# Improving Network Routing

1. Nodes periodically send *forward ants* to some recently recorded destinations
2. Collect information on way
3. Die if reach already visited node
4. When reaches destination, estimates time and turns into *backward ant*
5. Returns by same route, updating routing tables

# Some Applications of ACO

- Routing in telephone networks
- Vehicle routing
- Job-shop scheduling
- Constructing evolutionary trees from nucleotide sequences
- Various classic NP-hard problems
  - shortest common supersequence, graph coloring, quadratic assignment, …

# Improvements as Optimizer

- Can be improved in many ways
- E.g., combine local search with ant-based methods
- As method of stochastic combinatorial optimization, performance is promising, comparable with best heuristic methods
- Much ongoing research in ACO
- But optimization is not a principal topic of this course

# The Nonconvergence Issue

- AS often does not converge to single solution
- Population maintains high diversity
- A bug or a feature?
- Potential advantages of nonconvergence:
  - avoids getting trapped in local optima
  - promising for dynamic applications
- Flexibility & robustness are more important than optimality in natural computation

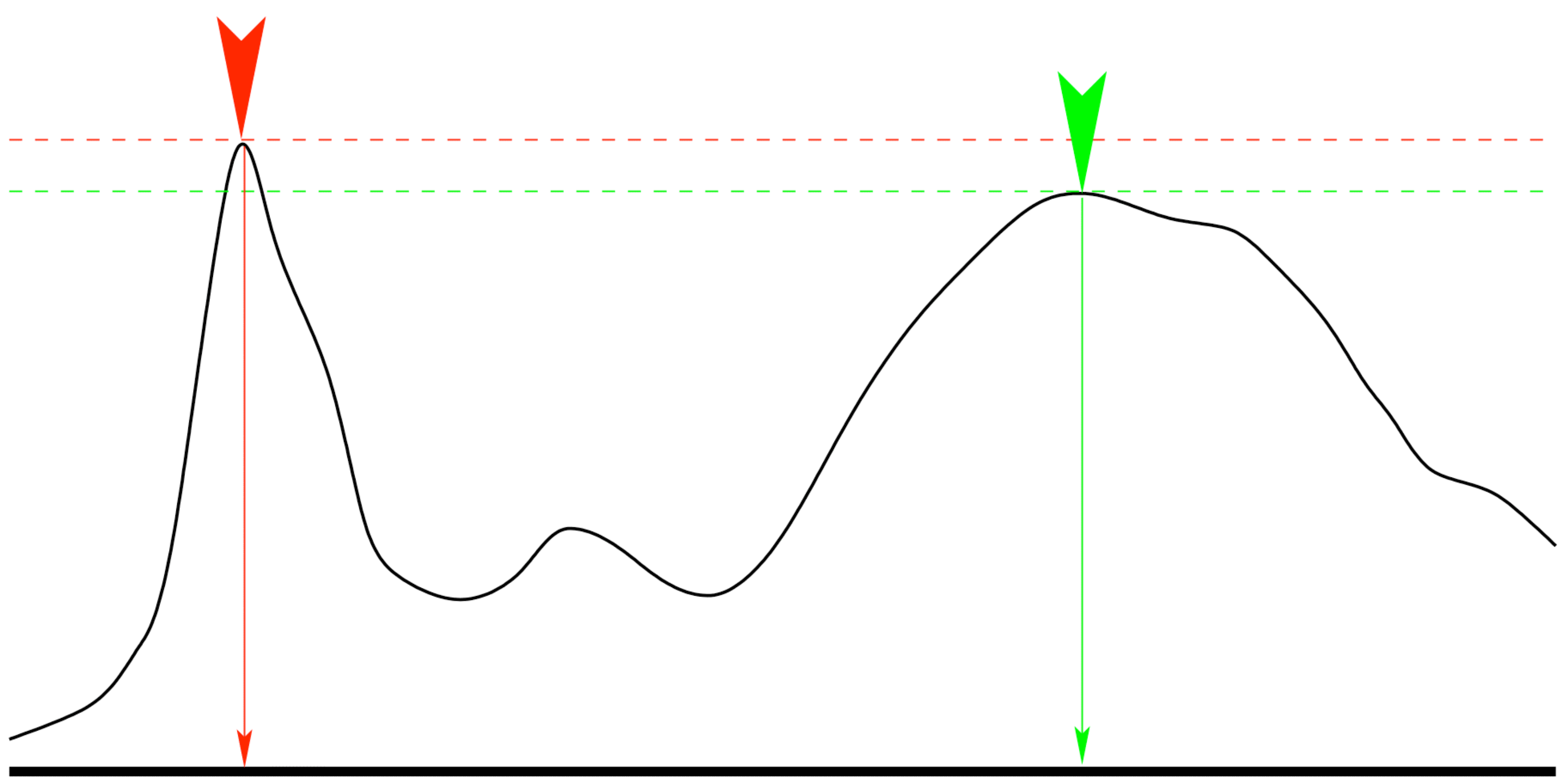
# Natural Computation

*Natural computation* is computation that occurs in nature or is inspired by computation occurring in nature

