Read Ch. 17: Cooperation & Competition
Alternatives to Self-Organization

• “Templates”
  – no evidence that water currents, light, chemicals guide collective movement

• “Leaders”
  – no evidence for leaders
  – those in front may drop behind
  – those on flank may find selves in front
  – each adjusts to several neighbors

• “Blueprint” or “Recipe”
  – implausible for coordination of large schools
  – e.g., millions of herring, hundreds of millions of cod
Self-Organization Hypothesis

• Simple attraction & repulsion rules generate schooling behavior
  – positive feedback: brings individuals together
  – negative feedback: but not too close

• Rules rely on local information
  – i.e. positions & headings of a few nearby fish
  – no global plan or centralized leader
Mechanisms of Individual Coordination

• Vision
  – governs attraction
  – & alignment

• Lateral line
  – sensitive to water movement
  – provides information on speed & direction of neighbors
  – governs repulsion
  – & speed matching

• How in this information integrated into a behavioral plan?
  – most sensitive to nearest neighbors
Basic Assumptions of Huth & Wissel (1992) Model

• All fish follow same rules
• Each uses some sort of weighted average of positions & orientations of nearest neighbors
• Fish respond to neighbors probabilistically
  – imperfect information gathering
  – imperfect execution of actions
• No external influences influence fish
  – e.g. no water currents, obstacles, …
Ranges of Behavior Patterns

Fig. adapted from Camazine & al., Self-Org. Biol. Sys.
Model Behavior of Individual

1. Determine a target direction from each of three nearest neighbors:
   if in repel range, then 180° + direction to neighbor
   else if in orient range, then heading of neighbor
   else if in attract range, then
       accelerate if ahead, decelerate if behind;
       return direction to neighbor
   else return our own current heading

2. Determine overall target direc. as average of 3 neighbors inversely weighted by their distances

3. Turn a fraction in this direction (determined by flexibility) + some randomness
Demonstration of Simulation of Flocking/Schooling

Run Flock.slogo
Limitations of Model

• Model addresses only motion in absence of external influences
• Ignores obstacle avoidance
• Ignores avoidance behaviors such as:
  – flash expansion
  – fountain effect
• Recent work (1997-2000) has addressed some of these issues
“Boids”

A model of flocks, herds, and similar cases of coordinated animal motion by Craig Reynolds (1986)
Boid Neighborhood
Steering Behaviors

- Separation
- Alignment
- Cohesion
Separation

Steer to avoid crowding local flockmates
Alignment

Steer towards average heading of local flockmates

Fig. from Craig Reynolds
Cohesion

Steer to move toward average position of local flockmates
Velocity Vector Update

• Compute $v_{\text{separate}}, v_{\text{align}}, v_{\text{cohere}}$ as averages over neighbors
• Let $v_{\text{change}} =$
  
  \begin{align*}
  &w_{\text{separate}} v_{\text{separate}} \\
  &+ w_{\text{align}} v_{\text{align}} \\
  &+ w_{\text{cohere}} v_{\text{cohere}}
  \end{align*}

• Let $v_{\text{new}} = \square v_{\text{old}} + (1 - \square) v_{\text{change}}$

\hspace{5cm} \textbf{momentum factor}
Demonstration of boids

Run Craig Reynold’s boids at http://www.red3d.com/cwr/boids
Obstacle Avoidance

- Boid flock avoiding cylindrical obstacles (Reynolds 1986)
- This model incorporates:
  - predictive obstacle avoidance
  - goal seeking (scripted path)
Use in Computer Animation

Extract from Stanley and Stella in “Breaking the Ice” (1987)

store.yahoo.com/odyssey3d/comanclascli2.html
Particle Swarm Optimization

(Kennedy & Eberhart, 1995)
Motivation

• Originally a model of social information sharing
• Abstract vs. concrete spaces
  – cannot occupy same locations in concrete space
  – can in abstract space (two individuals can have same idea)
• Global optimum (& perhaps many suboptima)
• Combines:
  – private knowledge (best solution each has found)
  – public knowledge (best solution entire group has found)
Particle Swarms

Idea
- moving points in the search space, which refine their knowledge by interaction

What is a particle?
- a particle consists of:
  - $\vec{x}_i$ position
  - $\vec{v}_i$ velocity
  - $\vec{p}_i$ best position found so far
- velocity and position update rules

(Kennedy and Eberhart, 1995)
Example

Particle Swarms

2D search space

fitness

max

min

x_1

x_2

Fig. from EVALife site
Example

Particle Swarms

Fig. from EVALife site
Example

Particle Swarms

Fig. from EVALife site
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Particle Swarms
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Particle Swarms

Fig. from EVALife site
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Particle Swarms
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Particle Swarms

Fig. from EVALife site
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Particle Swarms

Fig. from EVALife site
Variables

$x_k$ = current position of particle $k$
$v_k$ = current velocity of particle $k$
$p_k$ = best position found by particle $k$
$Q(x) = \text{quality of position } x$
$g$ = index of best position found so far
  i.e., $g = \text{argmax}_k Q(p_k)$
$\{f_1, f_2\} = \text{random variables uniformly distributed over } [0, 2]$
$w = \text{inertia}$
Velocity & Position Updating

\[ \mathbf{v}_k \leftarrow \mathbf{w} \mathbf{v}_k + \square_1 (\mathbf{p}_k - \mathbf{x}_k) + \square_2 (\mathbf{p}_g - \mathbf{x}_k) \]

- \( \mathbf{w} \mathbf{v}_k \) maintains direction (inertial part)
- \( \square_1 (\mathbf{p}_k - \mathbf{x}_k) \) turns toward private best (cognition part)
- \( \square_2 (\mathbf{p}_g - \mathbf{x}_k) \) turns towards public best (social part)

\[ \mathbf{x}_k \leftarrow \mathbf{x}_k + \mathbf{v}_k \]

- Allowing \( \square_1, \square_2 > 1 \) permits overshooting and better exploration (important!)
- Good balance of exploration & exploitation
- Limiting \( \mathbf{v}_k < \mathbf{v}_{\text{max}} \) controls resolution of search