University of Ljubljana
Faculty of
Computer and
Information Science

Fuzzy Model for a Computer Simulation of Bird Flocking

A PhD dissertation by

Iztok Lebar Bajec

Bird Flocks
[line formations]

High degree of regularity in spacing and alignment

Winged Migration, © 2003 Sony Picture Classics

Bird Flocks

[cluster formations]

Large flocks wheeling and turning without collisions

Winged Migration, © 2003 Sony Picture Classics

Bird Flocks

[computer models]

1980: Okubo, A. (oceanology)

- coordination can be achieved with equations of nonlinear dynamics

1987: Reynolds, C.W. (computer graphics)

- decentralized model based on geometrical computation

1990: Heppner, F.H. (ornithology) and Grenander, U.

- decentralized model based on stochastic differential equations

2003: Lebar Bajec, I. (computer science)

- proposal of a decentralized model based on fuzzy logic

Computer Models [weaknesses]

Syntactical confusion:

- scarce or no formal definitions
- difficult to re-implement

Lack of evaluation metrics:

- no analytical comparison
- unable to truth-test

Usability:

- complex mathematical methods
- difficult to understand by an interdisciplinary audience

The Digital Animal
[modelling an animal]

Exists in time and space, surrounded by inanimate and animate objects – universe

Able to perceive the state of the universe

- depending on its internal state only certain perceived information is important; represents positive impulses

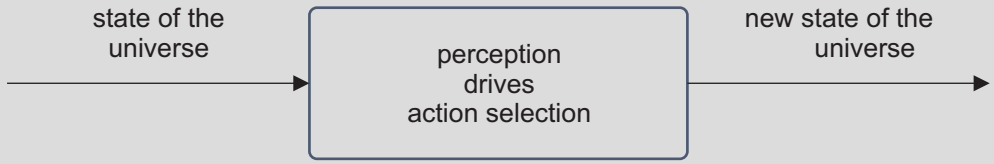
Capable of actions that influence its internal state and the state of the universe

- its drive is to perform such actions that will optimize the rate of occurrence of positive impulses

Performs a sequence of muscular movements that accomplish a combination of the selected actions – action selection

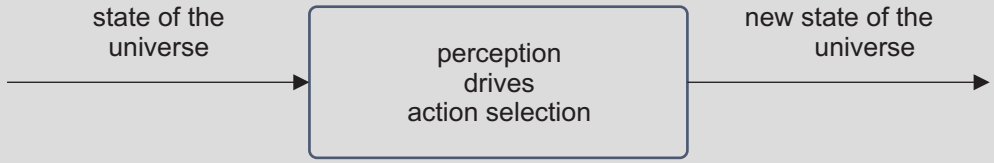
The Digital Animal
[the animat]

Animal

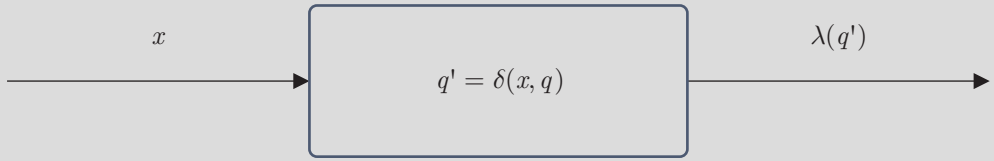


The Digital Animal
[the animat]

Animal

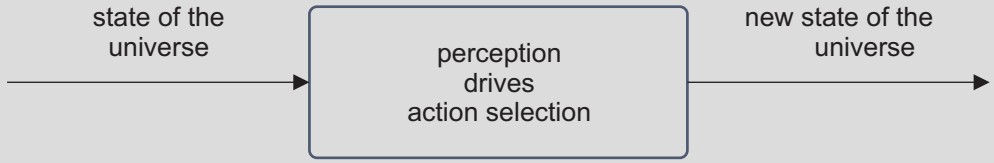


Moore automaton

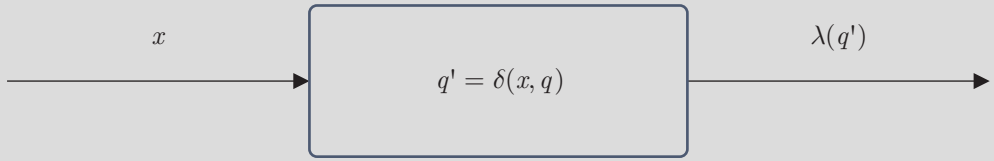


The Digital Animal
[the animat]

Animal



Moore automaton



Animat = Moore automaton

- $x = u = \langle \lambda_1, \ldots, \lambda_n \rangle$, universe
- $\delta(x, q) = S(\langle a_1, \ldots, a_l \rangle, q)$, action selection
  $a_j = D_j(\langle p_1, \ldots, p_k \rangle, q),\ j = 1, \ldots, l,$ drives
  $p_i = P_i(x, q),\ i = 1, \ldots, k.$ perception

