EE631 Cooperating Autonomous Mobile Robots

Lecture: Cooperative Control of Large Systems

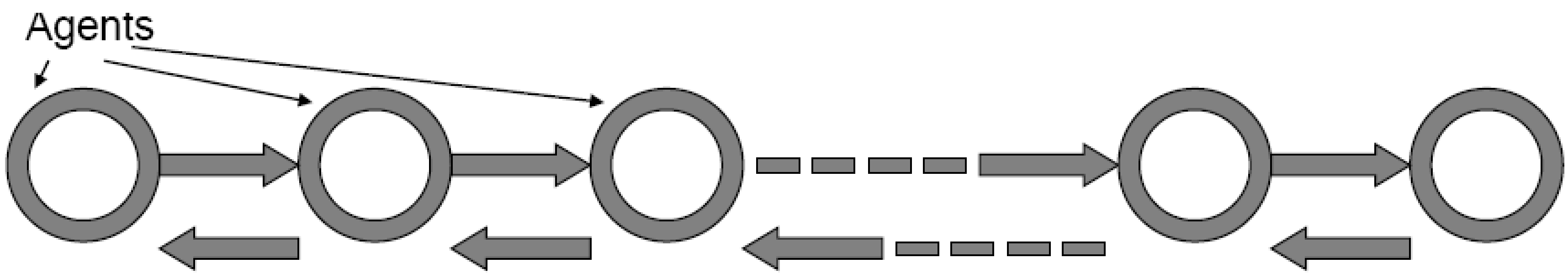
Prof. Yi Guo

Introduction

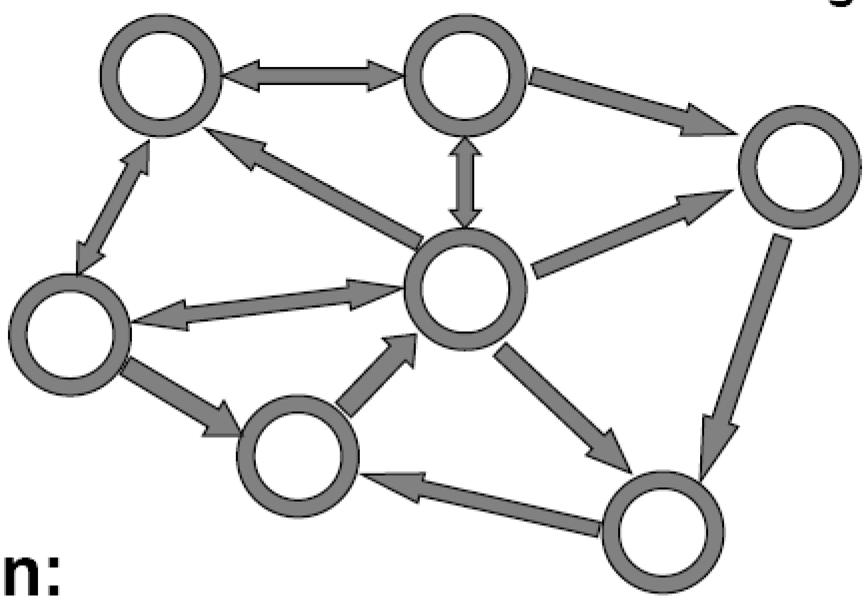
- Cooperative control is a term used to capture those problem areas in which some type of repetition of identical or non-identical subsystems, which are interconnected together, occurs.
- Components of large systems:
  - Agents that are autonomous and self driven
  - Interconnection topology which may be fixed or time-varying
  - Interactions between agents which may be linear or nonlinear

Examples of Cooperative Control Systems

- In nature:
  - Motion of clusters of birds, fish, insects, etc. moving together
  - Cell structure of mammals and life-forms
- In man-made systems:
  - Vehicle platoon in transportation systems
  - Network systems
- In various organs of human body
  - Intestinal system



Agents may interact in a **cascade** structure or in a **neighborhood** structure.



