Modeling and Control of Bio-Inspired Swarms

Sean Kerman

Daniel Brown

Michael A. Goodrich

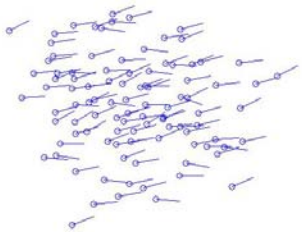
Swarms

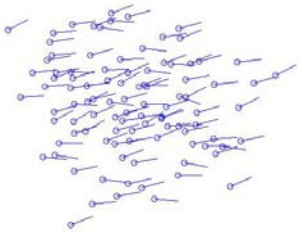
Applications

Firefighting

Convoy Protection

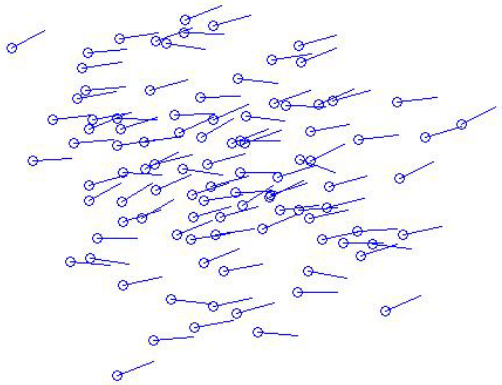
Search and Rescue

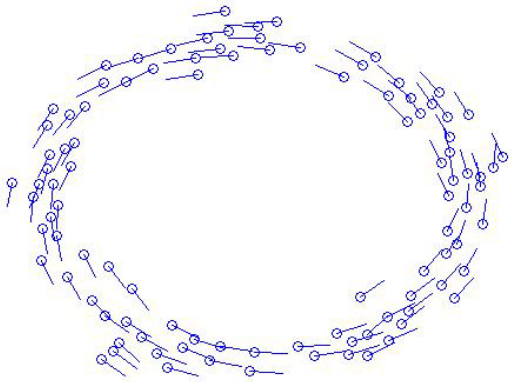




Concept

- 3 principles of interaction
  - Repulsion
  - Orientation
  - Attraction
- 2 collective structures
  - Flock
  - Torus





Swarm Model

Agent Dynamics

$$\begin{aligned}\dot{x}_i &= s \cdot \cos(\theta_i) \\ \dot{y}_i &= s \cdot \sin(\theta_i) \\ \dot{\theta}_i &= w_i\end{aligned}$$

$$w_i = k\alpha$$

$$\alpha = \text{atan2}(u_i) - \theta_i$$

Agent Connectivity

$$a_{ij}(t) = \begin{cases} 1/d_{ij}(t) & \text{if } d_{ij}(t) \geq 1 \\ 1 & \text{otherwise} \end{cases}$$

$$\begin{aligned} n_i^r &= \{j : \|c_i - c_j\| \leq R_r, a_{ij} = 1\} \\ n_i^o &= \{j : \|c_i - c_j\| \leq R_o, a_{ij} = 1\} \\ n_i^a &= \{j : a_{ij} = 1\} \end{aligned}$$

Nominal Agent Control

$$u_i^r = -\sum_{n_i^r} \frac{c_j - c_i}{\|c_j - c_i\|^2}$$

$$u_i^o = \frac{v_i + \sum_{n_i^o} v_j}{\|v_i + \sum_{n_i^o} v_j\|}$$

$$u_i^a = \frac{\sum_{n_i^a}(c_j - c_i)}{\|\sum_{n_i^a}(c_j - c_i)\|}.$$

$$u_i = u_i^r + u_i^o + u_i^a$$

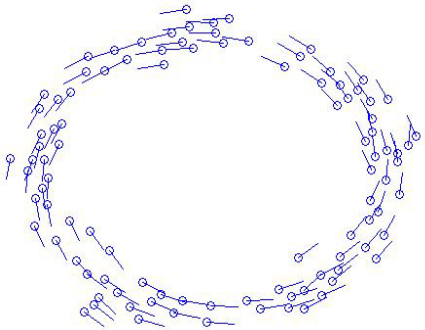
Redefinitions

$$\begin{aligned} v_i &= [\cos(\theta_i), \sin(\theta_i)]^T \\ c_i &= [x, y]^T \end{aligned}$$