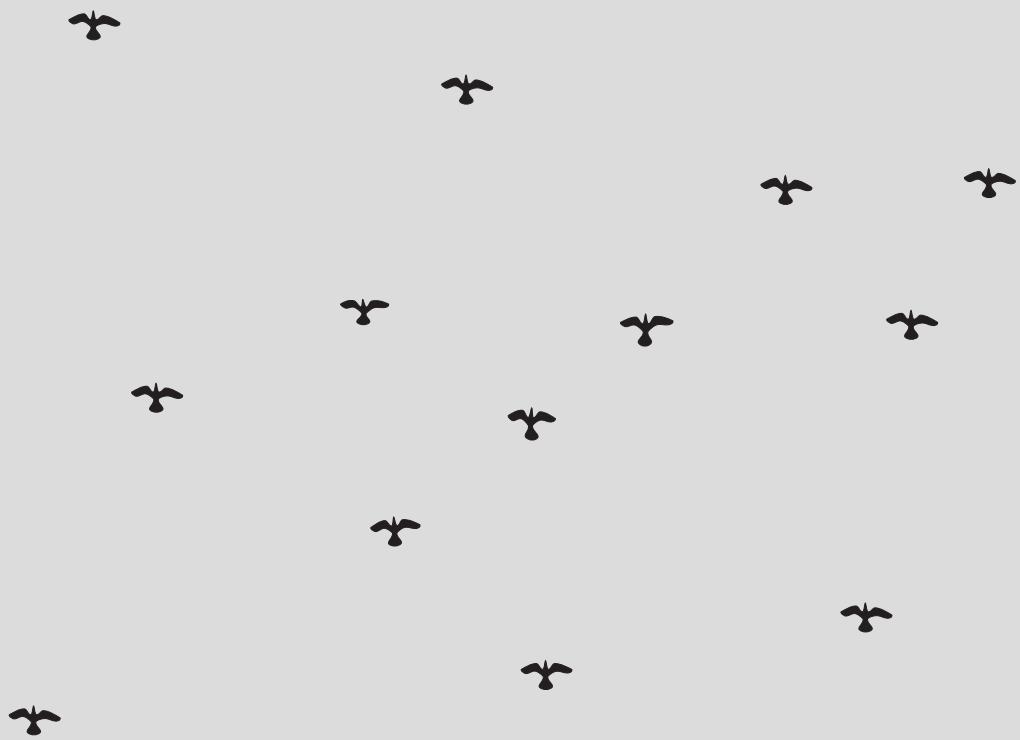
The Fuzzy Digital Bird
[fuzzy model]

A flock is a collection of fuzzy digital birds, each obeying three drives

- attraction – stay close enough to nearby neighbours
- repulsion – stay far enough from nearby neighbours
- alignment – match flight speed and direction with nearby neighbours

The Fuzzy Digital Bird

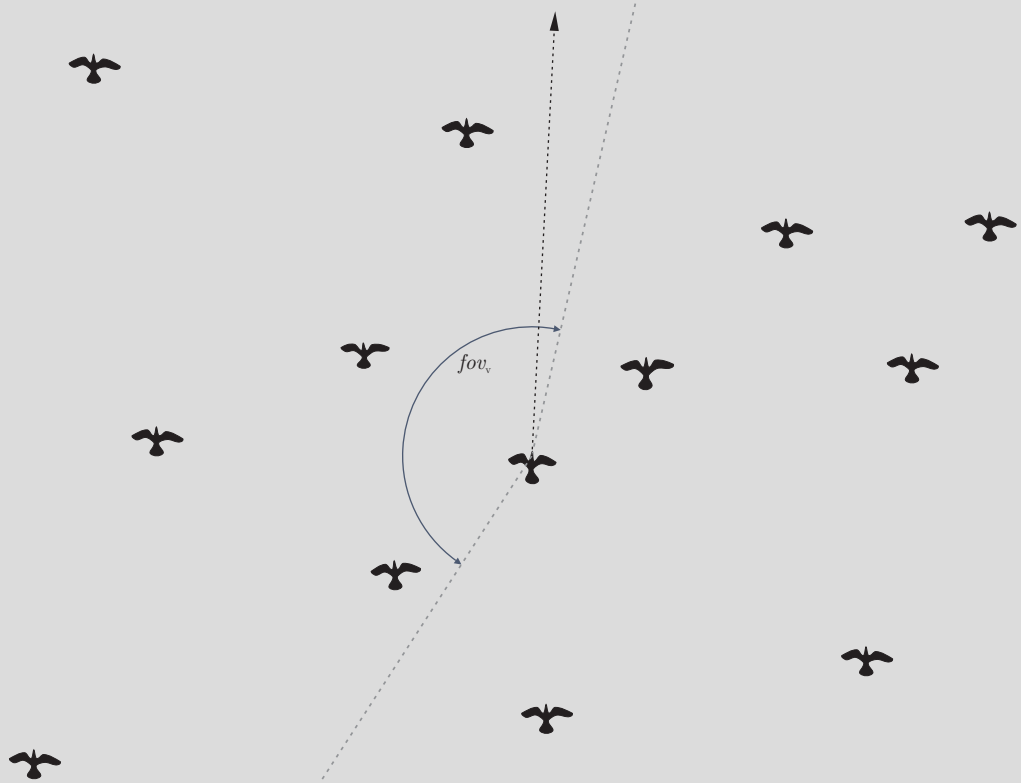
[modelling visual perception]



Fuzzy Model for a Computer Simulation of Bird Flocking

The Fuzzy Digital Bird

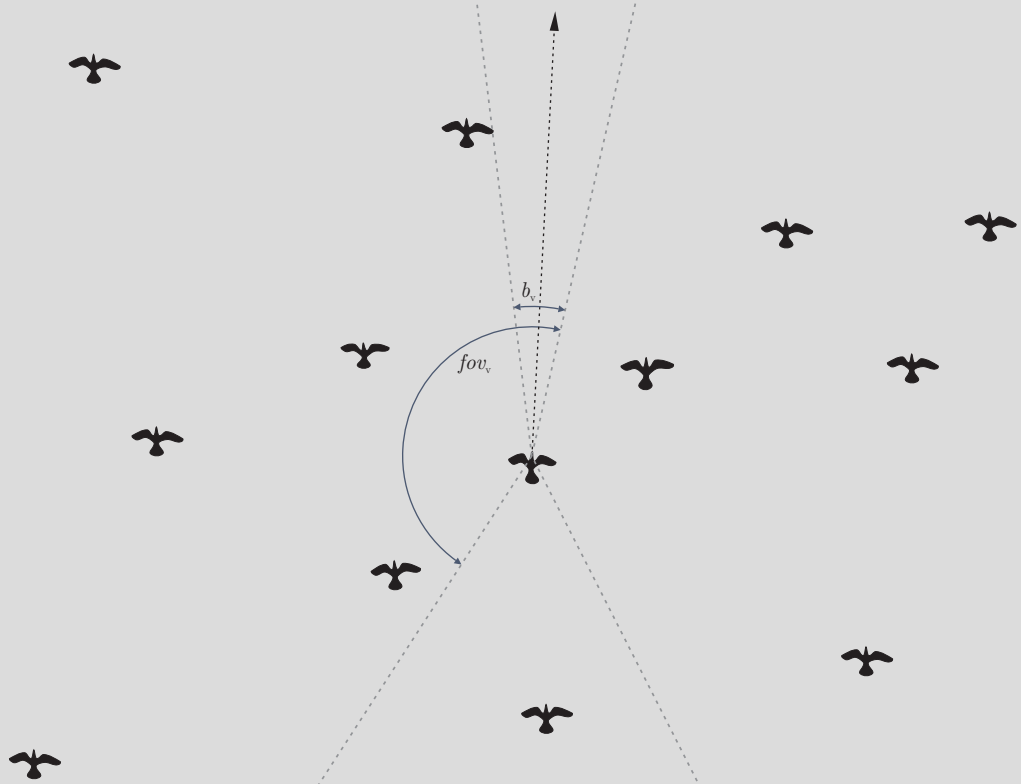
[modelling visual perception]



