Georgia Tech Systems Research GTSR

Bio-Inspired Source Seeking Using Dynamic Collaboration

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Outline

- Motivation
- Problem Formulation
- Algorithm
- Simulation
- Next steps

Why Bio-inspired?

- Animals search for targets:
  - Without any localization service
  - Without any infrastructure for high data rate communication
  - Information exchange is random and asynchronous
  - Uncertainties in the environment

Our Goal:

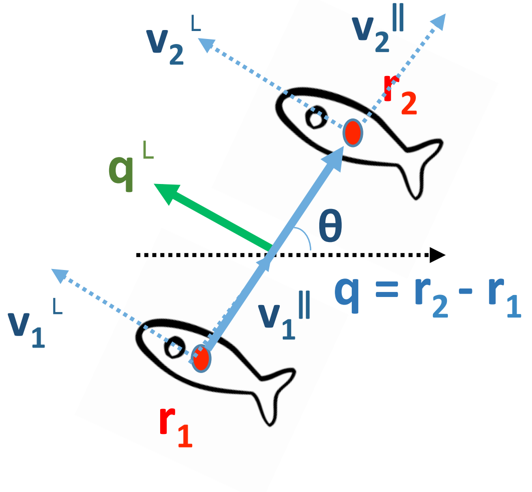
Get inspiration from such behavior and find **scalable algorithms** that balance **adaptiveness** and **robustness** for engineering systems

Source Seeking Model (SSM)

- Inspired by **fish behavior**, this model develops a **source-seeking algorithm** for a **group of agents** with **no explicit gradient estimation** of a scalar field.

$$\mathbf{v}_i^{\parallel} = k_p \sum_{j \in N_i} ((\mathbf{r}_j - \mathbf{r}_i).\mathbf{q} - a_{j,i}^0) \begin{pmatrix} cos\theta \\ sin\theta \end{pmatrix}$$

$$\mathbf{v}_i^{\perp} = (kz(\mathbf{r}_i) + C) \begin{pmatrix} -sin\theta \\ cos\theta \end{pmatrix}$$