Assumption:

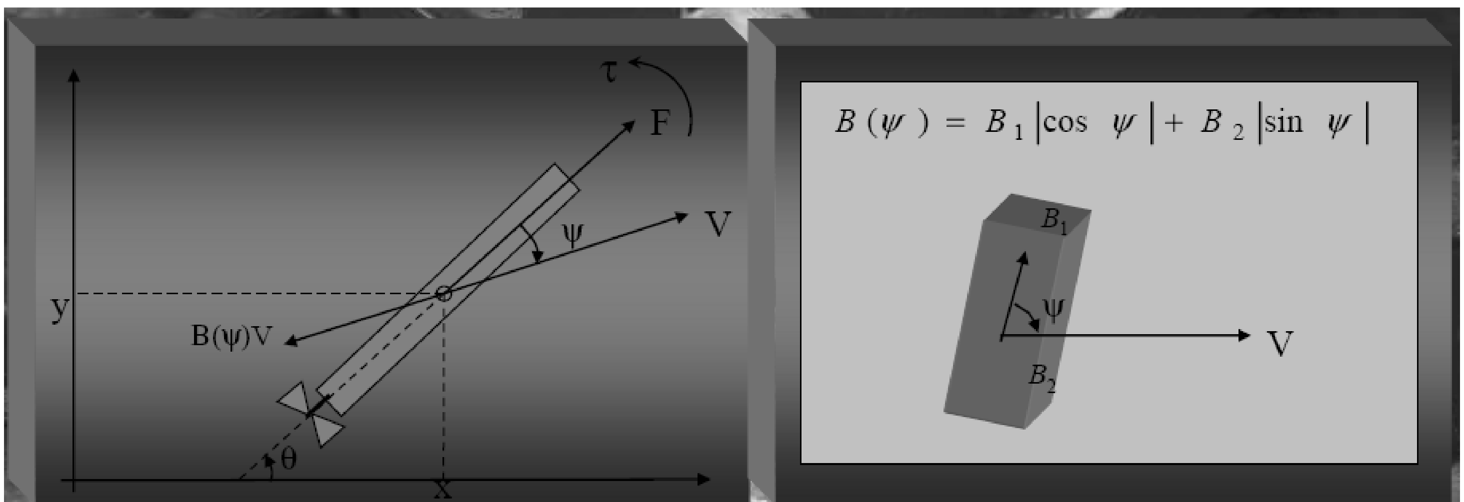
Agents are **identical in structure**, but may have **different parameters**.

Near-Identical Objects

- It is desired to develop an understanding of such interconnected systems; in particular,
  - When the number of subsystems is very large
  - When the control of such inter-connected system is constrained to be decentralized

Control of "Fish"