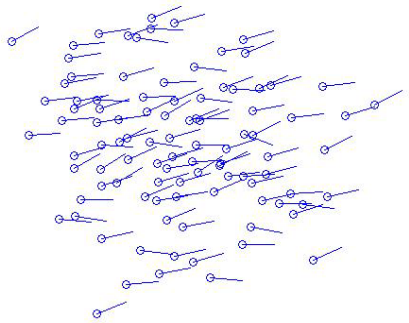
Switching Between Groups

Control

Torus **Flock**



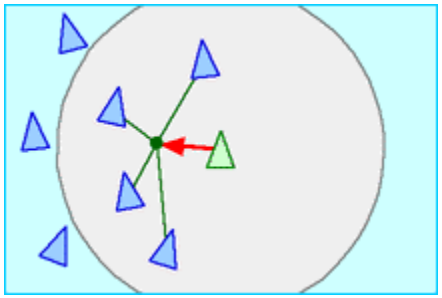
Control



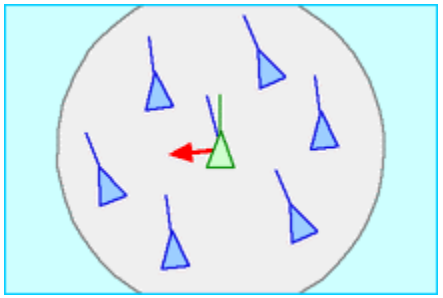
Previous Work

- Reynold's Boids

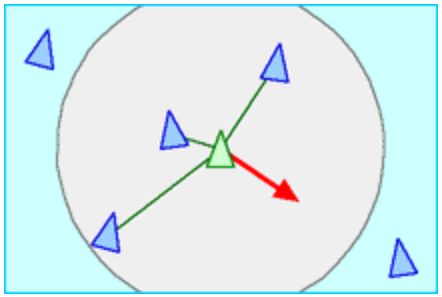
Attraction



Orientation



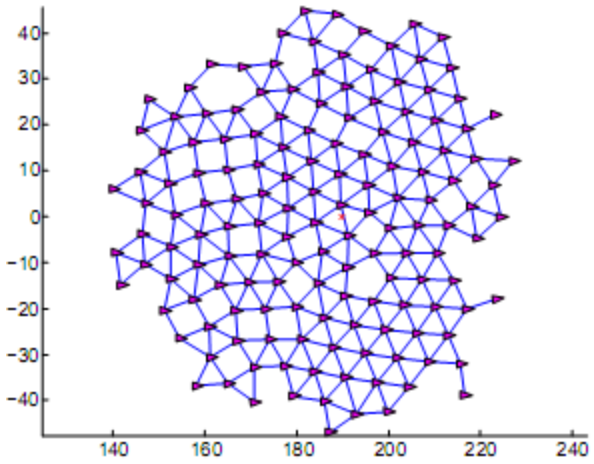
Repulsion

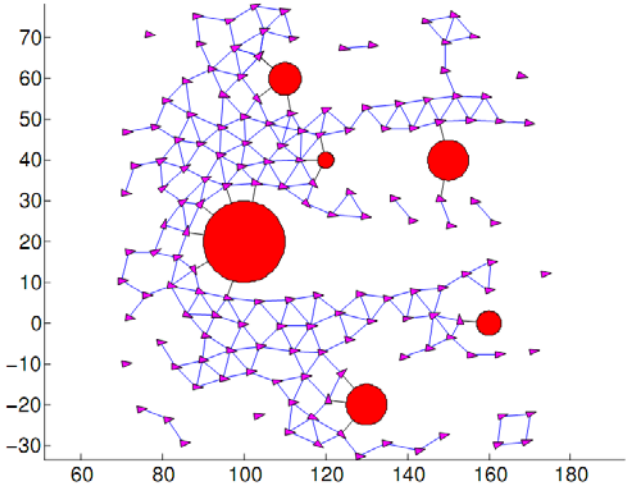


Reynolds, C. W. (1987) Flocks, Herds, and Schools: A Distributed Behavioral Model, in Computer Graphics, 21(4) (SIGGRAPH '87 Conference Proceedings) pages 25-34.