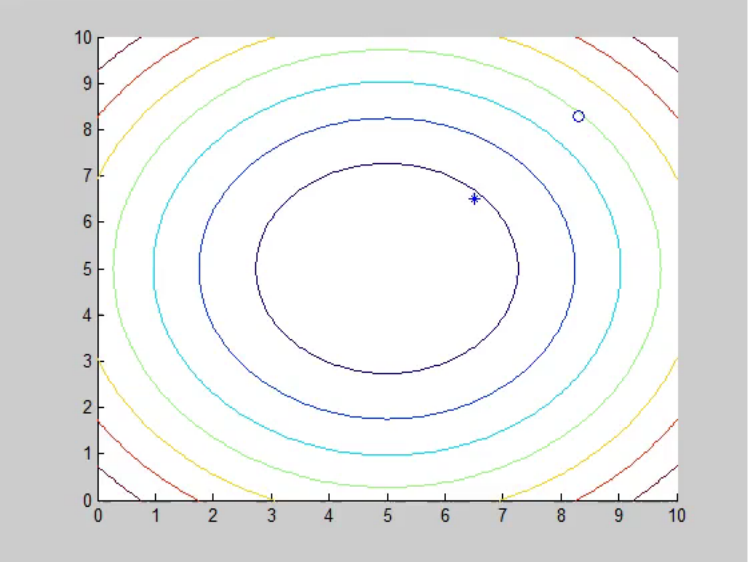


N=2 case where $r_1, r_2 \in R^2$

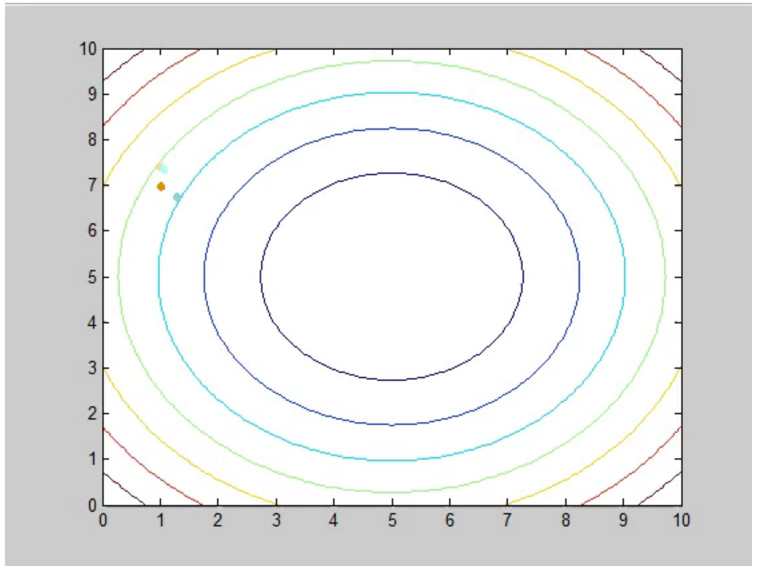
W. Wu, I. D. Couzin, and Fumin Zhang, "Bio-inspired Source Seeking with no Explicit Gradient Estimation" in *Proc. 3rd IFAC Workshop on Distributed Estimation and Control in Networked Systems(NecSys'12)*, 240-245, 2012.

Simulation – Single source/minimum at (5,5)