- Motion of underwater object is modeled as a nonlinear system



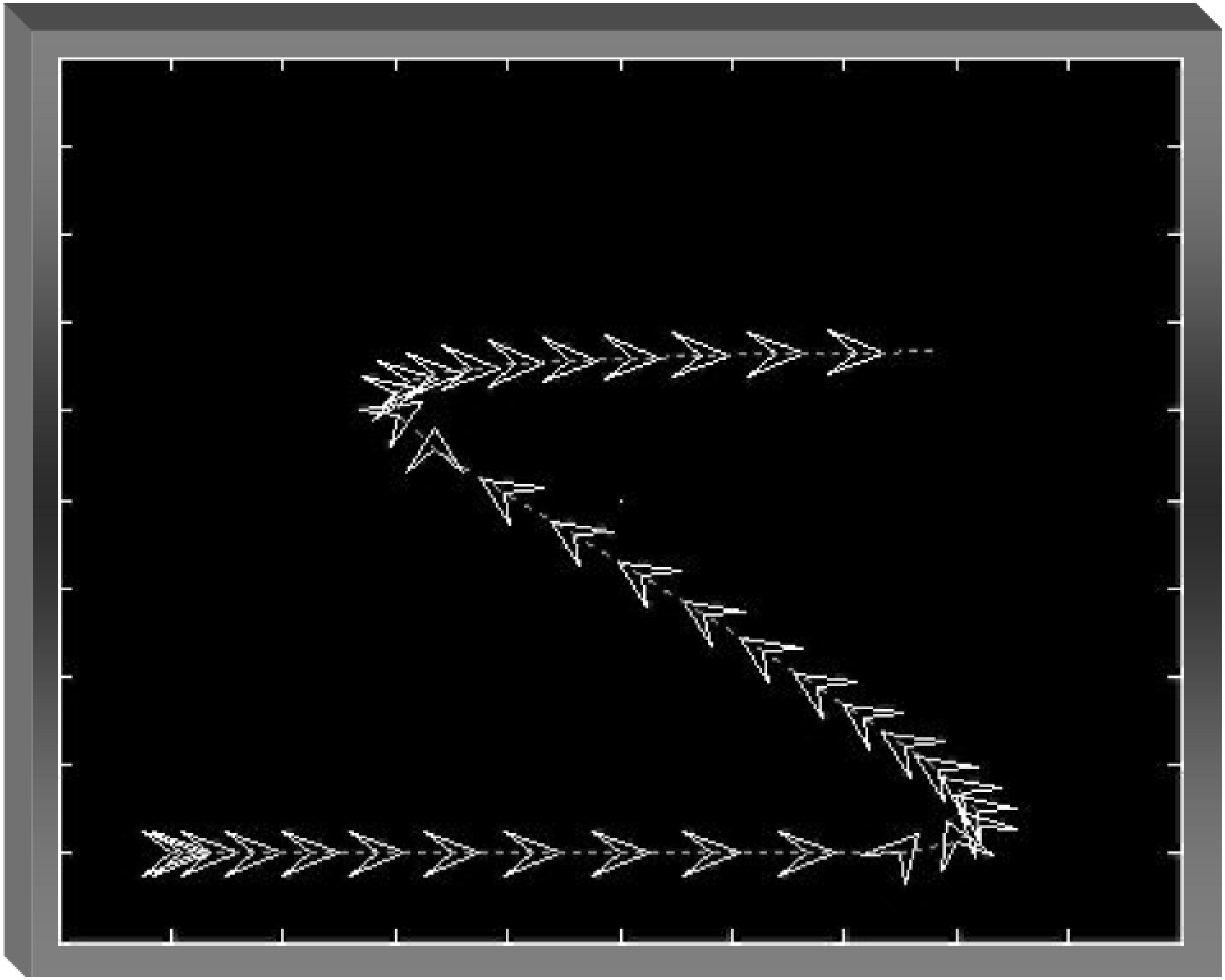
$$B(\psi) = B_1 |\cos \psi| + B_2 |\sin \psi|$$

