Consensus Problems in Multi-Robot Systems
Flocking in Fixed and Switching Networks

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(2003, 2005 versions)
Motivation

- Theoretically explain the Reynolds [1987] flocking phenomenon
- Flocking results from each individual following three steering behaviors based on the positions/velocities of its neighbors:

  - **Separation**: Avoid crowding local flockmates
  - **Alignment**: Steer toward average heading of local flockmates
  - **Cohesion**: Move toward average position of local flockmates

Local Robot Control Laws

Agent model:

\[
\begin{align*}
\dot{r}_i &= v_i \\
\dot{v}_i &= u_i \quad i = 1, \ldots, N \\
\dot{u}_i &= \alpha_i + a_i
\end{align*}
\]

\[
\begin{align*}
r_i &= [x_i \ y_i]^T \\
v_i &= [\dot{x}_i \ \dot{y}_i]^T \\
r_{ij} &= r_i - r_j \\
u_i &= [u_x \ u_y]^T
\end{align*}
\]

\(\alpha_i\)  Align agent velocity vectors, make them move with common speed and direction

\(a_i\)  Produce collision avoidance and cohesion
Local Robot Control Laws

\( \mathcal{G} = \{ \mathcal{V}, \mathcal{E} \} \) \hspace{1cm} \text{Neighboring graph}

- Undirected graph consisting of:
  \[ \mathcal{V} = \{ n_1, \ldots, n_N \} \] indexed by agents
  \[ \mathcal{E} = \{ (n_i, n_j) \in \mathcal{V} \times \mathcal{V} \mid n_i \sim n_j \} \]
  unordered pairs of vertices that represent neighboring relations

**Neighboring set of agent** \( i \):

\[ \mathcal{N}_i \triangleq \{ j \mid i \sim j \} \subseteq \{1, \ldots, N\} \setminus \{i\} \]

- Reflects physical proximity or existence of communication channel
Flock Simulations: Fixed Network

1

2

3

4
No way to ensure collision avoidance between two agents unless they are interconnected; switching network solves this problem.
Flock Simulations: Switching Network

$R = 2 \text{ m}$
Flock Simulations: Switching Network

Agent degrees vs. time

Agent speeds vs. time
Cooperative Control of Mobile Sensor Networks: Adaptive Gradient Climbing in a Distributed Environment

Petter Ögren, Edward Fiorelli, Naomi Leonard
Motivation

- Stable coordination of a group of vehicles to cooperatively climb the gradient of an environmental field
  - Inspired by fish schools, which efficiently climb nutrient gradients using local rules at the individual level
  - Can be used to track ocean features such as fronts and eddies

- Decouple formation stabilization problem from performance of network mission

Framework for Formation Control

- Vehicle modeled as point mass with fully actuated dynamics

- vehicle $i = 1, \ldots, N$
- virtual leader $l = 1, \ldots, M$
- COM of "virtual body"

\[ \ddot{x}_i = u_i \quad u_i \in \mathbb{R}^3 \]

\[ x_{ij} = x_i - x_j \]
\[ h_{il} = x_i - b_l \]
Implementation

AOSN-II project: Adaptive, coupled observation/modeling system in the ocean

Figure 3. Triangle formation snapshots at various UTC times on August 16, 2003. Dotted line: path of formation centroid; Piecewise linear dash-dotted line: desired virtual leader path.

Figure 4. The actual average of vehicle distances during the demonstration and the desired vehicle spacing as a function of time from the August 16, 2003 demonstration.