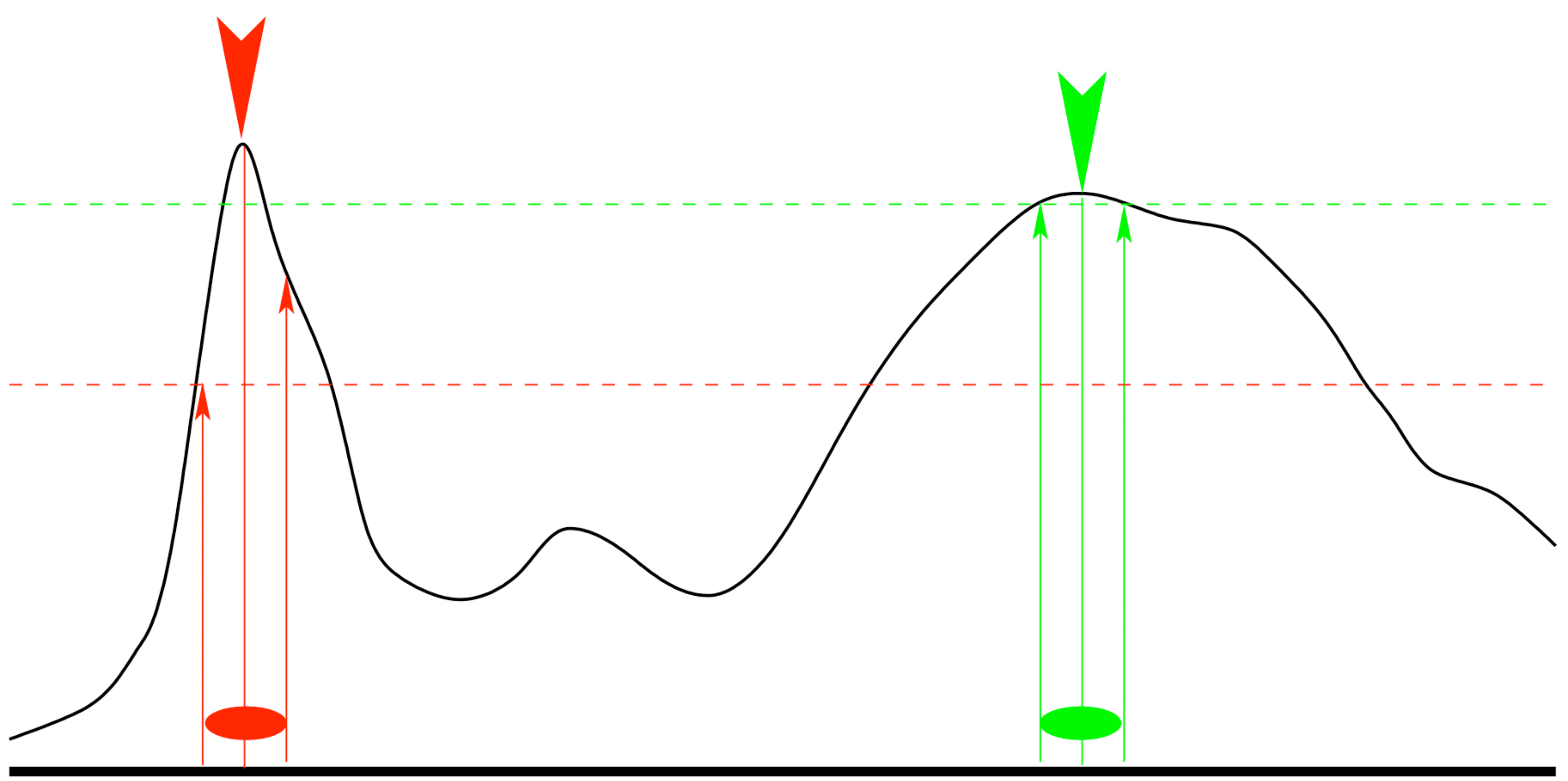
# Optimization in Natural Computation

- Good, but suboptimal solutions may be preferable to optima if:
  - suboptima can be obtained more quickly
  - suboptima can be adapted more quickly
  - suboptima are more robust
  - an ill-defined suboptimum may be better than a sharp optimum
- "The best is often the enemy of the good"