Dynamics

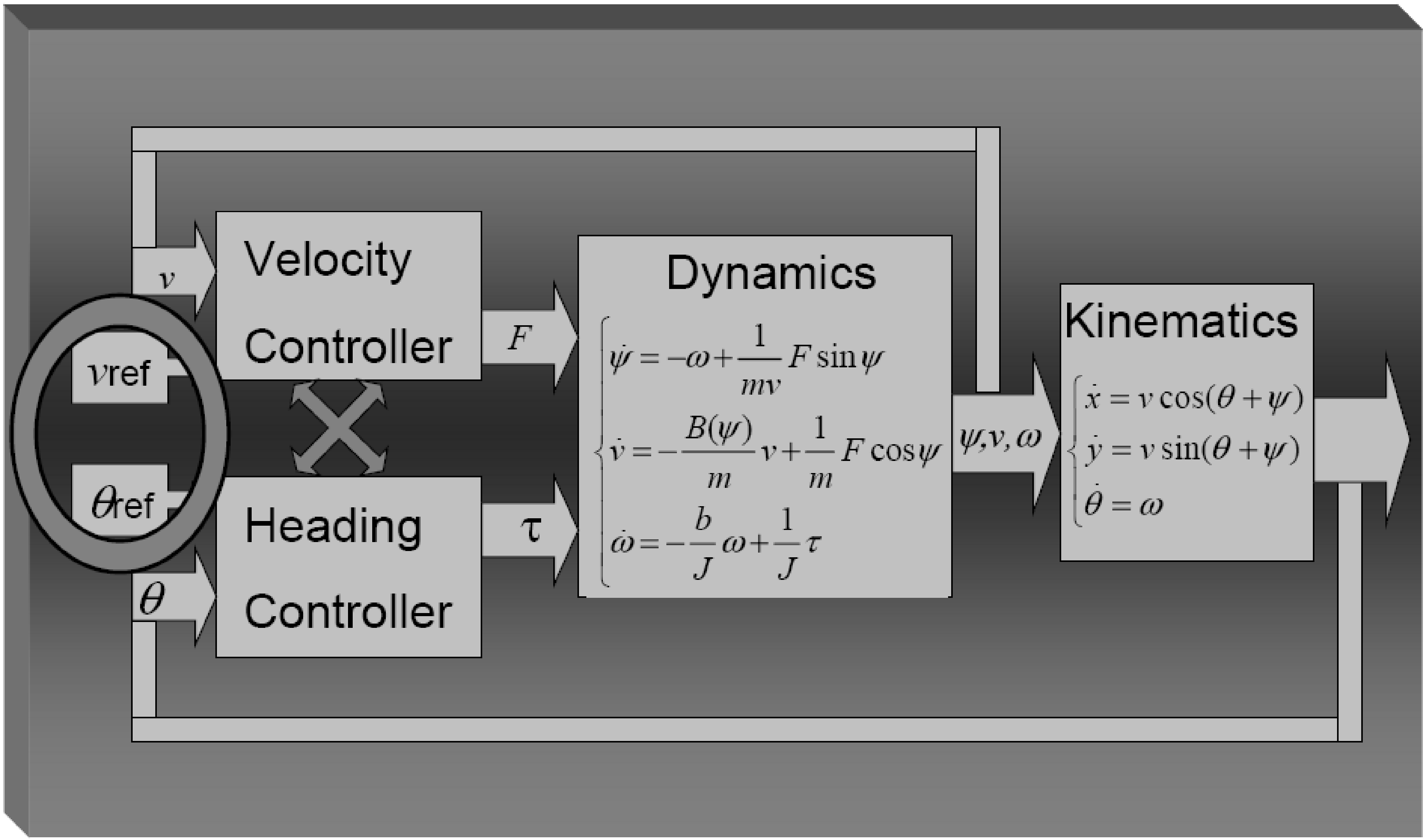
$$\begin{cases} \dot{\psi} = -\omega + \frac{1}{mv} F \sin \psi \\ \dot{v} = -\frac{B(\psi)}{m} v + \frac{1}{m} F \cos \psi \\ \dot{\omega} = -\frac{b}{J} \omega + \frac{1}{J} \tau \end{cases}$$

Kinematics

$$\begin{cases} \dot{x} = v \cos(\theta + \psi) \\ \dot{y} = v \sin(\theta + \psi) \\ \dot{\theta} = \omega \end{cases}$$