Fuzzy Model for a Computer Simulation of Bird Flocking

The Fuzzy Digital Bird

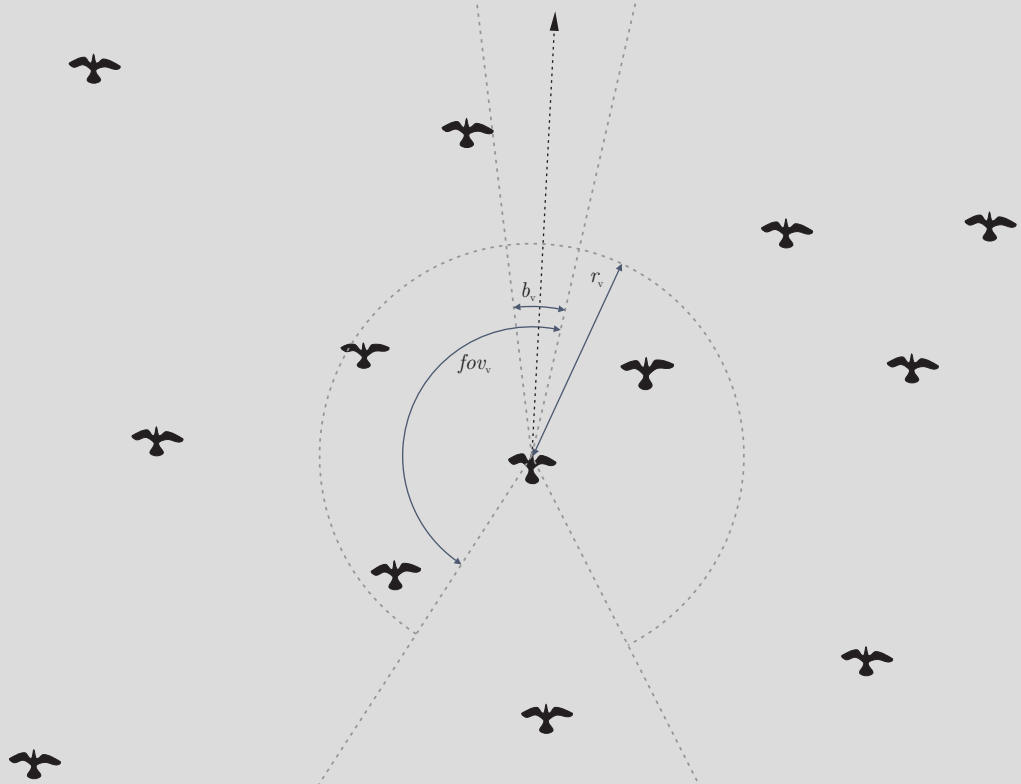
[modelling visual perception]



Fuzzy Model for a Computer Simulation of Bird Flocking

The Fuzzy Digital Bird

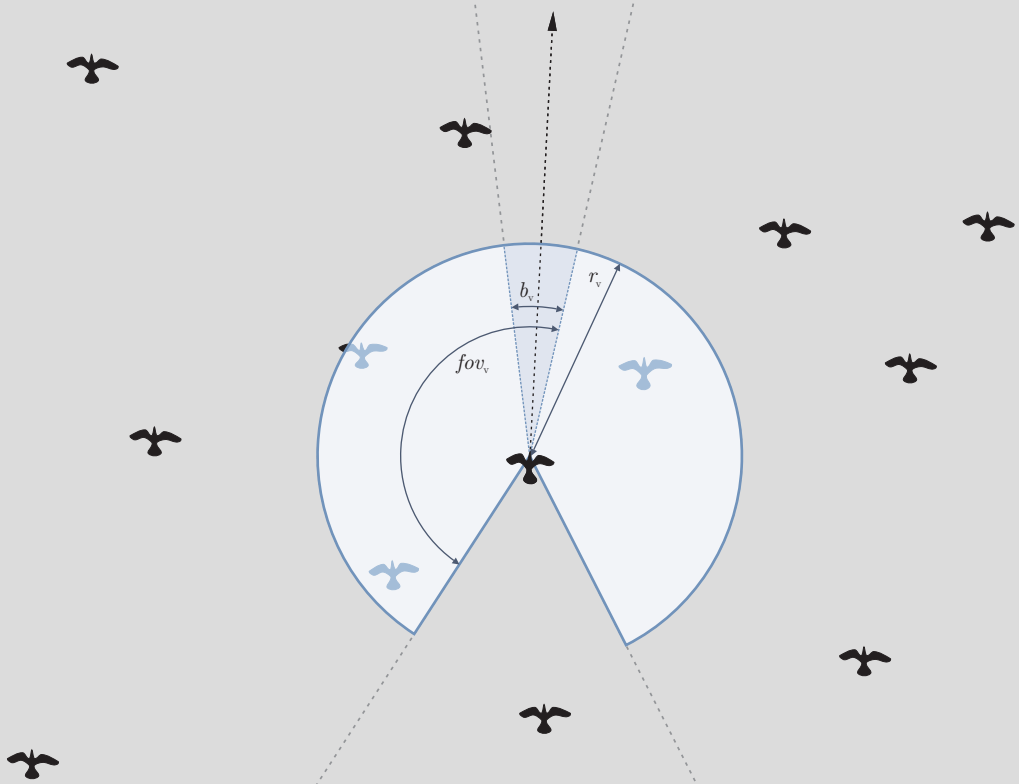
[modelling visual perception]



