbirds. This caused a higher dispersion of the synbirds and also longer times to the initiation of circling around and feeding within the area that was chosen for feeding. Nevertheless even when the difference in the amount of food was merely

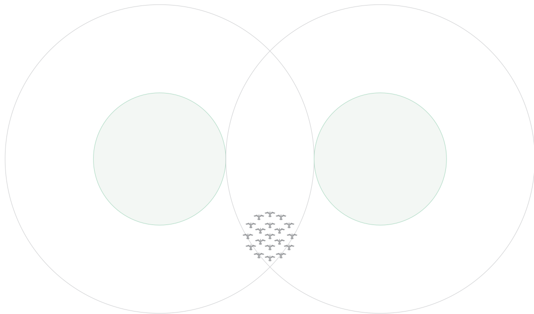

Fig. 3 The initial configuration in the experiments with two feeding areas. The synbirds' level of hunger and the initial amount of food situated within the feeding areas were modified between the experiments.

10%, more than half of the hungry synbirds decided to feed within the area with the higher amount of food. A higher dispersion and longer times can also be noticed when the number of hungry synbirds is higher. We can ascribe this phenomenom to the influence of the presence of satiated synbirds on the hungry ones induced by the core drives.

4 Conclusion

The introduction of foraging behavior extends the core model from pure flocking and brings the model a step closer to a naturalistic simulation of bird behavior. We here report the approaches taken while performing this extension. A secondary goal of ours was to demonstrate the simplicity with which the core model can be extended, while still obtaining naturalistic flocking behavior. Indeed we believe that even in its present form the work presented here could prove useful to ethologists for the analysis of feeding behavior and its effects on flock organization and behavior. The approach described above provides a first approximation toward the development of metrics that will permit truth-testing of synthetic flocking and swarming models against their natural counterparts.

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t_c	t_f	p_h	n_f	n_s
397	1497	1	1	0
407	1501	1	1	0
419	1502	0.63	2	0

Tab. 1 Results of the experiments where all of the synbirds were hungry. The first line of the table represents the results where the difference in food was 90%, the second 50% and the third 10%.

t_c	t_f	p_h	n_f	n_s
410.3 ± 3.0	1497.4	1	1	0
434.8 ± 17.4	1500.8 ± 0.2	1	1	0
453.0 ± 15.3	1502.8 ± 0.4	0.6 ± 0.1	2	0

Tab. 2 Average results of 5 experiments where 90% of randomly selected synbirds were hungry. The first line represents the results where the difference in food was 90%, the second 50% and the third 10%.

t_c	t_f	p_h	n_f	n_s
438.7 ± 37.2	1497.5 ± 0.3	1	1.2	0.2
521.7 ± 93.5	1502.3 ± 1.1	1	1	0
552.4 ± 53.5	1505.5 ± 0.9	0.6 ± 0.1	2.4	0.8

Tab. 3 Average results of 5 experiments where 50% of randomly selected synbirds were hungry. The first line are the results where the difference in food was 90%, the second 50% and the third 10%.

t_c	t_f	p_h	n_f	n_s
630.1 ± 264.6	1498.5 ± 0.8	1	2.2	1.4
647.3 ± 208.5	1502.2 ± 3.0	1	2	0.4
836.2 ± 268.2	1508.4 ± 5.2	0.7 ± 0.3	2.1	1

Tab. 4 Average results of 5 experiments where 10% of randomly selected synbirds were hungry. The first line of the table represents the results where the difference in food was 90%, the second 50% and the third 10%.

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