Slides from Davison and Khatir



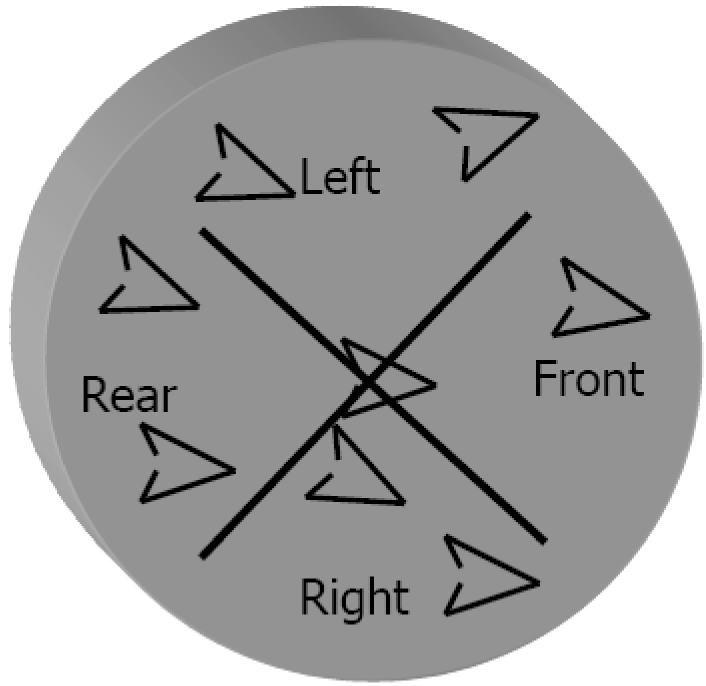
v
Velocity
Controller
F
vref
θref
Dynamics
$\dot{\psi} = -\omega + \frac{1}{mv} F \sin\psi$
$\dot{v} = -\frac{B(\psi)}{m} v + \frac{1}{m} F \cos\psi$
$\dot{\omega} = -\frac{b}{J}\omega + \frac{1}{J}\tau$
ψ,v,ω
Kinematics
$\dot{x} = v\cos(\theta + \psi)$
$\dot{y} = v\sin(\theta + \psi)$
$\dot{\theta} = \omega$
τ
Heading
Controller
θ

Averaging

$$Vref_i(t+1) = \frac{V_i(t) + \sum_{j \in \{\text{Neighbors of Agent i}\}} V_j(t)}{1 + N\{\text{Neighbors of Agent i}\}} \quad \forall i \in [1, n]$$