Fuzzy Model for a Computer Simulation of Bird Flocking

The Fuzzy Digital Bird

[modelling visual perception]



Fuzzy Model for a Computer Simulation of Bird Flocking

The Fuzzy Digital Bird
[modelling attraction drive]

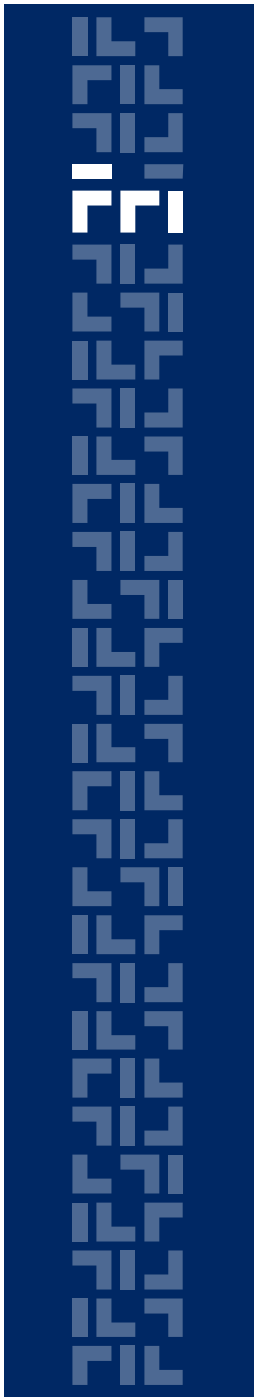
In general do not change flight speed or direction;

When a perceived neighbour is close enough, change neither flight speed nor direction;

When a perceived neighbour is too far and in front, speed up;

When a perceived neighbour is too far and anywhere to the left or behind, slow down and turn toward it;

When a perceived neighbour is too far and anywhere to the right or behind, slow down and turn toward it.



The Fuzzy Digital Bird
[modelling attraction drive]

if (*distance* **is** *too far*) **then** (*flight speed* **is** *keep speed*),

if (*distance* **is** *too far*) **then** (*flight direction* **is** *keep direction*),

if (*distance* **is** *close enough*) **then** (*flight speed* **is** *keep speed*),

if (*distance* **is** *close enough*) **then** (*flight direction* **is** *keep direction*),

if (*distance* **is** *too far*) **and** (*position* **is** *in front*)
then (*flight speed* **is** *accelerate*),

if (*distance* **is** *too far*) **and** (*position* **is** *left or behind*)
then (*flight speed* **is** *decelerate*),

if (*distance* **is** *too far*) **and** (*position* **is** *left or behind*)
then (*flight direction* **is** *turn left*),

if (*distance* **is** *too far*) **and** (*position* **is** *right or behind*)
then (*flight speed* **is** *decelerate*),

if (*distance* **is** *too far*) **and** (*position* **is** *right or behind*)
then (*flight direction* **is** *turn right*).

The Fuzzy Digital Bird

[modelling repulsion drive]

In general do not change flight speed or direction;

When a perceived neighbour is far enough, change neither flight speed nor direction;

When a perceived neighbour is too close and anywhere behind, speed up;

When a perceived neighbour is too close and in front or right, slow down and turn away from it;

When a perceived neighbour is too close and in front or left, slow down and turn away from it.

The Fuzzy Digital Bird

[modelling alignment drive]

In general do not change flight speed or direction;

When a perceived neighbour is too far or too close, change neither flight speed nor direction;

When a perceived neighbour is at a good distance and flying with the same speed, keep flight speed;

When a perceived neighbour is at a good distance and flying faster, speed up;

When a perceived neighbour is at a good distance and flying slower, slow down;

When a perceived neighbour is at a good distance and flying in the same direction, keep flight direction;

When a perceived neighbour is at a good distance and flying more to the left, turn left;

When a perceived neighbour is at a good distance and flying more to the right, turn right.

Fuzzy Model for a Computer Simulation of Bird Flocking

The Fuzzy Digital Bird
[modelling action selection]

Actions resulting from the drives

- Newtonian forces that induce the desired change in flight speed and/or direction
- $\mathbf{a}_\mathrm{a}$ – attraction, $\mathbf{a}_\mathrm{r}$ – repulsion, $\mathbf{a}_\mathrm{p}$ – alignment