# Robust Optima

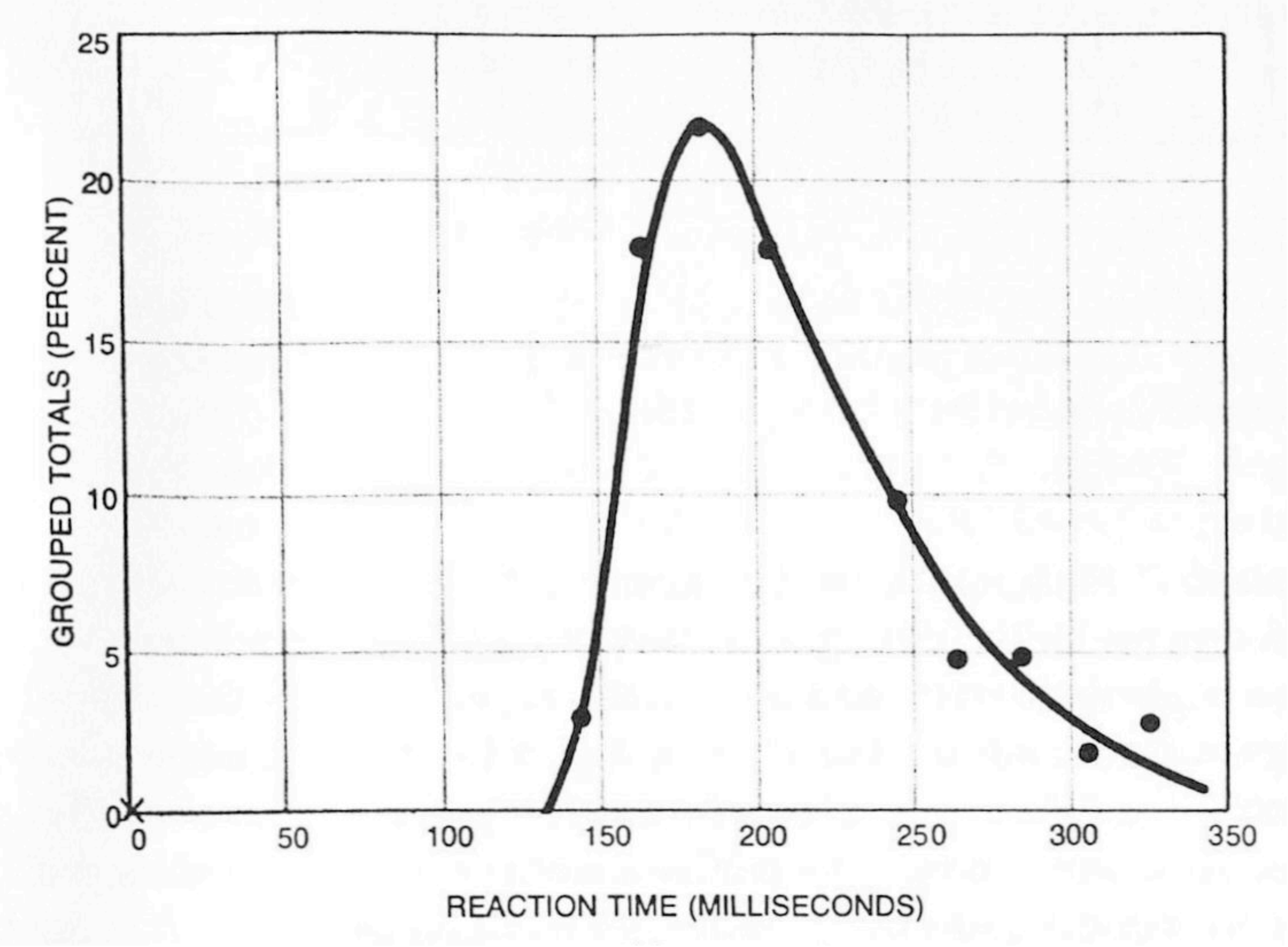


# Effect of Error/Noise



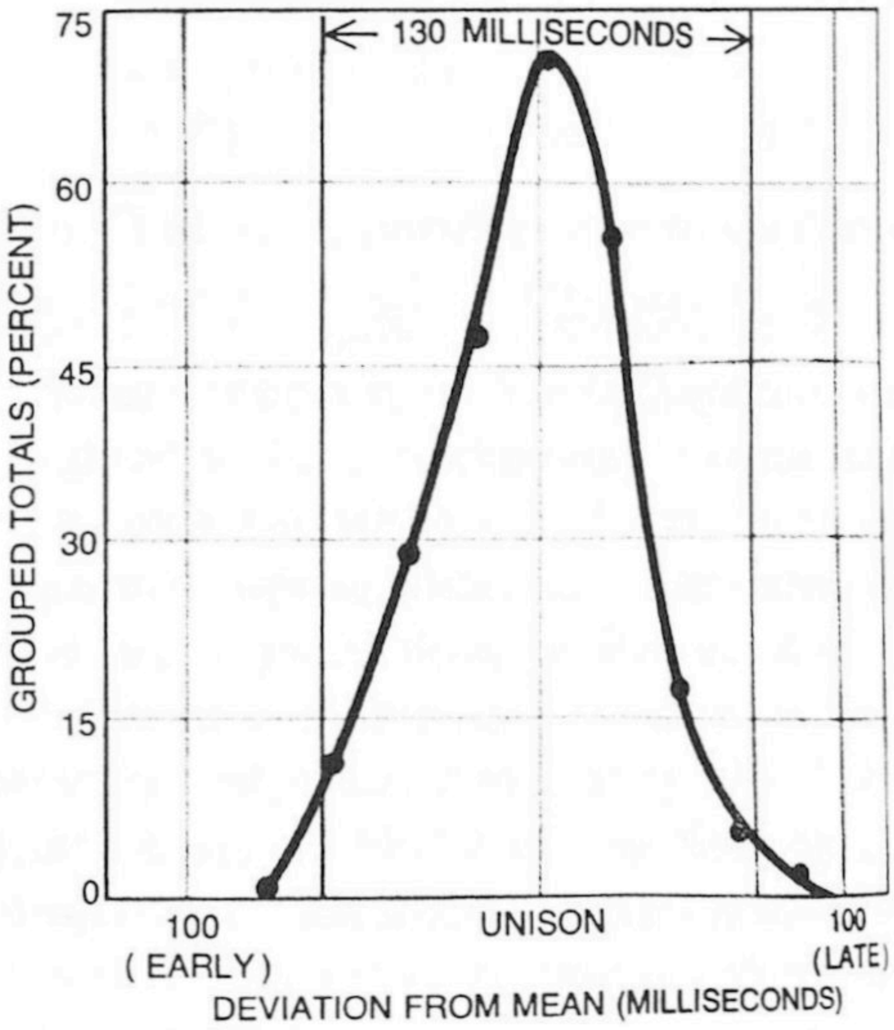
# Demonstration: Human Synchronization

# Reaction Time



Fig, from Buck & Buck (1976)

# Synchronization



Fig, from Buck & Buck (1976)