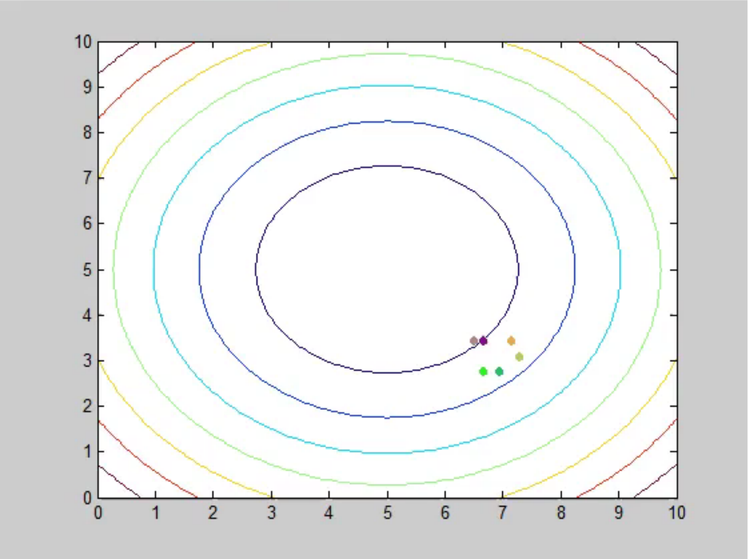
N=2



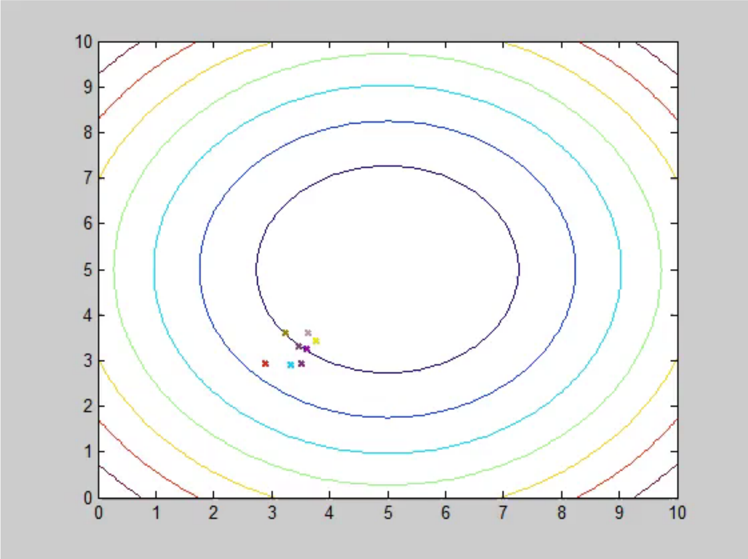
N=4



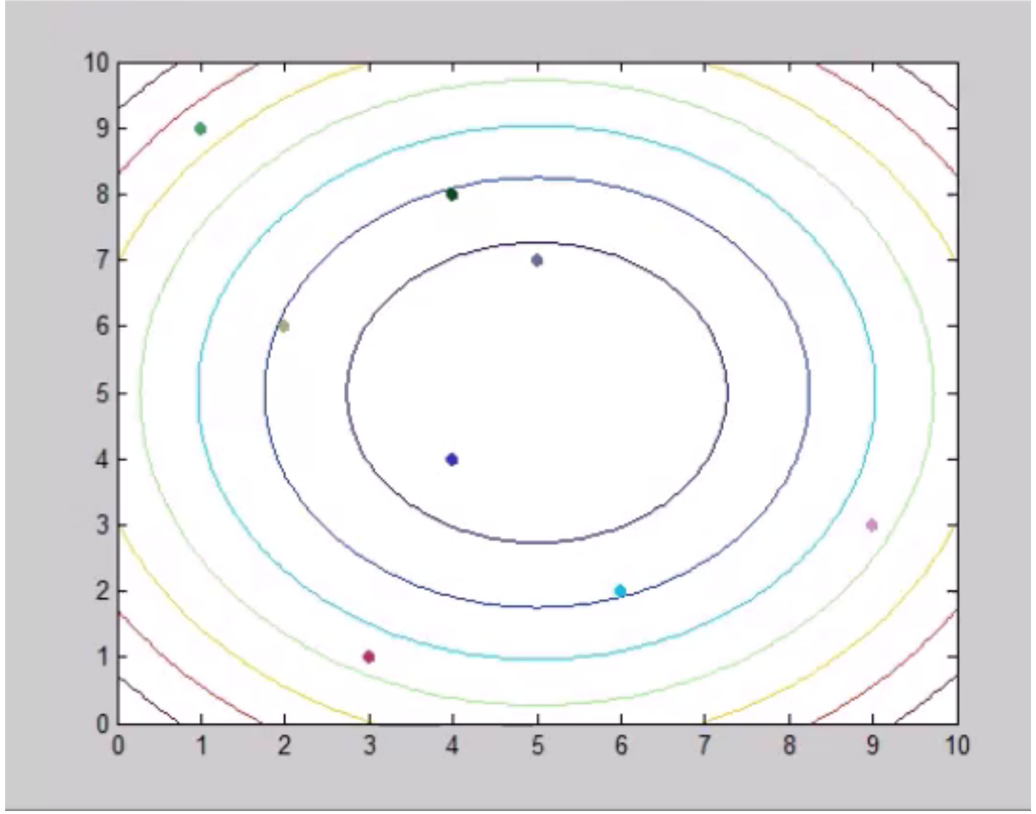
N=6



N=8

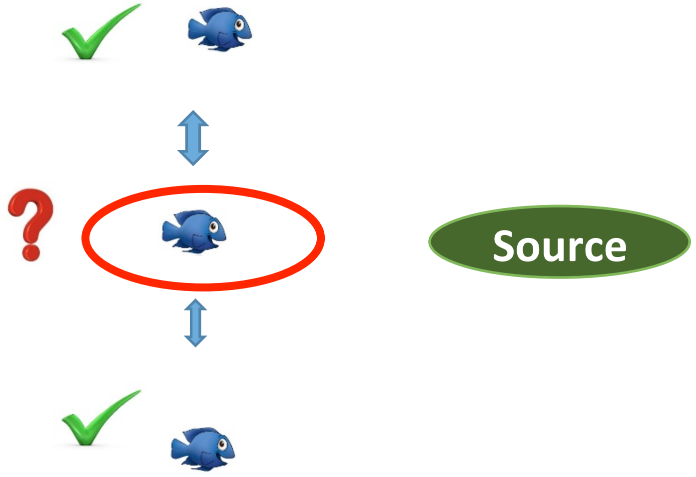


What just happened?