Weighted sum of the actions

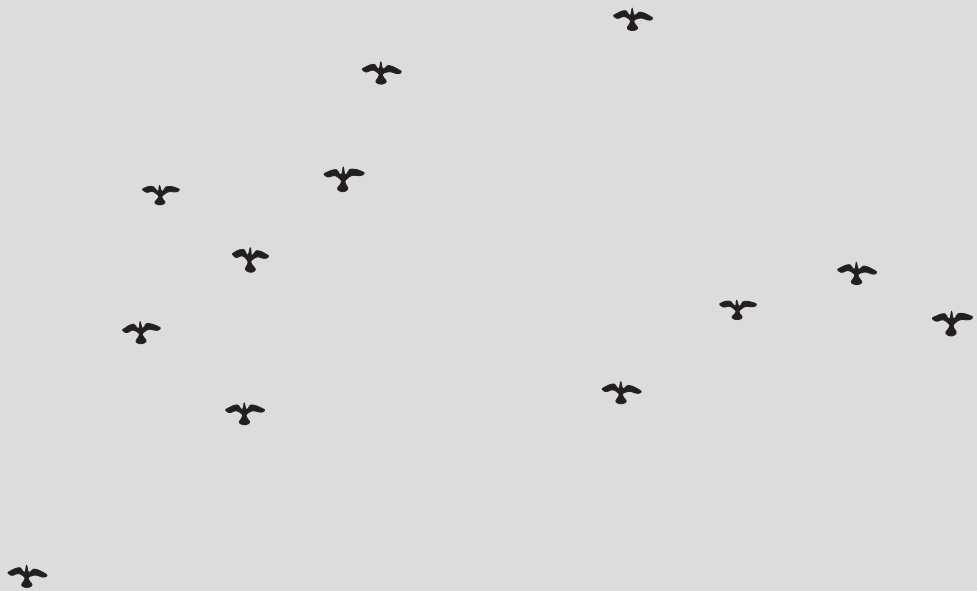
- $\mathbf{F} = w_\mathrm{a}\mathbf{a}_\mathrm{a} + w_\mathrm{r}\mathbf{a}_\mathrm{r} + w_\mathrm{p}\mathbf{a}_\mathrm{p}$

Geometrical flight

- $\mathbf{v}' = \lfloor \mathbf{v} + (\lfloor \mathbf{F} \rceil^{f_\mathrm{M}}/m)\,dt \rceil^{v_\mathrm{M}}$
- $\mathbf{p}' = \mathbf{p} + \mathbf{v}'\,dt$

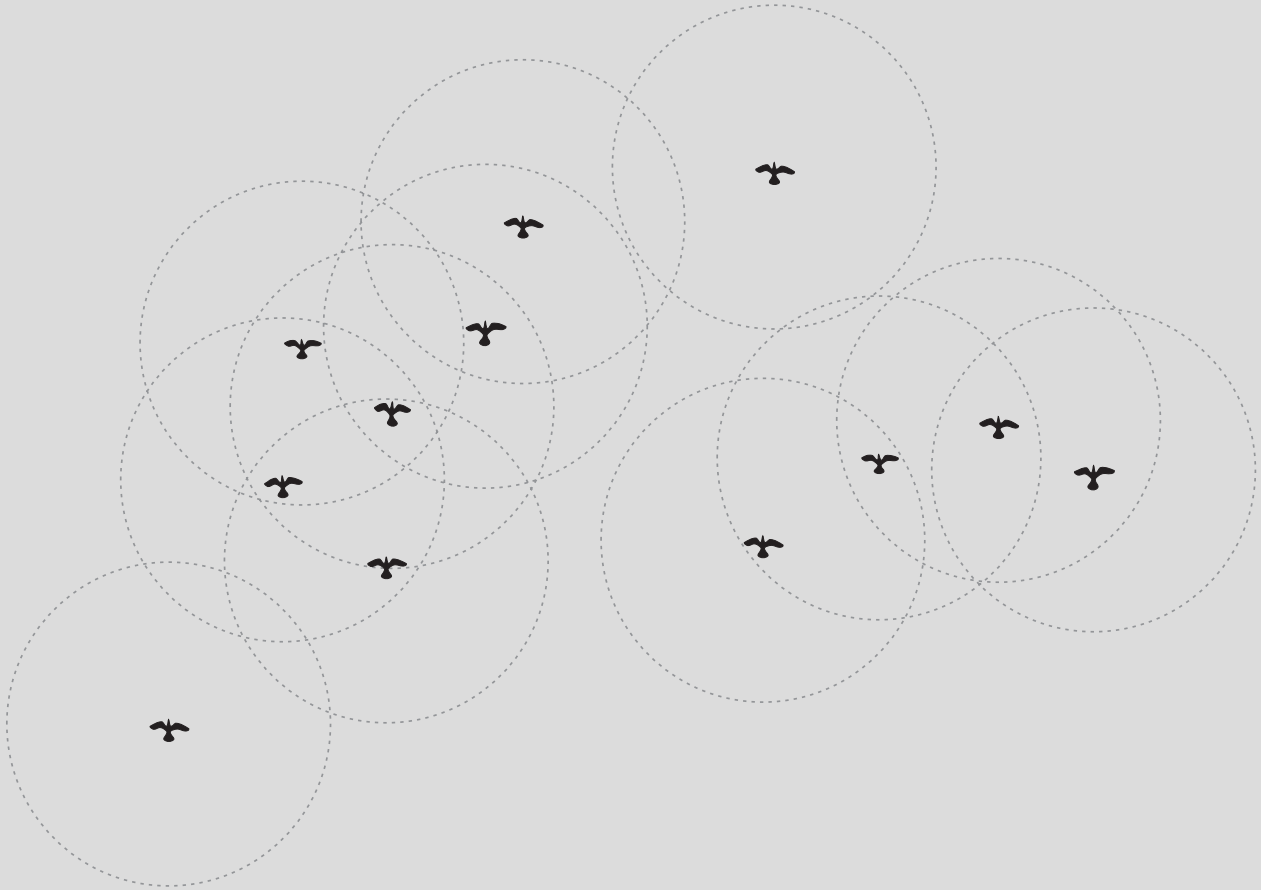
Behaviour Analysis

[straggler, flock, leader]