# Flashing Among Fireflies

# Synchronous Flashing

- In SE Asia enormous numbers of fireflies gather in trees and flash in synchrony
- A group of trees spread over 1/10 mile may flash in synchrony
- Only males do synchronous flashing
- Had been unexplained for 300 years
- Early 1900s: claimed to be an illusion because no explanation could be imagined

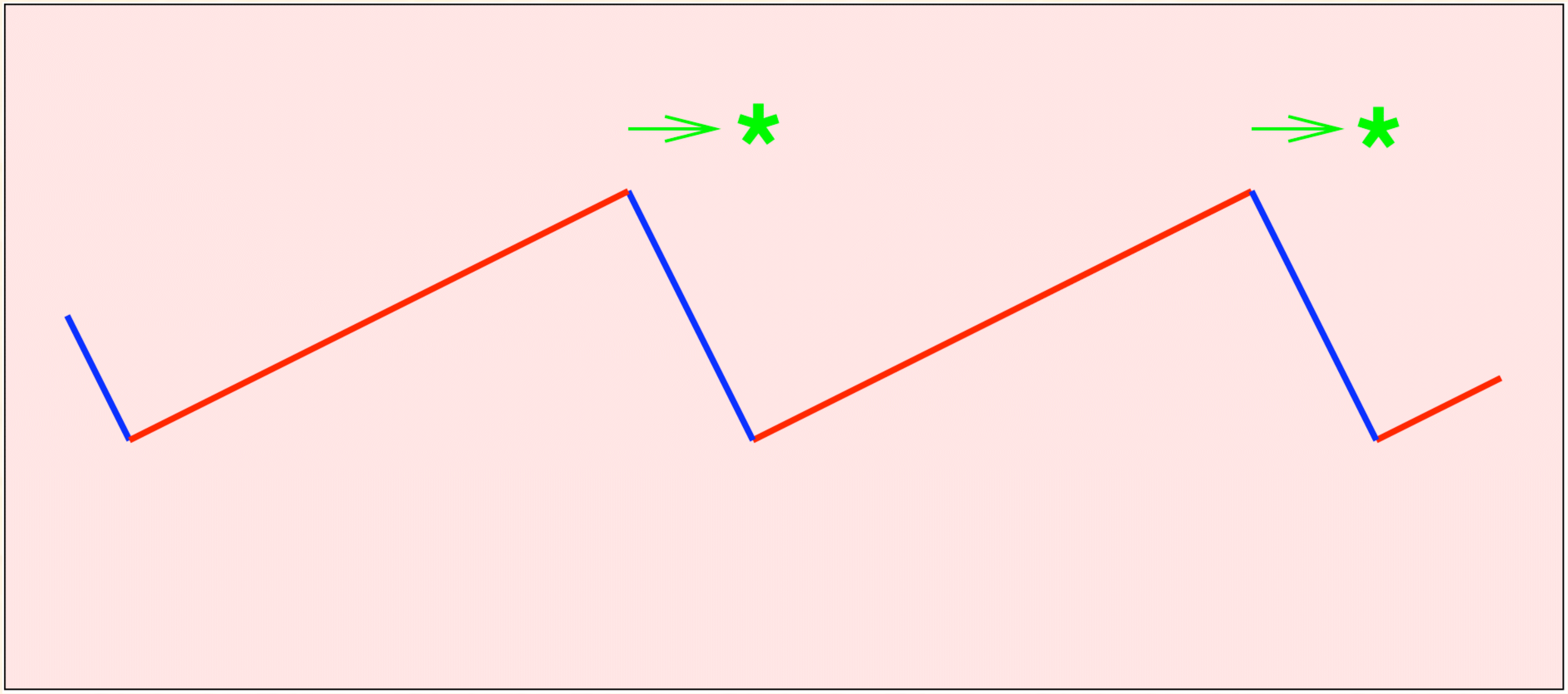
# Why Do They Do It?

- Females identify males of their own species by flashing rate
  - difficult to do if they flash chaotically
- Allows males to detect (unsynchronized flashing of nearby females)
  - i.e., enhanced detection
- Allows small groups of males to attract larger numbers of females
  - i.e., signal enhancement