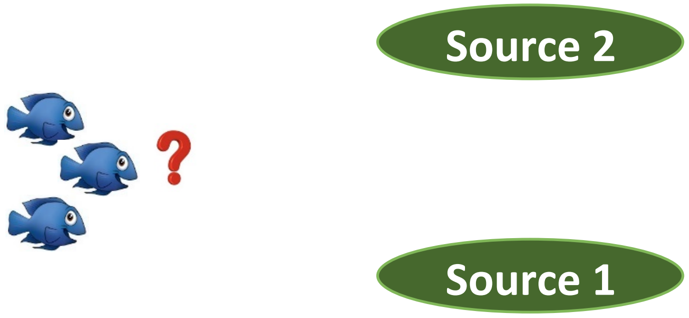


Limitations of the SSM Model

Dynamic Collaboration

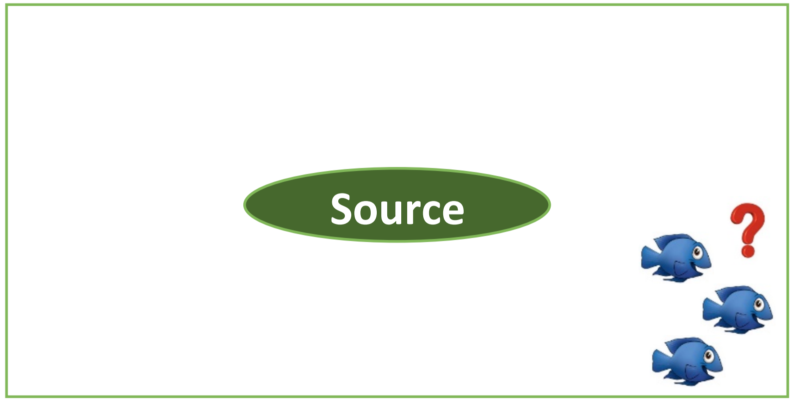


Multiple sources effect



Behavior of a single agent

Beyond the workspace or away from the source



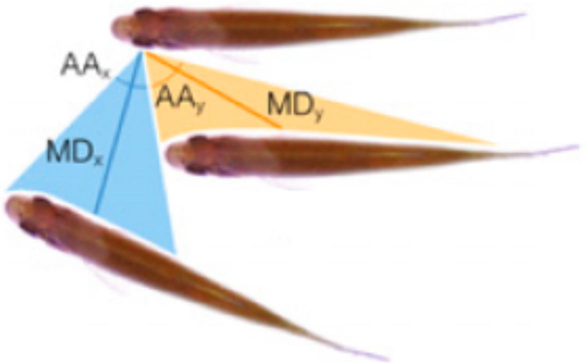
- We try to **extend the SSM model** to overcome its limitations to achieve the following:

Our Objective

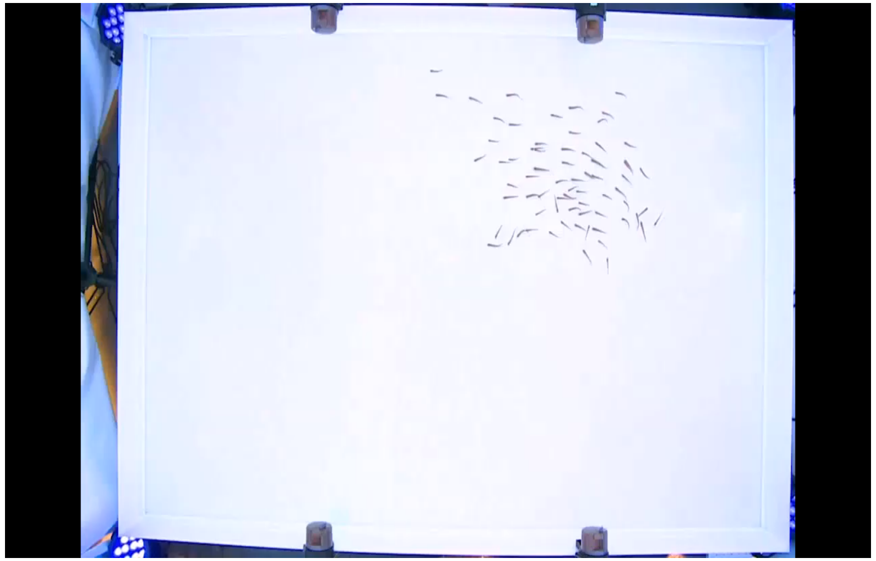
Devise an optimization algorithm in which individuals are able to explore sources at **multiple sites** by using a **collaborated approach** while remaining confined inside the **region of interest**

Random signaling among fish

- The model in this paper finds conditional probabilities for the impact of a single fish behavior on others using inter-fish distances and ranked angular areas.



$$P(i|j) = (1 + exp(-\beta_1 - \beta_2 L_D - \beta_3 A_R))^{-1}$$



where,

- $P(i|j)$ is the probability that fish i will exhibit behavioral change given that fish j is already startled
- L_D is log of the metric distance between fish j and fish i
- A_R is the ranked angular area of fish j subtended on the eye of fish i

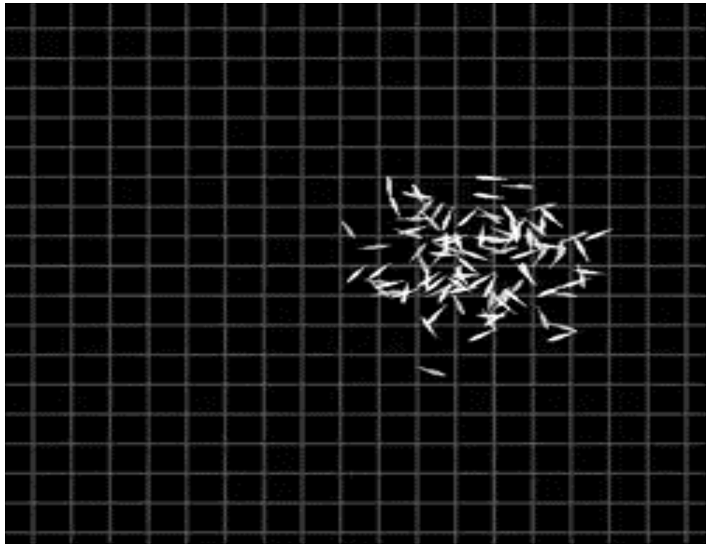
S. Brin, C. R. Twomey, A. T. Hartnett, H. Shan, and I. D. Couzin, "Revealing the hidden networks of interaction in mobile animal groups allows prediction of complex behavioral contagion," *Proc. Natl. Acad. Sci.*, vol. 112, no. 15, p. 201420068, 2015.

