Lecture 17

Schools, Flocks, & Herds

“and the thousands of fishes moved as a huge beast, piercing the water. They appeared united, inexorably bound to a common fate. How comes this unity?”

— anon., 17th cent.

Images from EVALife site

Coordinated Collective Movement

• Groups of animals can behave almost like a single organism
• Can execute swift maneuvers
  – for predation or to avoid predation
• Individuals rarely collide, even in frenzy of attack or escape
• Shape is characteristic of species, but flexible

Adaptive Significance

• Prey avoiding predation
• More efficient predation by predators
• Other efficiencies

Avoiding Predation

• More compact aggregation
  – predator risks injury by attacking
• Confusing predator by:
  – united erratic maneuvers (e.g. zigzagging)
  – separation into subgroups (e.g., flash expansion & fountain effect)

Flash Expansion

Fig. from Camazine et al., Self-Org. Biol. Sys.
Part 3: Autonomous Agents

Flash Expansion

Fountain Effect

Fountain Effect

Fountain Effect

Fountain Effect

Better Predation

- Coordinated movements to trap prey
  - e.g., parabolic formation of tuna
- More efficient predation
  - e.g., killer whales encircle dolphins
  - take turns eating
Other Efficiencies

• Fish schooling may increase hydrodynamic efficiency
  – endurance may be increased up to 6x
  – school acts like “group-level vehicle”
• V-formation increases efficiency of geese
  – range 70% greater than that of individual
• Lobsters line up single file by touch
  – move 40% faster than when isolated
  – decreased hydrodynamic drag

Characteristic Arrangement of School

• Shape is characteristic of species
• Fish have preferred distance, elevation & bearing relative to neighbors
• Fish avoid coming within a certain minimum distance
  – closer in larger schools
  – closer in faster moving schools

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 is 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 affect fish
  – e.g. no water currents, obstacles, …
Ranges of Behavior Patterns

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)
Steering Behaviors

- Separation
- Alignment
- Cohesion

Separation
Steer to avoid crowding local flockmates

Alignment
Steer towards average heading of local flockmates

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 $v_{\text{change}} = w_{\text{separate}} v_{\text{separate}} + w_{\text{align}} v_{\text{align}} + w_{\text{cohere}} v_{\text{cohere}}$
- Let $v_{\text{new}} = \mu v_{\text{old}} + (1 - \mu) v_{\text{change}}$

Demonstration of boids
Run Craig Reynolds’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/comanclascl2.html