Previous Work

- Olfati-Saber

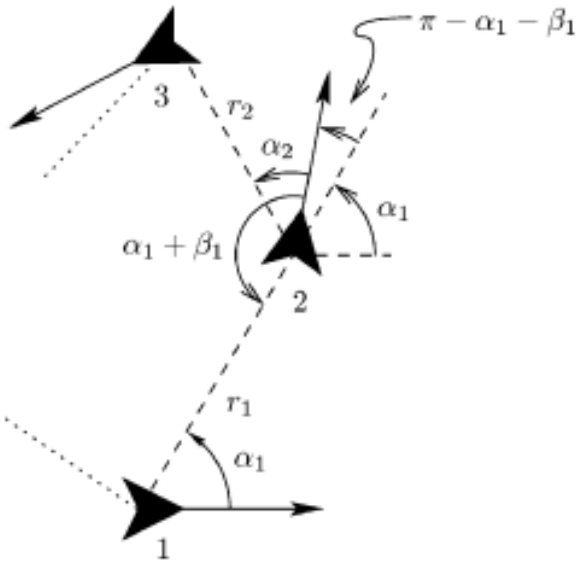


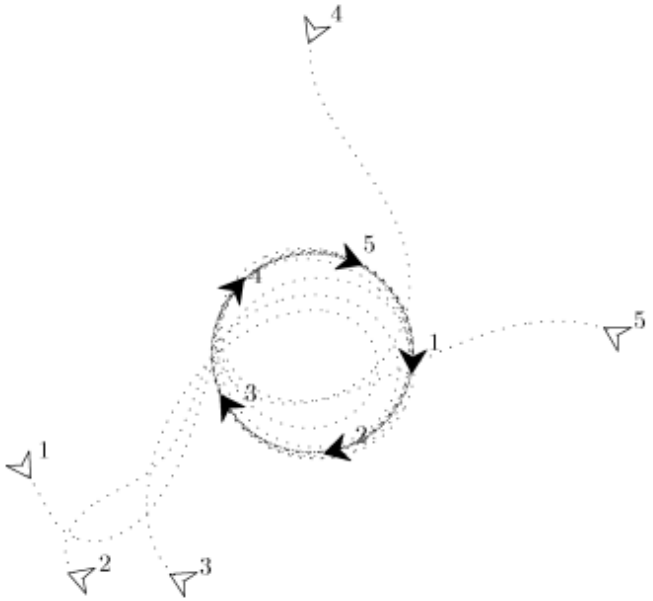


R. Olfati-Saber. "Flocking for Multi-Agent Dynamic Systems: Algorithms and Theory," *IEEE Trans. on Automatic Control, vol. 51(3), pp. 401-420, Mar. 2006*.

Previous Work

- Cyclic Pursuit

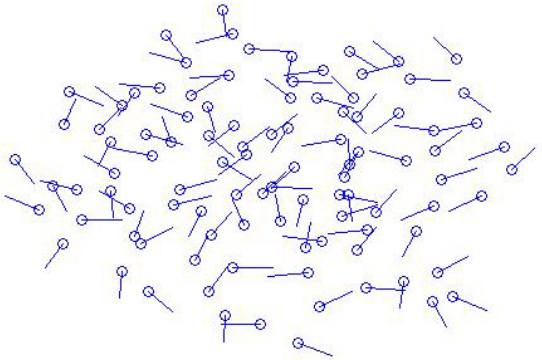




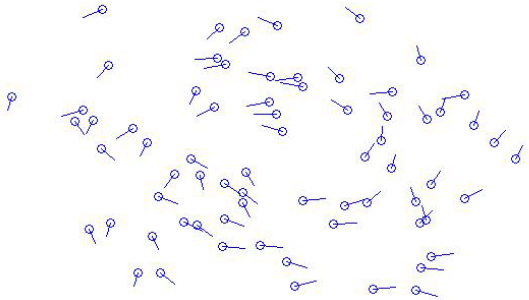
J. Marshall , M. Broucke and B. Francis "Formation of vehicles in cyclic pursuit", *IEEE Trans. Autom. Control*, vol. 49, p.1963 , 2004.
Abstract |Full Text: PDF (592KB)

Couzin's Model

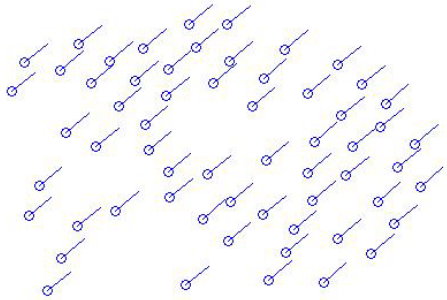
Swarm



Torus



Flock

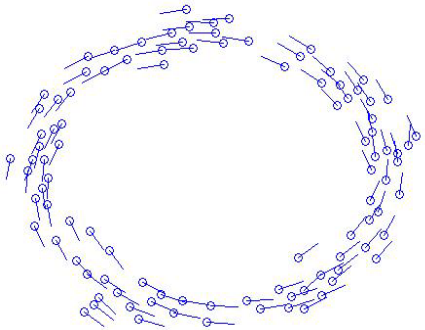


Couzin, I.D., Krause, J., James, R., Ruxton, G.D. & Franks, N.R., (2002) Collective memory and spatial sorting in animal groups. ***Journal of Theoretical Biology*** 218, 1-11.