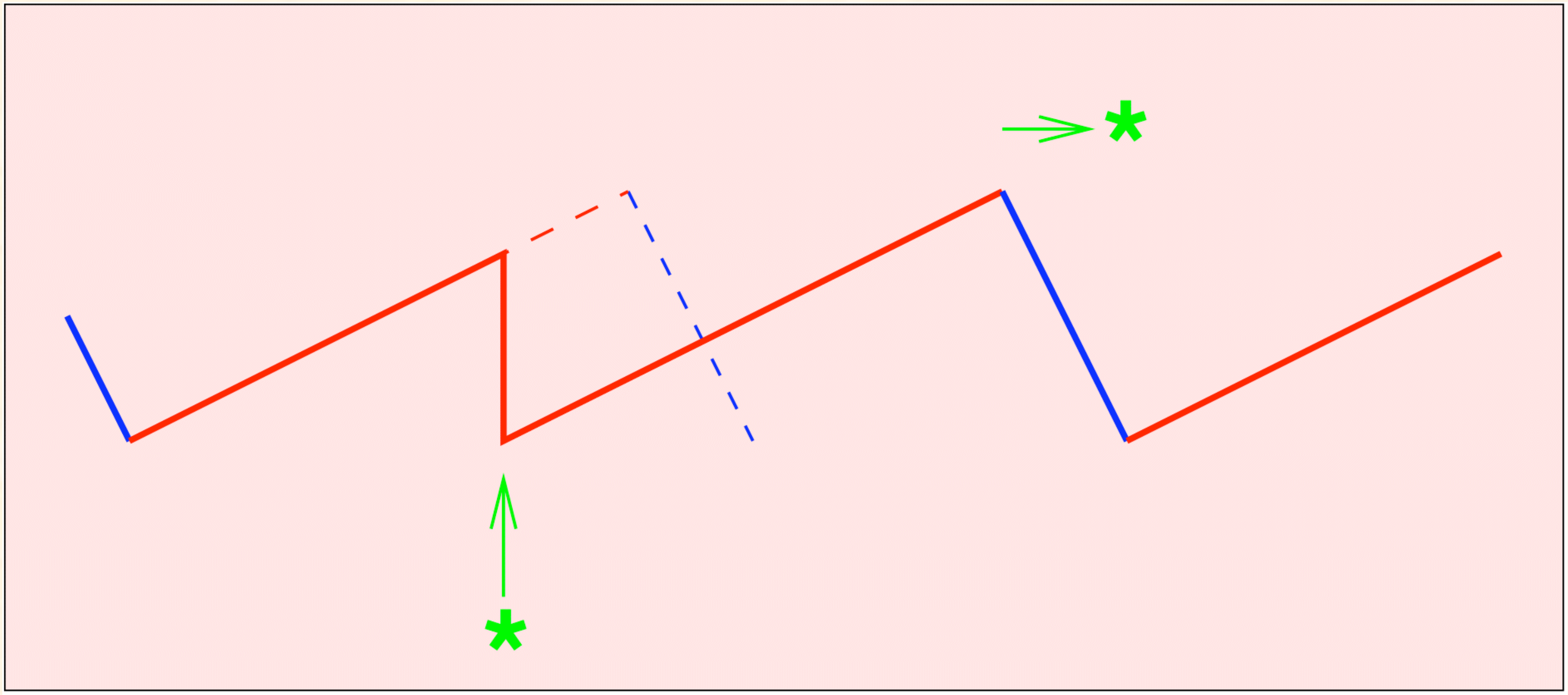
# How Do They Do It?

- “innate individual rhythmicity with phase-dependent sensitivity to mutual influences”
- Natural flashing period: 965±90 msec (≈ 1 sec)
- Flash from firefly *A* will reset the clock of nearby firefly *B*
  - thereby shifting the *phase* of *B*’s clock
- If *A* flashes in first 840 ms of *B*’s cycle, will inhibit *B*’s next flash & delay until 1 sec after stimulus (i.e. retarded so it is in sync with *A*)
- If A flashes in last 160 ms, *B*’s next flash occurs normally, but subsequent flash will be advanced to be in sync with *A*