Behaviour Analysis

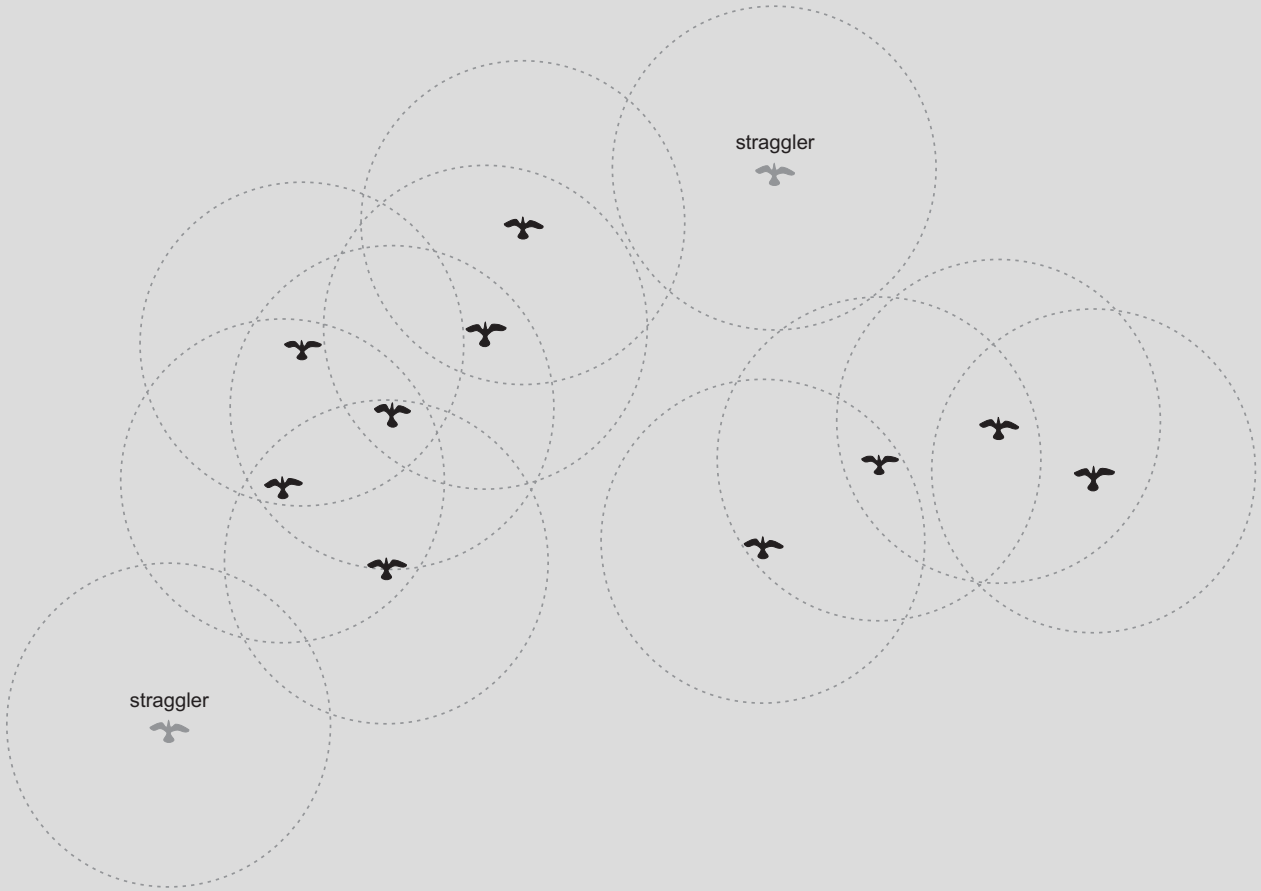
[straggler, flock, leader]



Fuzzy Model for a Computer Simulation of Bird Flocking

Behaviour Analysis

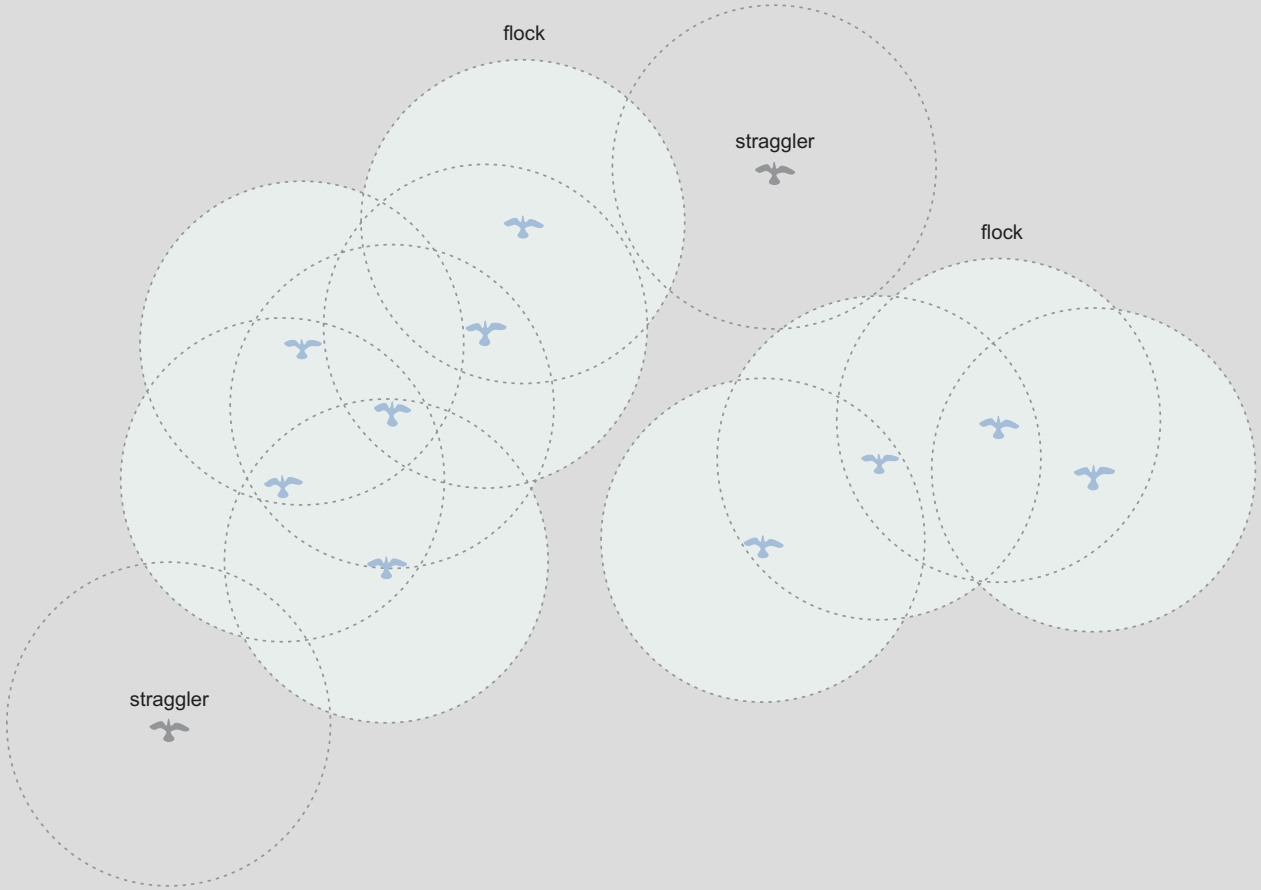
[straggler, flock, leader]