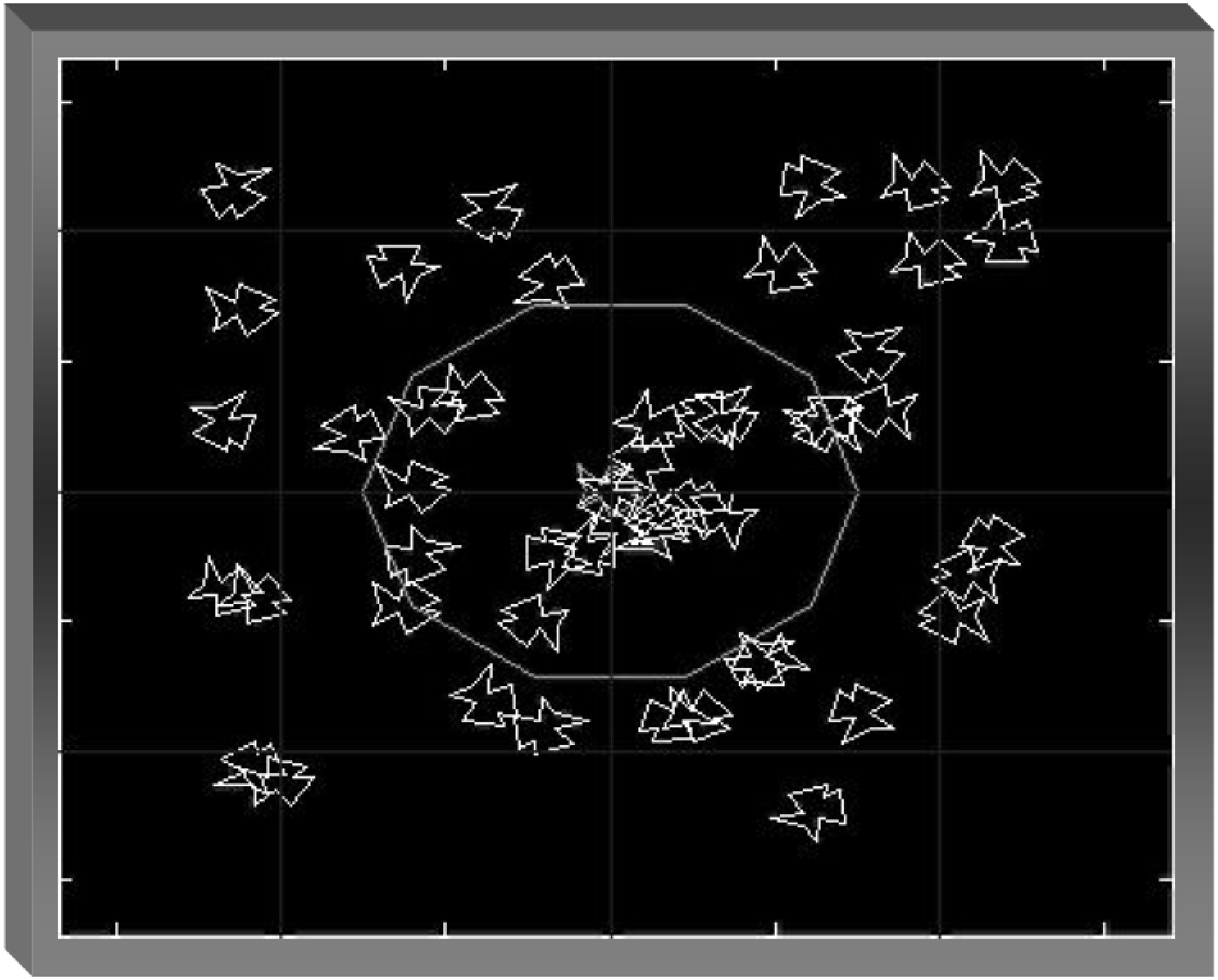
$$\theta ref_i(t+1) = \frac{\theta_i(t) + \sum_{j \in \{\text{Neighbors of Agent i}\}} \theta_j(t)}{1 + N\{\text{Neighbors of Agent i}\}} \quad \forall i \in [1, n]$$

Attraction and Repulsion



In each section:

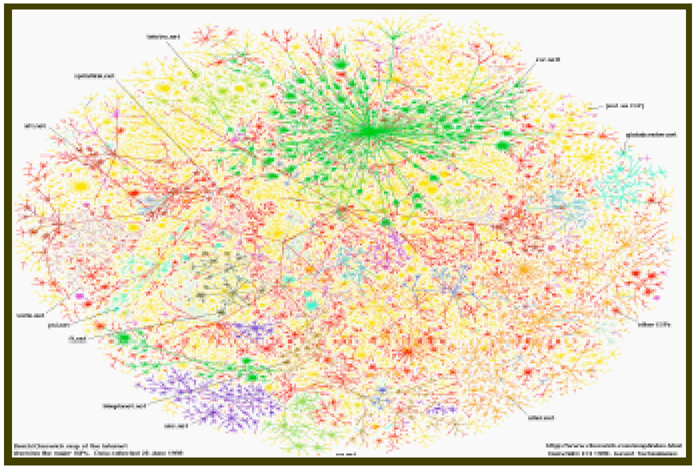
Repel very close agents,
Attract far agents, but not very far agents.