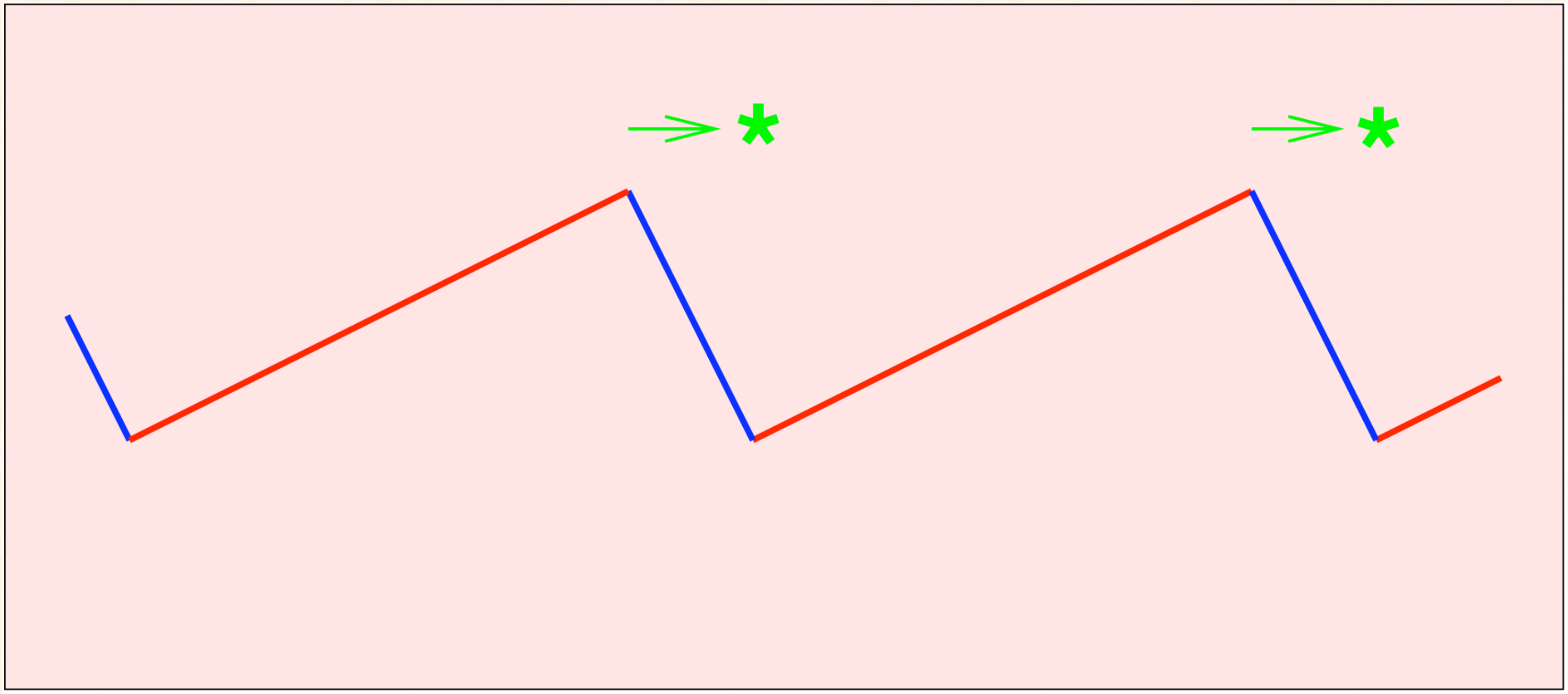
# Free-running Flashing



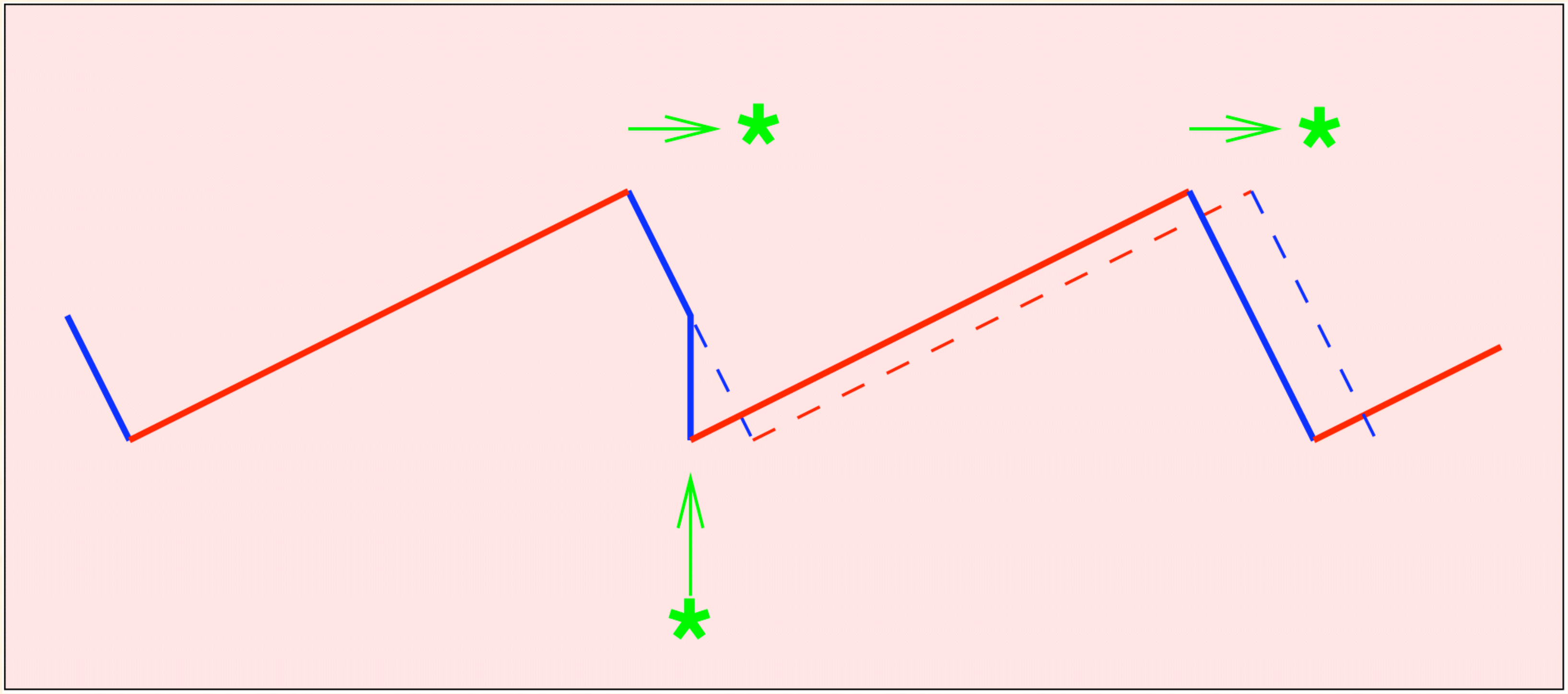
# Stimulus in first 840 msec



# Free-running Flashing (again)



# Stimulus in last 120 msec



# Starlogo Simulation of Firefly Synchronization

Run firefly.slogo Simulation