Fuzzy Model for a Computer Simulation of Bird Flocking

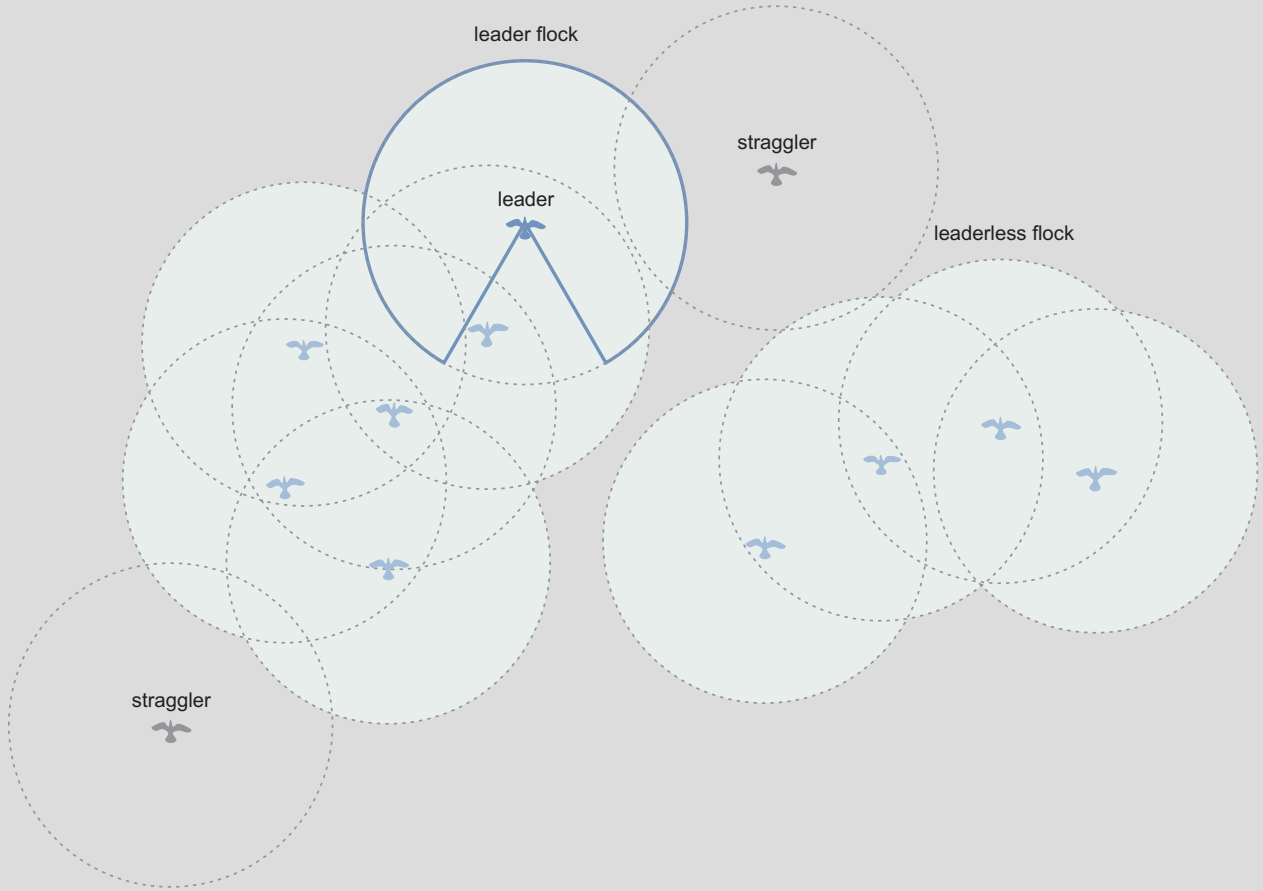
Behaviour Analysis

[straggler, flock, leader]