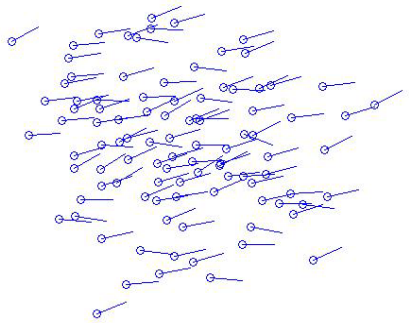
Switching Between Groups

Control

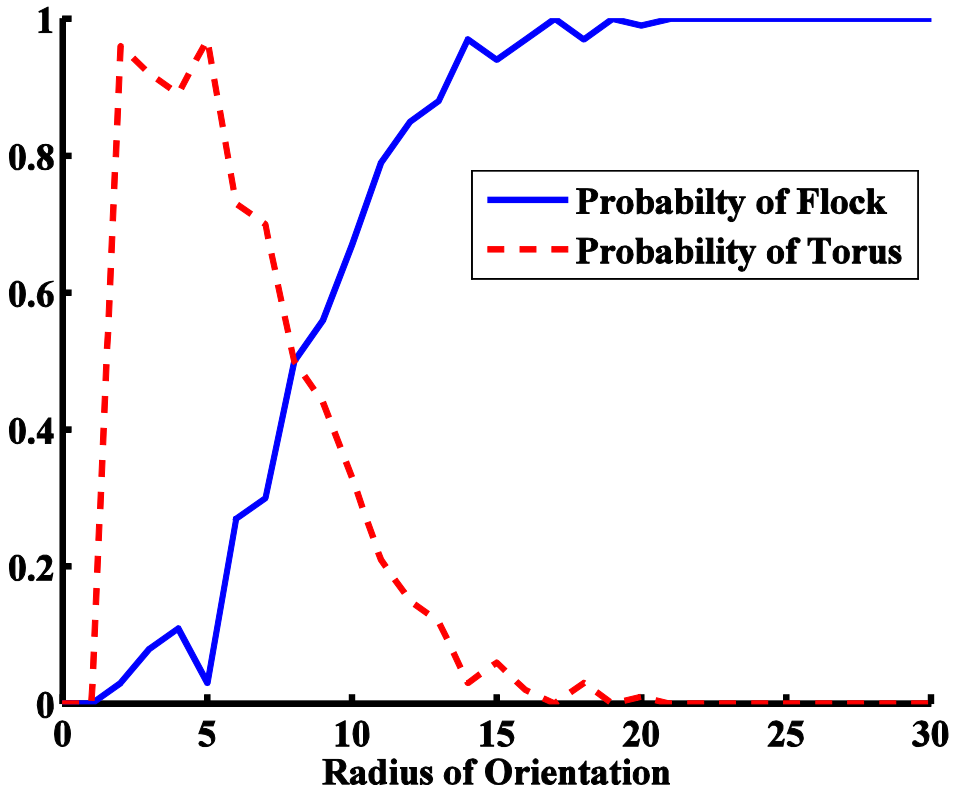
Torus **Flock**



Control



Choosing Orientation Radius

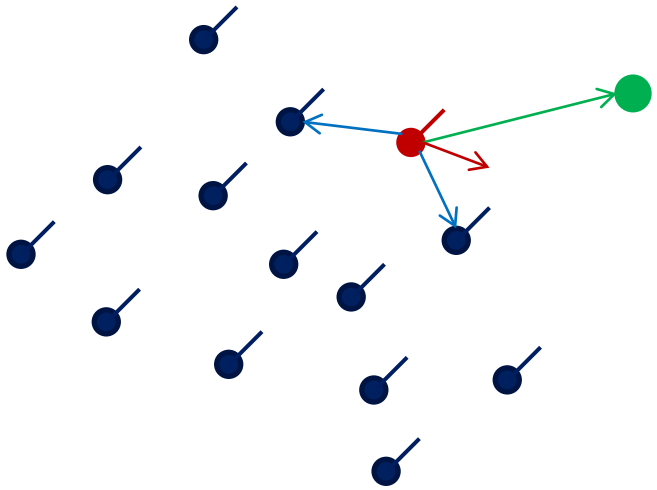


500 seconds allowed to converge

100 Trials for each value of the orientation radius

Parameters: N=100, Rr = 1, s = 5, k = 0.5

Stakeholders



Nominal Agent Control

$$u_i^r = -\sum_{n_i^r} \frac{c_j - c_i}{\|c_j - c_i\|^2}$$

$$u_i^o = \frac{v_i + \sum_{n_i^o} v_j}{\|v_i + \sum_{n_i^o} v_j\|}$$

$$u_i^a = \frac{\sum_{n_i^a}(c_j - c_i)}{\|\sum_{n_i^a}(c_j - c_i)\|}.$$

$$u_i = u_i^r + u_i^o + u_i^a$$

Stakeholder Agent Control

$$\hat{q}_i = \frac{q - c_i}{\|q - c_i\|}$$

$$u_i^{so} = \frac{\rho\hat{q}_i + (1-\rho)u_i^o}{\|\rho\hat{q}_i + (1-\rho)u_i^o\|}$$