# 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

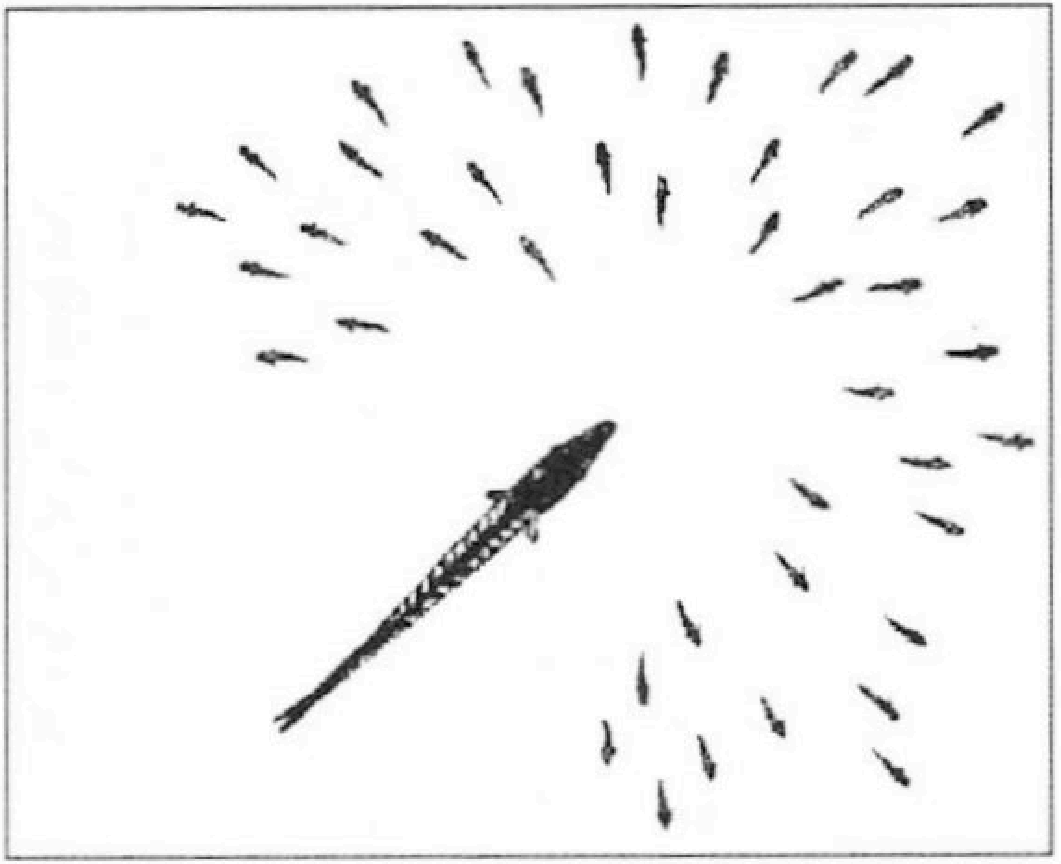


Fig. from Camazine & al., *Self-Org. Biol. Sys.*

# Fountain Effect

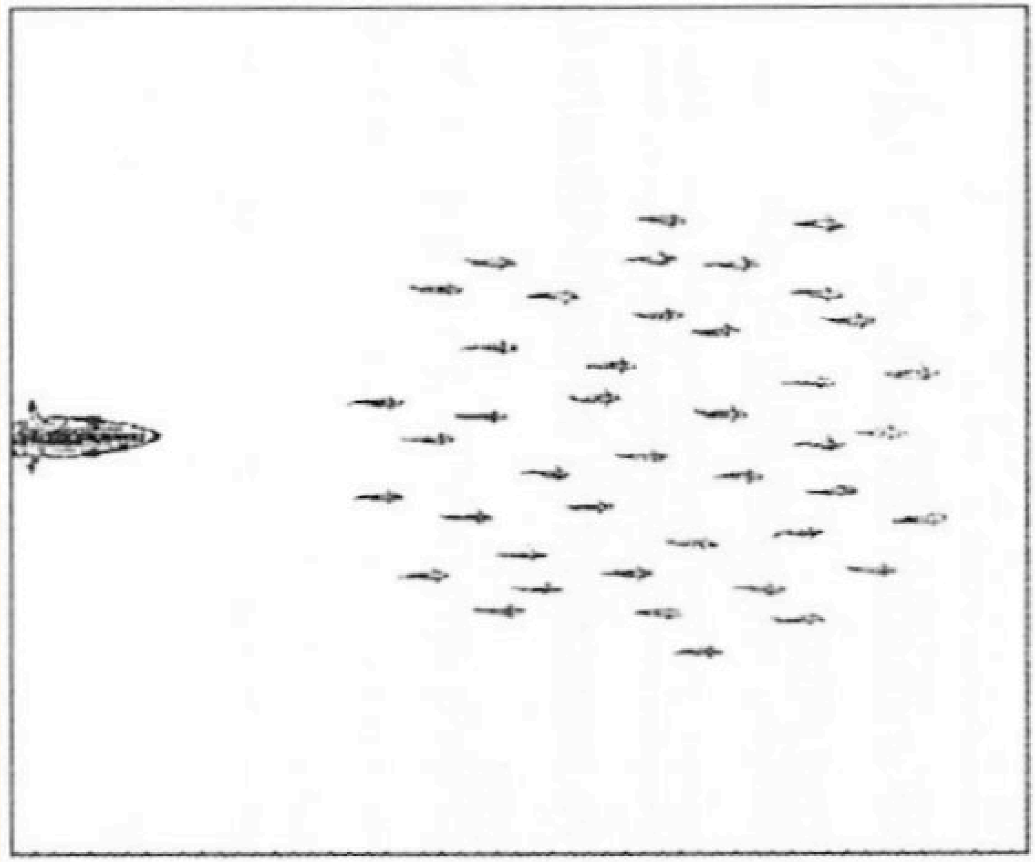


Fig. from Camazine & al., *Self-Org. Biol. Sys.*