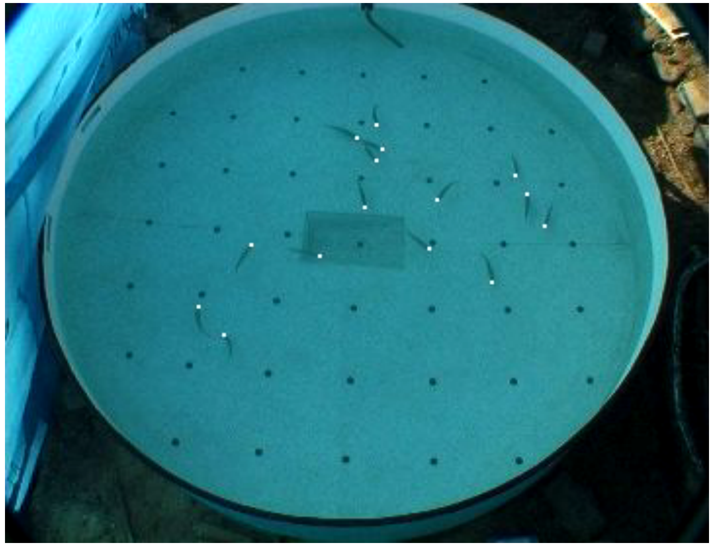
Strolling Motion

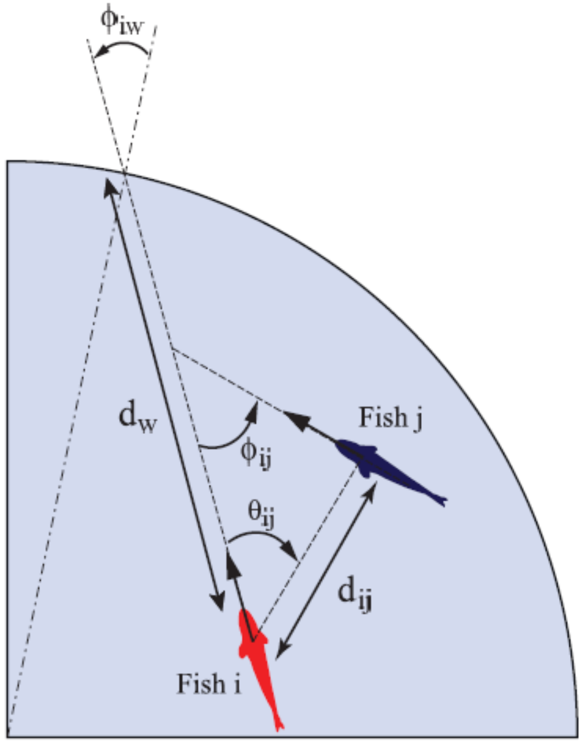
- Each agent has a constant speed but its steering control is given by the following equations:

$$dw_i(t) = -v[\frac{dt}{\xi}(w_i(t) - w_i^*(t)) - \hat{\sigma} dW] \quad (1)$$

$$w_i^*(t) = \hat{k}_W \frac{sgn(\phi_{iW})}{\tau_{iW}} + \frac{1}{N_i} \sum_{j \in V_i} (k_p d_{ij} sin\theta_{ij} + \hat{k}_v v sin\phi_{ij}) \quad (2)$$







Gautrais J, Ginelli F, Fournier R, Blanco S, Soria M, Et al. (2012) Deciphering Interactions In Moving Animal Groups. *PLoS Comput Biol* 8(9): e1002678.

Dynamic Teaming

Our idea is to modify the formation control law in SSM:

$$v_i^{\|} = k_p \sum_{j \in N_i} ((\mathbf{r}_j - \mathbf{r}_i).\mathbf{q} - a^0_{j,i})$$

and the steering control law in strolling motion:

$$w_i^*(t) = \hat{k}_W \frac{sgn(\phi_{iW})}{\tau_{iW}} + \frac{1}{N_i} \sum_{j \in V_i} (k_p d_{ij} sin\theta_{ij} + \hat{k}_v v sin\phi_{ij})$$

so that the neighborhood is determined by the following probability:

$$P(i|j) = (1 + exp(-\beta_1 - \beta_2 L_D - \beta_3 A_R))^{-1}$$

Switching Strategy

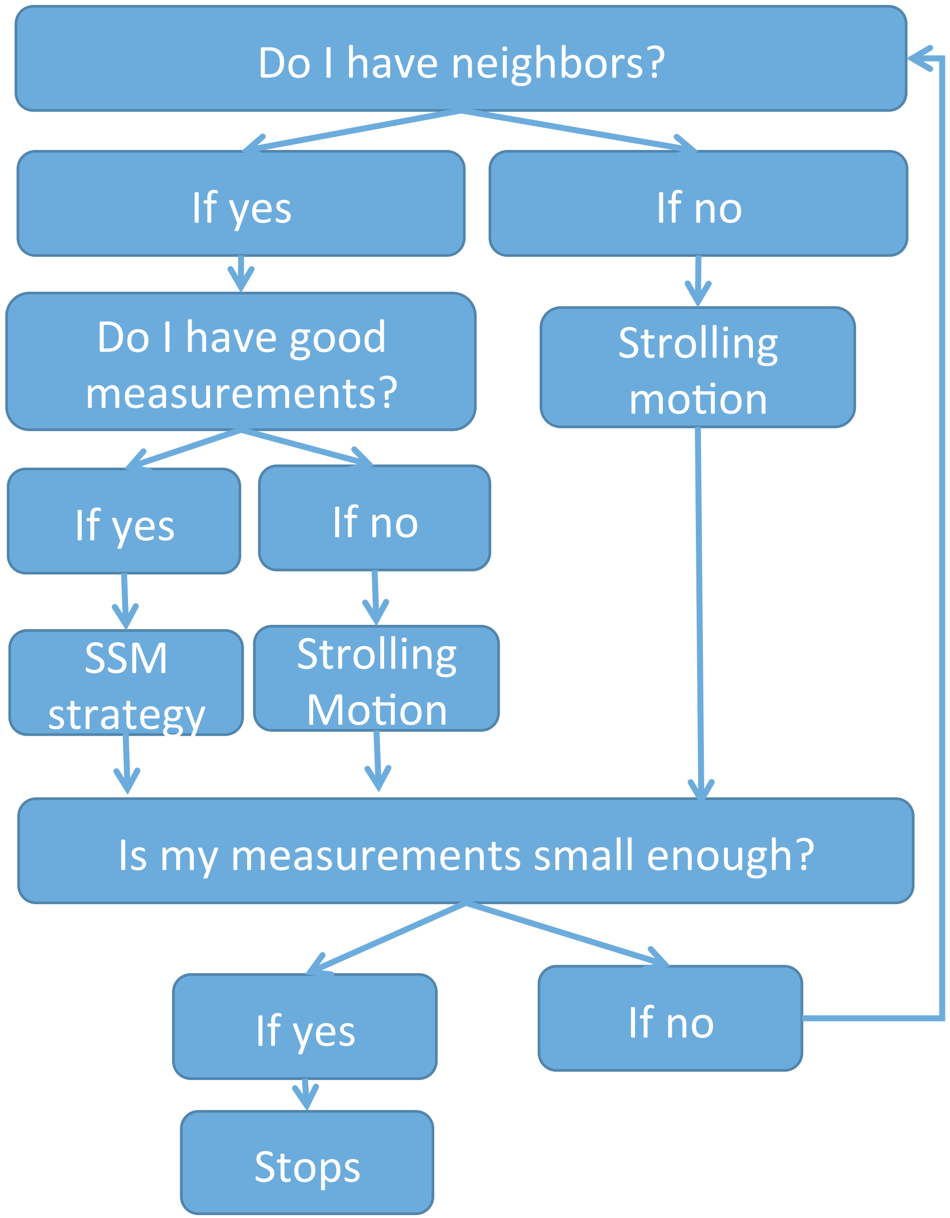
We introduced a **switching approach** between both the models:

- **Team:**
  - If the measurement > threshold (away from the source) => agents stroll around
  - If measurement < threshold (near the source) => agents switch to SSM
- **Single agent:**