$$u_i^{sa} = \frac{\rho\hat{q}_i + (1-\rho)u_i^a}{\|\rho\hat{q}_i + (1-\rho)u_i^a\|}$$

$$u_i = u_i^a + u_i^{so} + u_i^r$$

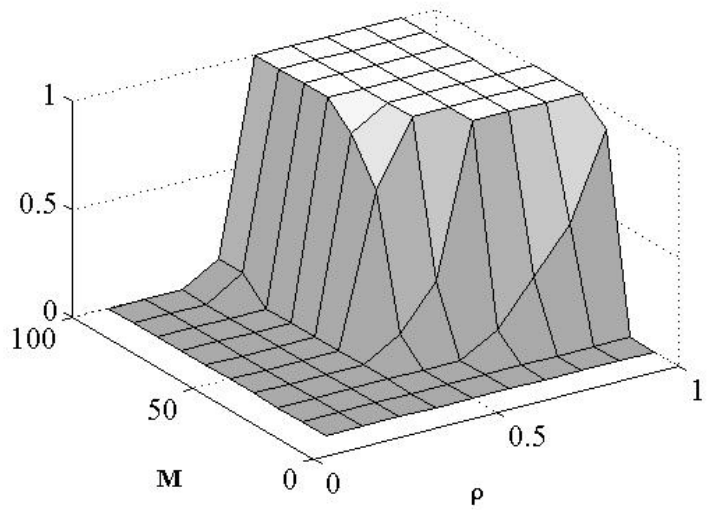
$$u_i = u_i^{sa} + u_i^o + u_i^r$$

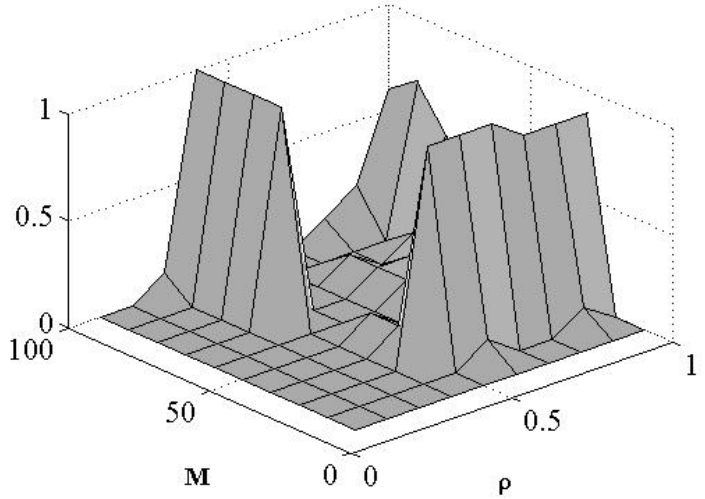
Probability of Switching

Flock To Torus

