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)

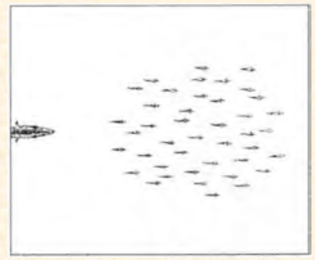
Flash Expansion

Fig. from Camazine & al., *Self-Org. Biol. Sys.*

Flash Expansion

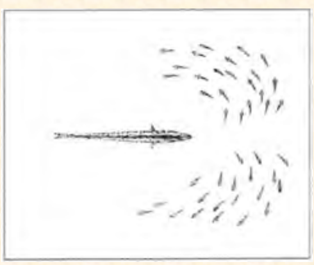
10/20/07 Fig. from Camazine & al., *Self-Org. Biol. Sys.* 7

Fountain Effect



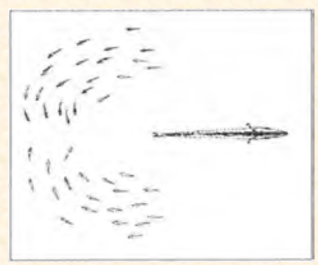
10/20/07 Fig. from Camazine & al., *Self-Org. Biol. Sys.* 8

Fountain Effect



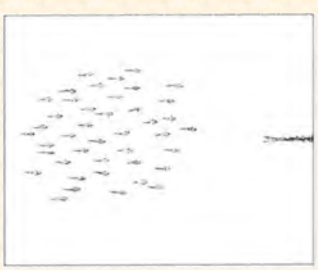
10/20/07 Fig. from Camazine & al., *Self-Org. Biol. Sys.* 9

Fountain Effect



10/20/07 Fig. from Camazine & al., *Self-Org. Biol. Sys.* 10

Fountain Effect



10/20/07 Fig. from Camazine & al., *Self-Org. Biol. Sys.* 11

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

10/20/07 12

Other Efficiencies

- Fish schooling may increase hydrodynamic efficiency
  - endurance may be increased up to 6×
  - 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

10/20/07 13

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

10/20/07 14

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

10/20/07 15

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

10/20/07 16

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*

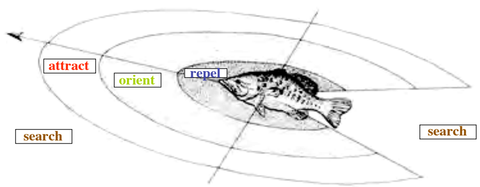
10/20/07 17

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, …

10/20/07 18

Ranges of Behavior Patterns



10/20/07 Fig. adapted from Camazine & al., *Self-Org. Biol. Sys.* 19

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

10/20/07 20

Demonstration of Simulation of Flocking/Schooling

Run Flock.slogo

10/20/07 21

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

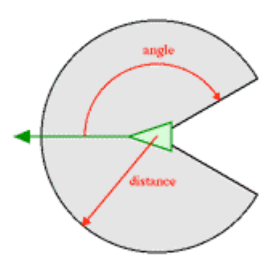
10/20/07 22

"Boids"

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

10/20/07 23

Boid Neighborhood



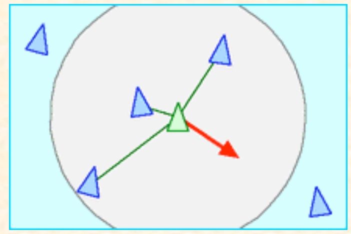
10/20/07 24

Steering Behaviors

- Separation
- Alignment
- Cohesion

10/20/07 25

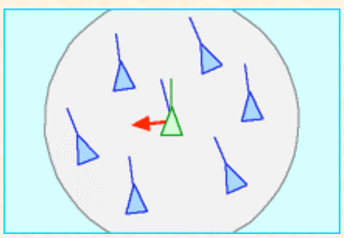
Separation



Steer to avoid crowding local flockmates

10/20/07 Fig. from Craig Reynolds 26

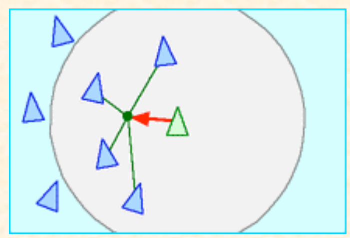
Alignment



Steer towards average heading of local flockmates

10/20/07 Fig. from Craig Reynolds 27

Cohesion



Steer to move toward average position of local flockmates

10/20/07 Fig. from Craig Reynolds 28

Velocity Vector Update

- Compute $\mathbf{v}_{separate}$, $\mathbf{v}_{align}$, $\mathbf{v}_{cohere}$ as averages over neighbors
- Let $\mathbf{v}_{change}$ =

  $w_{separate}\ \mathbf{v}_{separate}$

  $+\ w_{align}\ \mathbf{v}_{align}$

  $+\ w_{cohere}\ \mathbf{v}_{cohere}$

  momentum factor
- Let $\mathbf{v}_{new} = \mu\ \mathbf{v}_{old} + (1 - \mu)\ \mathbf{v}_{change}$

10/20/07 29

Demonstration of boids

Run Craig Reynold's boids
at http://www.red3d.com/cwr/boids

10/20/07 30

Obstacle Avoidance

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

10/20/07 31

Use in Computer Animation

- Extract from *Stanley and Stella in "Breaking the Ice"* (1987)
- store.yahoo.com/ odyssey3d/ comanclascli2.html

10/20/07 32