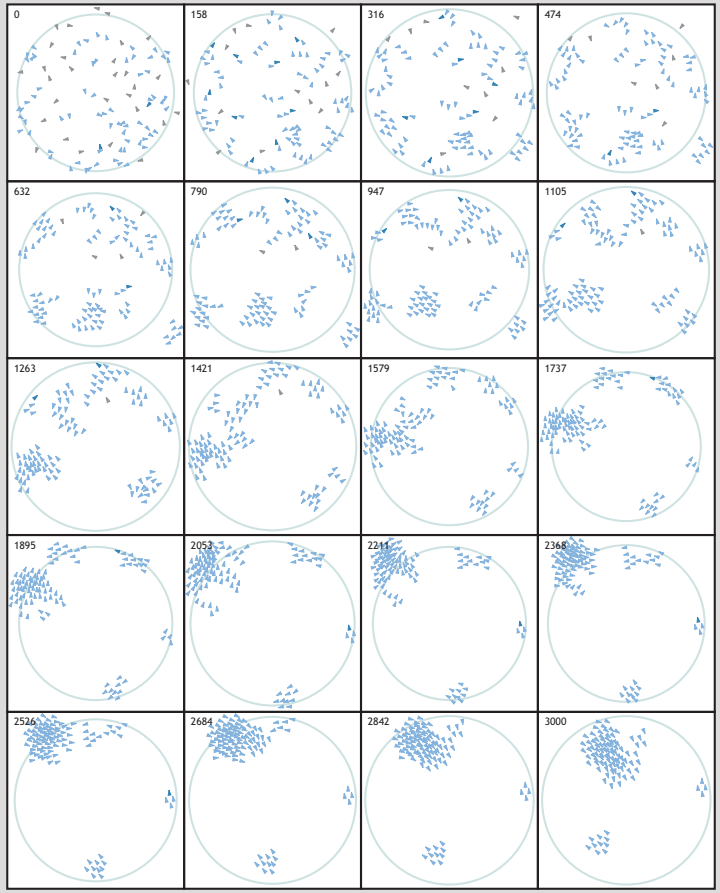


Fuzzy Model for a Computer Simulation of Bird Flocking

Behaviour Analysis
[straggler, flock, leader]

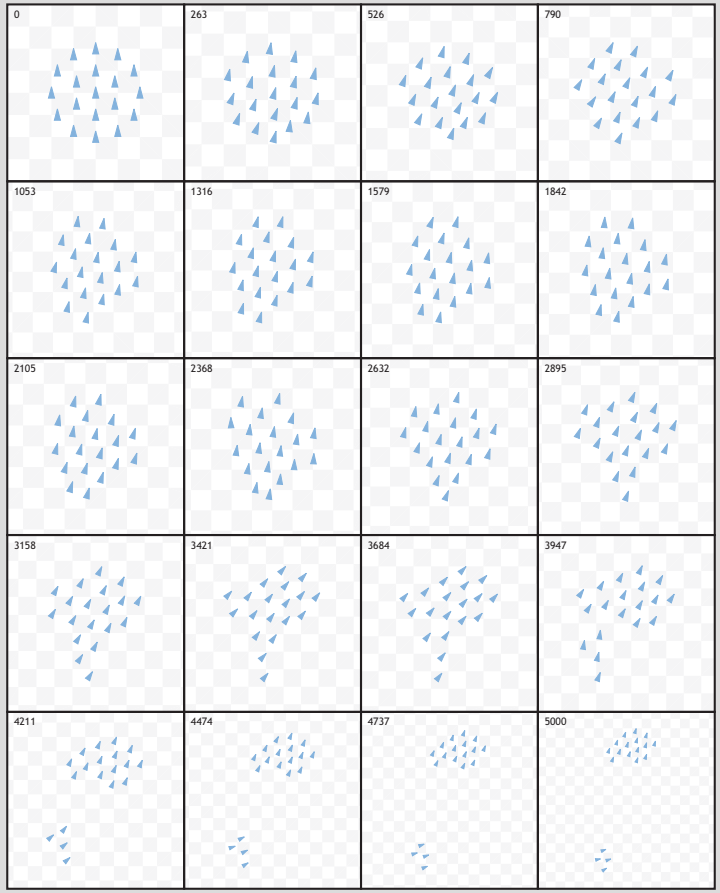


Behaviour Analysis
[flocking ability]



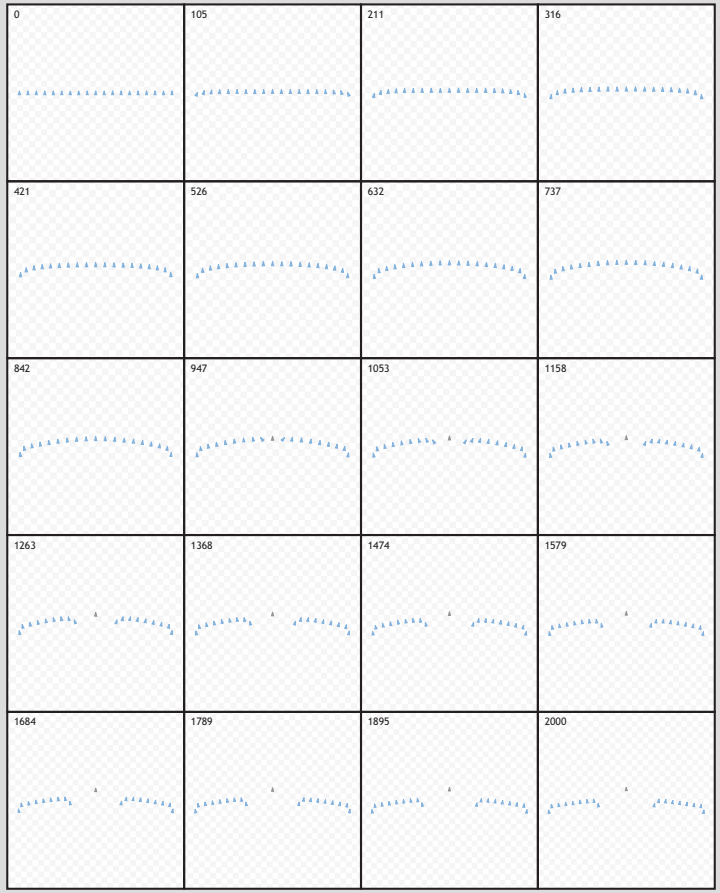
Fuzzy Model for a Computer Simulation of Bird Flocking

Behaviour Analysis
[cluster flocks]



Fuzzy Model for a Computer Simulation of Bird Flocking

Behaviour Analysis
[line flocks]



Future work

Fuzzy flocks in three dimensions

Inaccurate perception

Obstacles

Other groups of moving animals

…

… sky is the limit

For the Birds, © 2000 Pixar