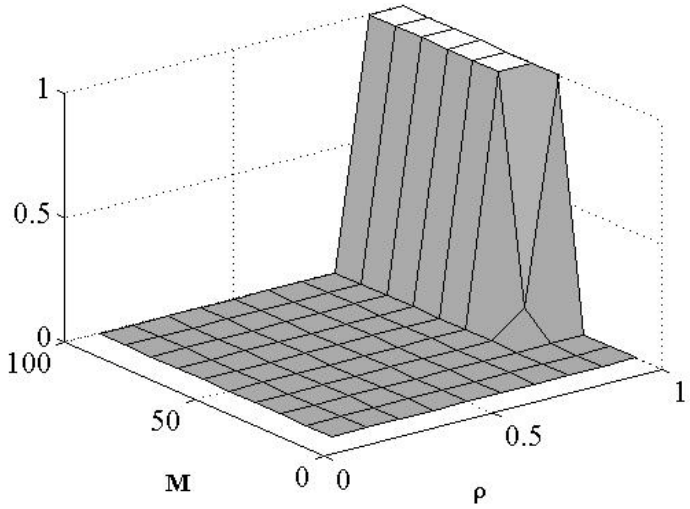
Torus To Flock

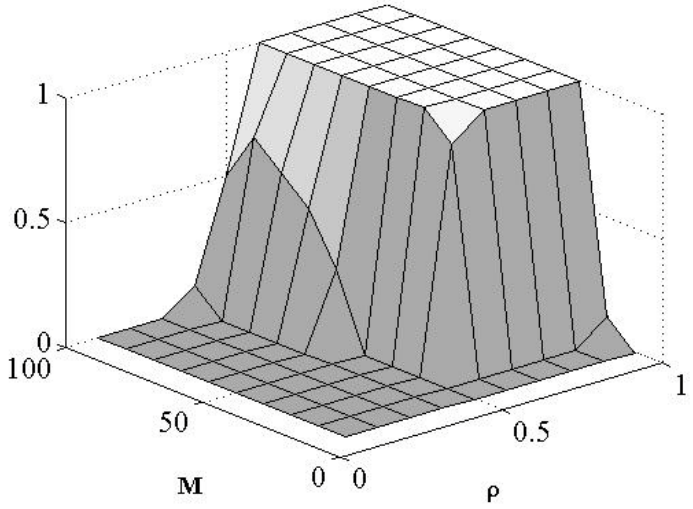
Attraction





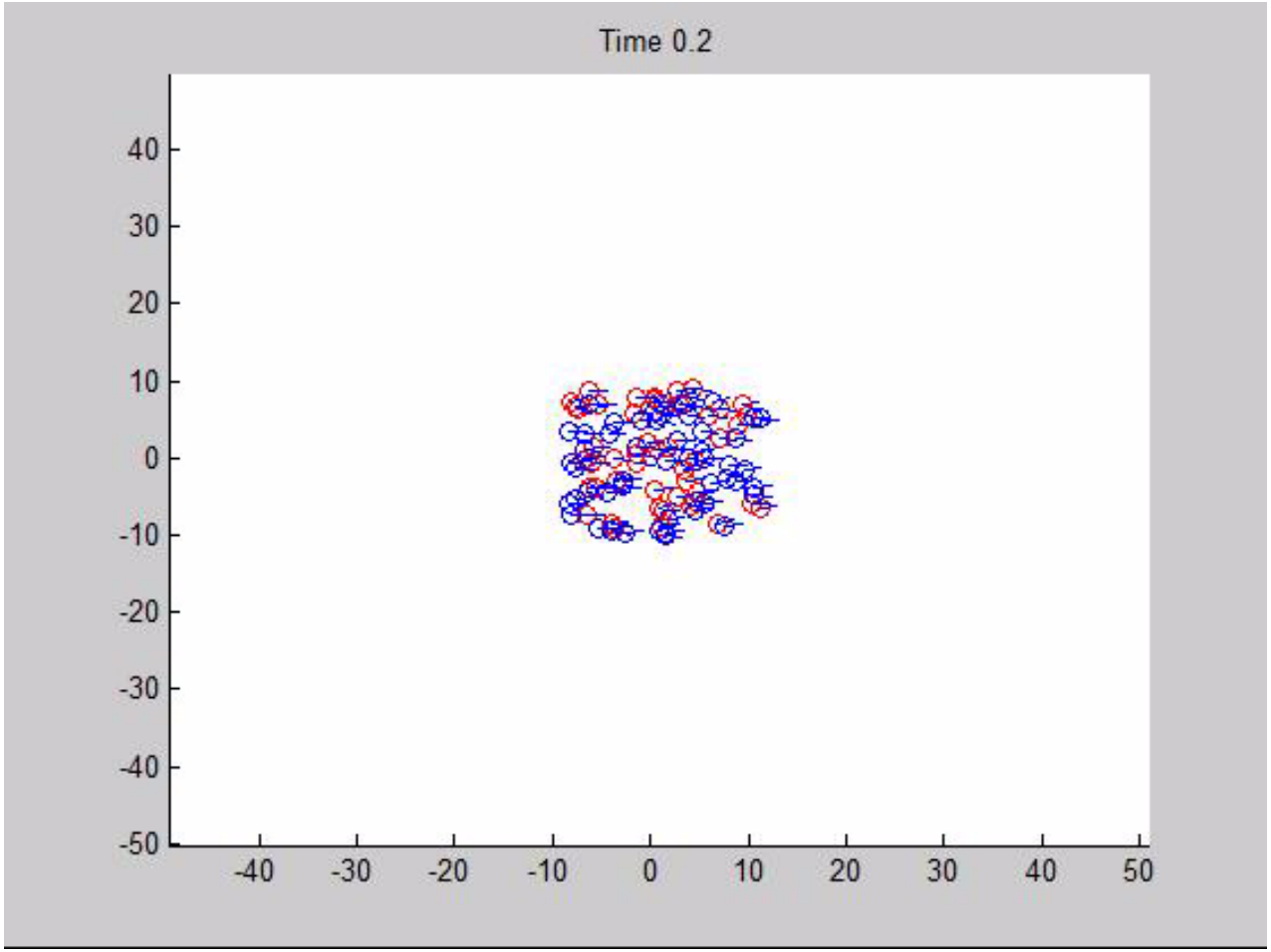
Orientation





Ten two-hundred second trials for each parameter set.
50 seconds allowed after the trial for group to stabilize.