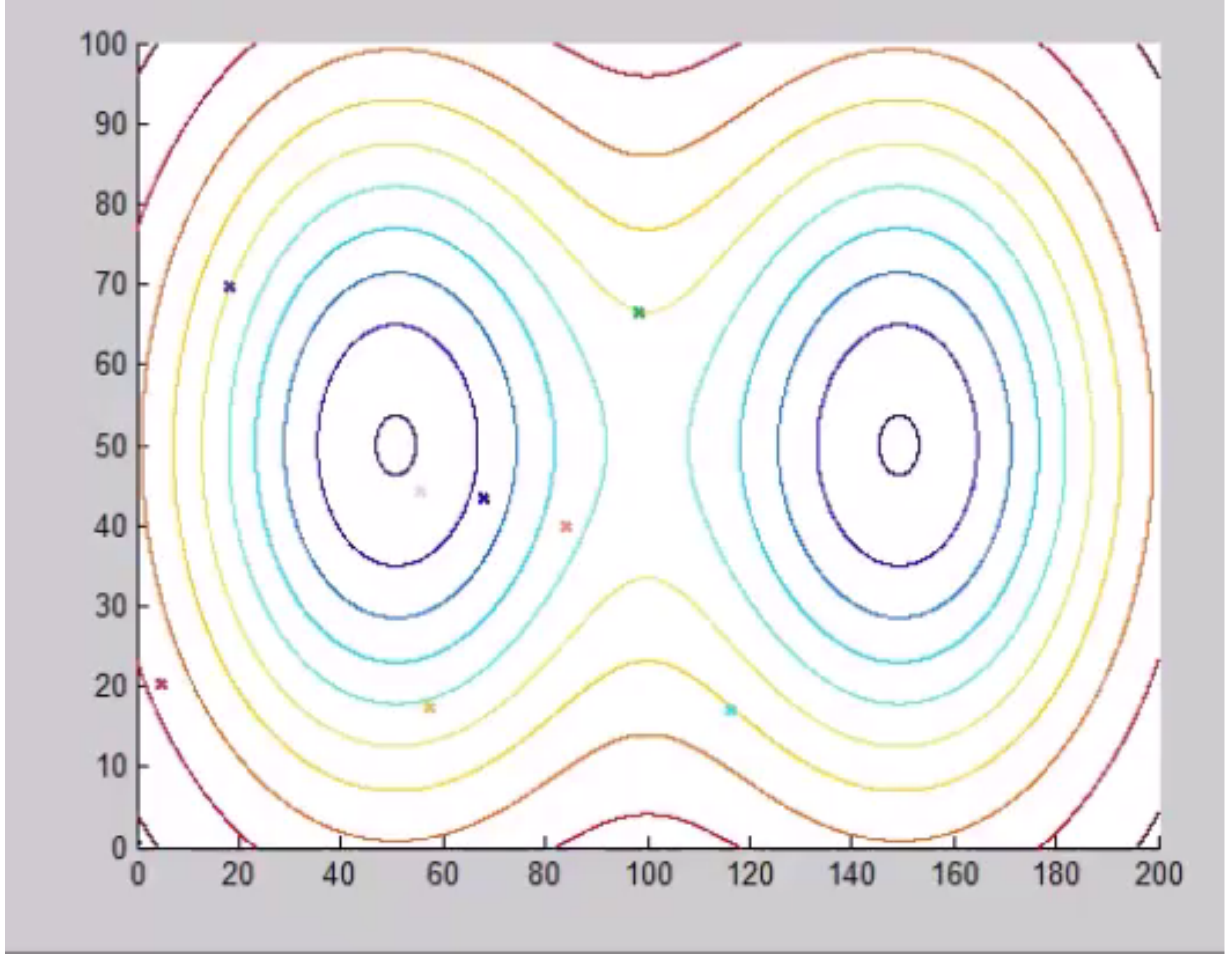
  Randomly strolls around until
  - It reaches the source by luck

    OR
  - It encounters another agent to team up and keeps following either strolling motion or SSM according to the approach mentioned above

Combined Algorithm



Simulation – N=8 agents with 2 minima at (50,50)(150,50)



Next Steps

- Enable transition between both the models so that the trajectory remains smooth
- Even in the presence of wall avoidance term, the agents sometimes go beyond the boundaries
- Giving more weightage to those agents which are near the source
- Find applications for these algorithms in fields of controls and robotics.

Questions/Comments?