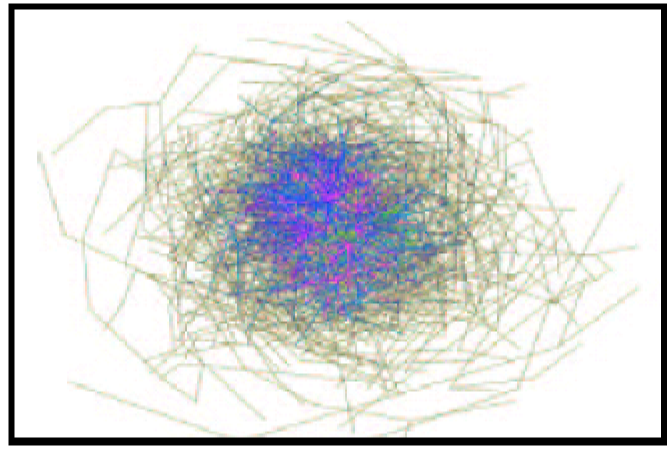
Cooperative behavior of passing obstacles

Man-Made Networked Systems

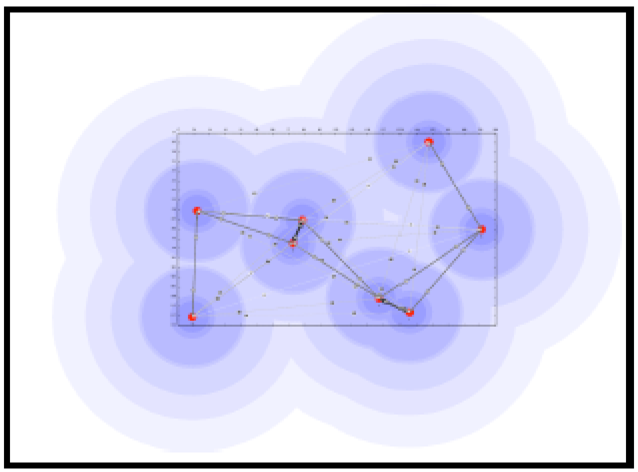
- Food webs
- Electric power grids
- World-Wide Web
- Telephone call graphs
- Etc.



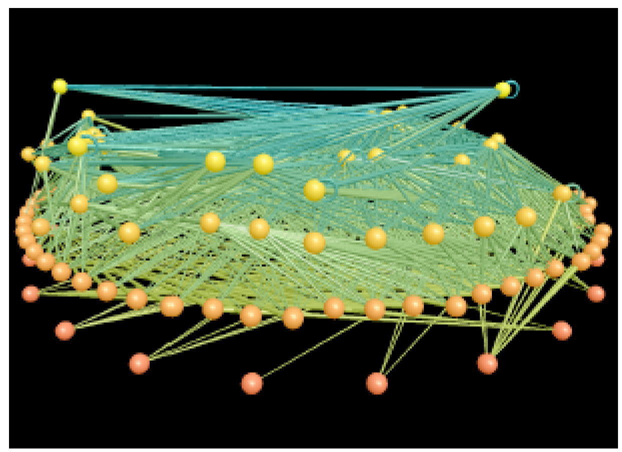
The Internet



File sharing peer to peer system



A Sensor Network



Food Web of
Little Rock Lake, WI

Complications in Networked Systems

- Structural complexity: the wiring diagram could be intricate tangle
- Network evolution: the wiring diagram could change over time
- Connection diversity: links between nodes could have different weights, signs etc.
- Dynamic complexity: the node could be nonlinear dynamic systems
- Node diversity: different kinds of nodes
- Meta-complication: one complication could affect another over time

In Summary

- Early stage of exploring the fascinating subject
- Fundamental problems in cooperative control is to be defined
- Next, we'll focus on a problem called "consensus", which is relatively well studied, and discuss its application in vehicle formation control

Readings:

- Cooperative Control of Large Systems, by M. E. Khatir and E. J. Davison, IN Cooperative Control, A Post-Workshop Volume 2003 Block Island Workshop on Cooperative Control, Edited by V. Kumar, N. Leonard, A. S. Morse, page 119-136.
- Exploring Complex Networks, by S. H. Strogatz, Nature 410, 268-276 (8 March 2001)