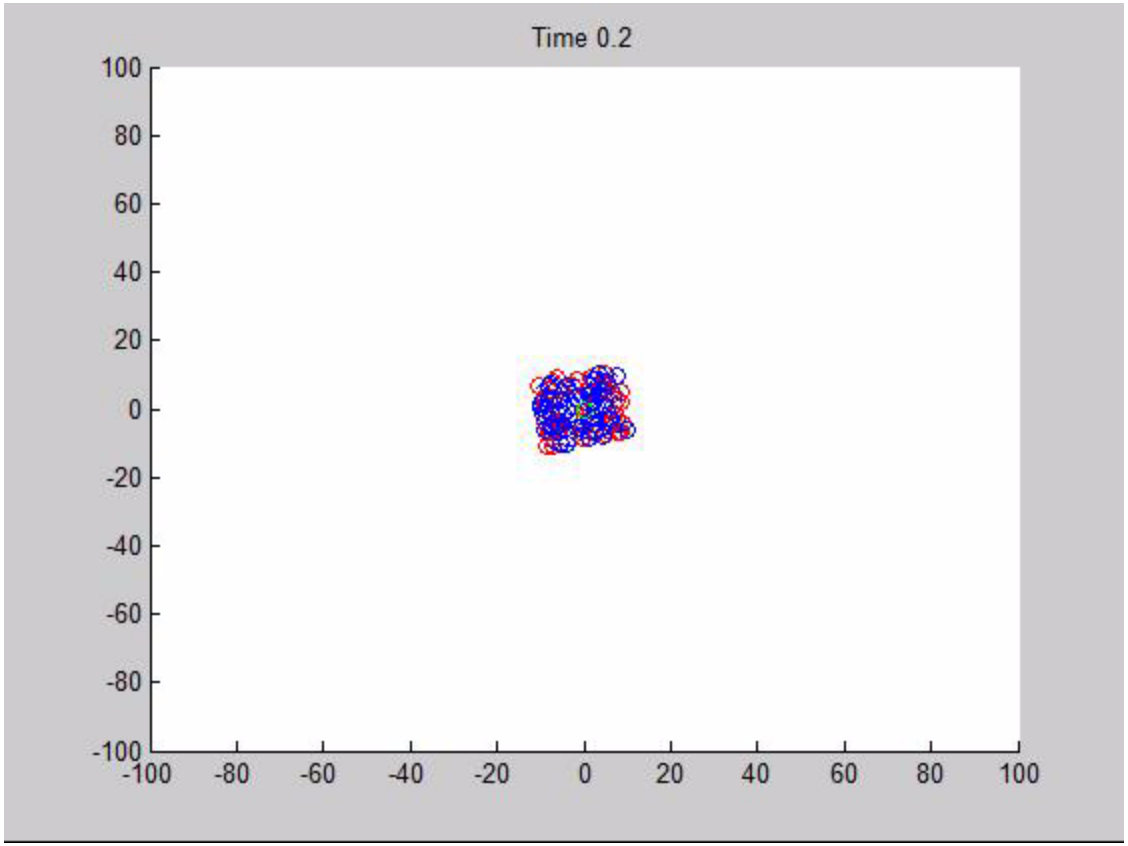
Switching Between Groups



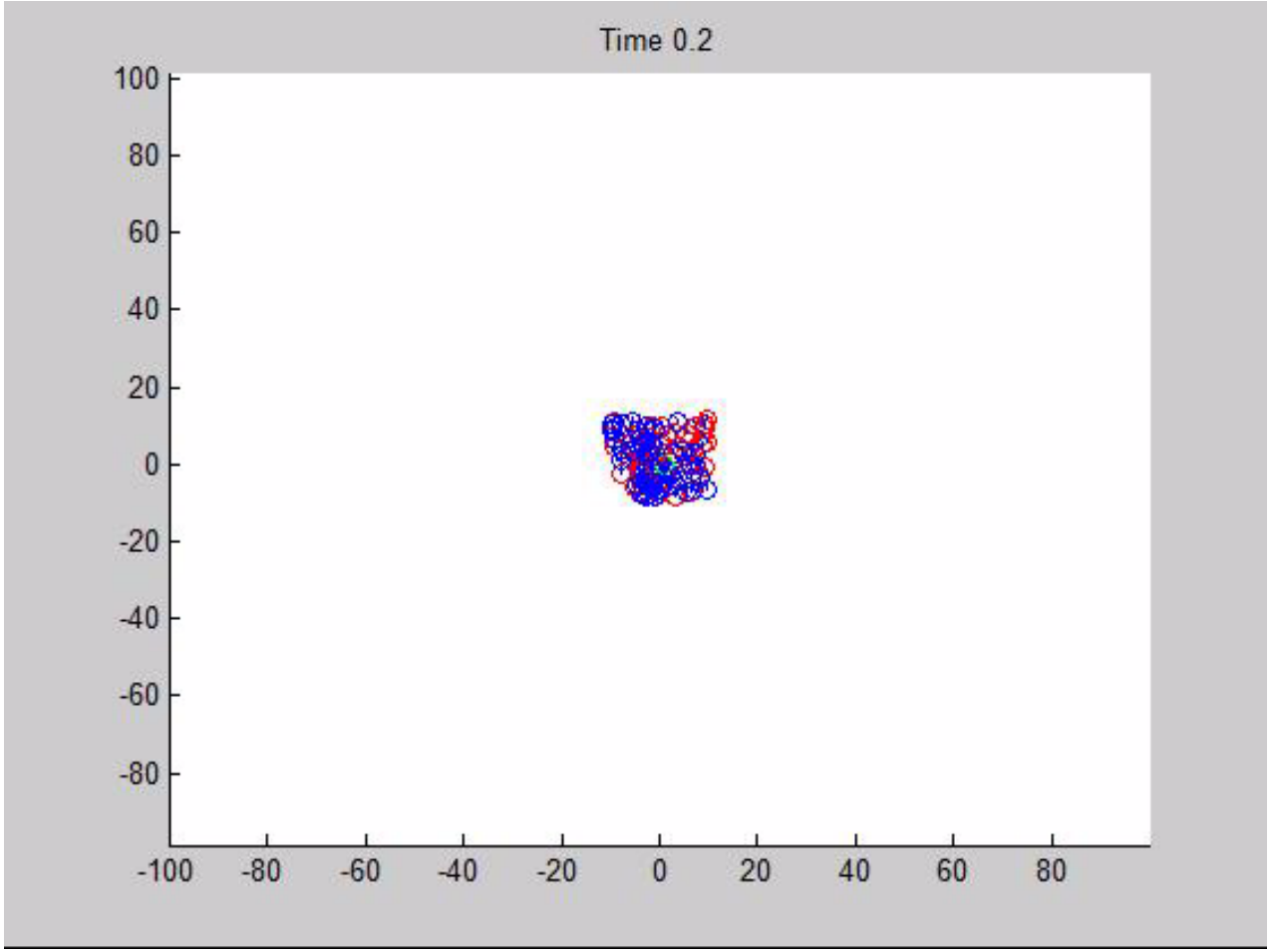
Steady State Leadership

- Torus:
  - Control position
  - Lead by attraction
  - $\rho = 0.8$
- Flock
  - Control heading
  - Lead by orientation
  - $\rho = 0.8$

Torus Leadership



Flock Leadership

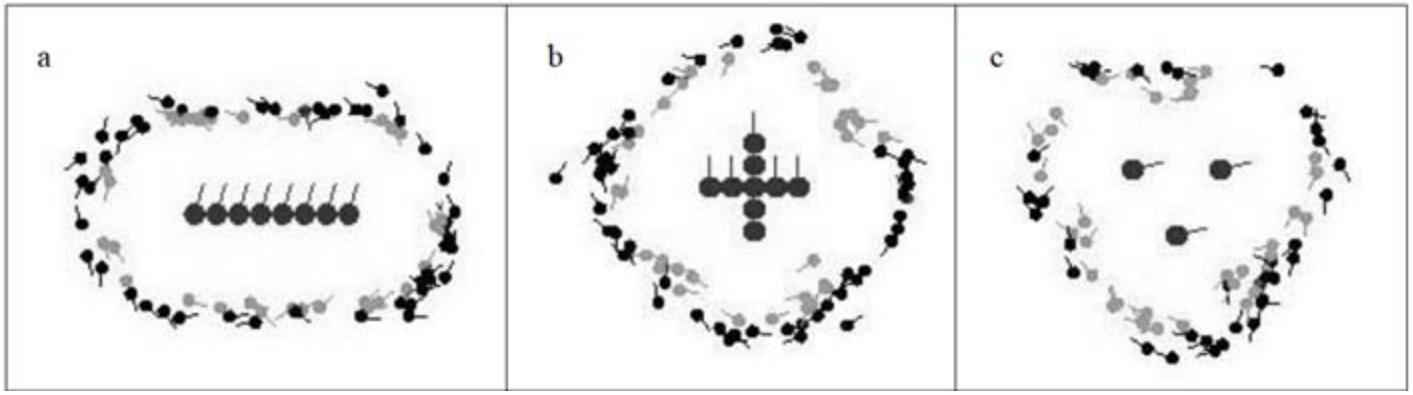


Conclusions

- A human operator can use stakeholders to change between attractors in a swarm using a subset of the agents in the group
- Stakeholders can also be used to lead the steady state groups of a swarm using a subset of agents in the swarm

Future Work

- Develop steady state dynamics for flock and torus groups
- Investigate limitations of model
- Implementation with real robots
- Investigate additional leadership strategies



Questions?