# Fountain Effect

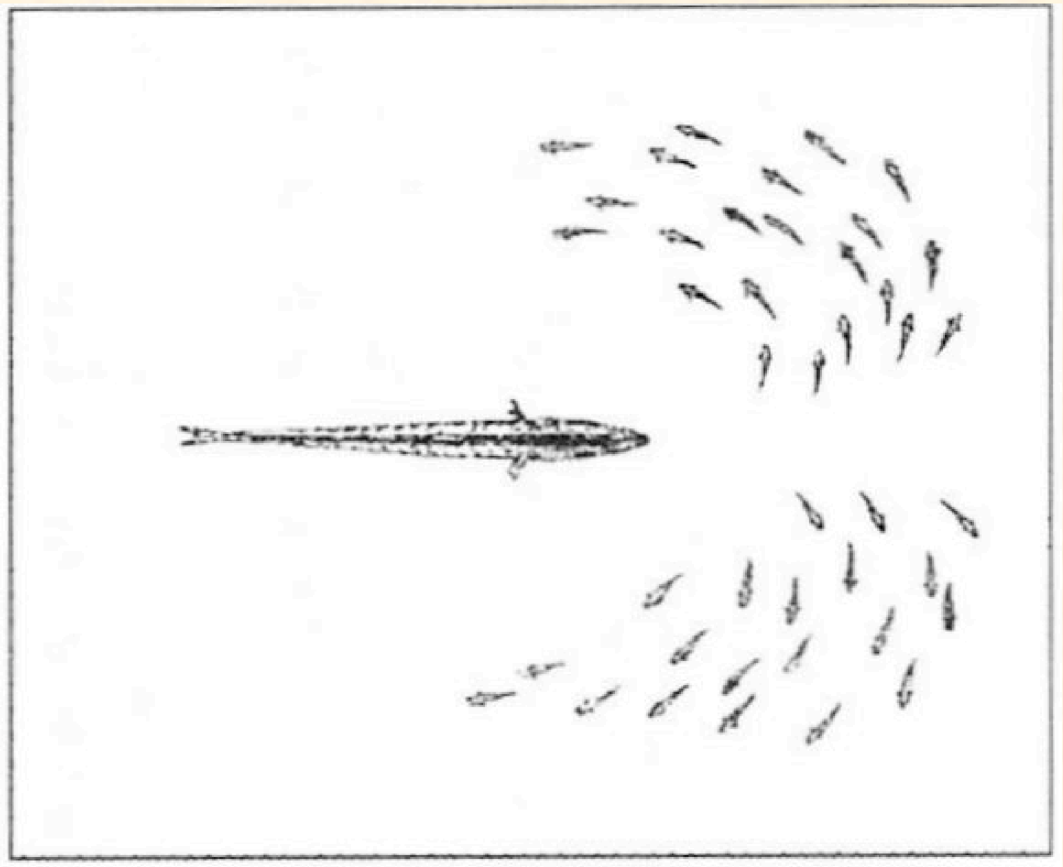


Fig. from Camazine & al., *Self-Org. Biol. Sys.*

# Fountain Effect

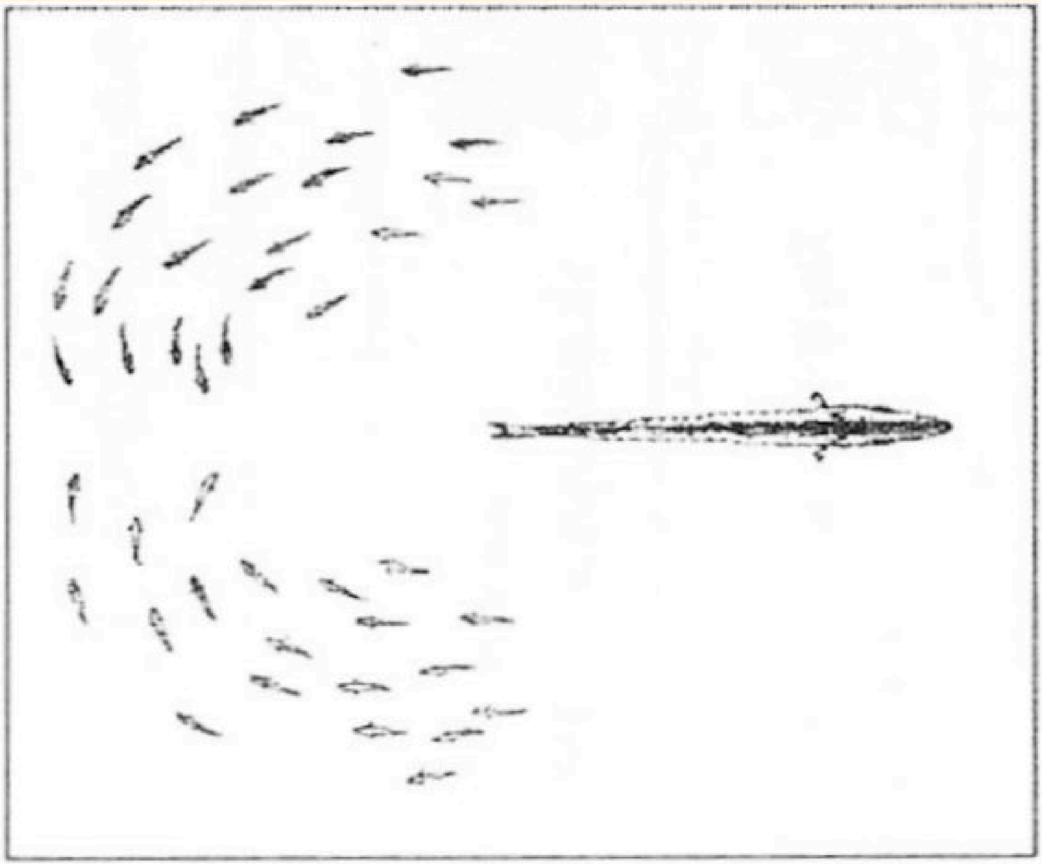


Fig. from Camazine & al., *Self-Org. Biol. Sys.*

# Fountain Effect

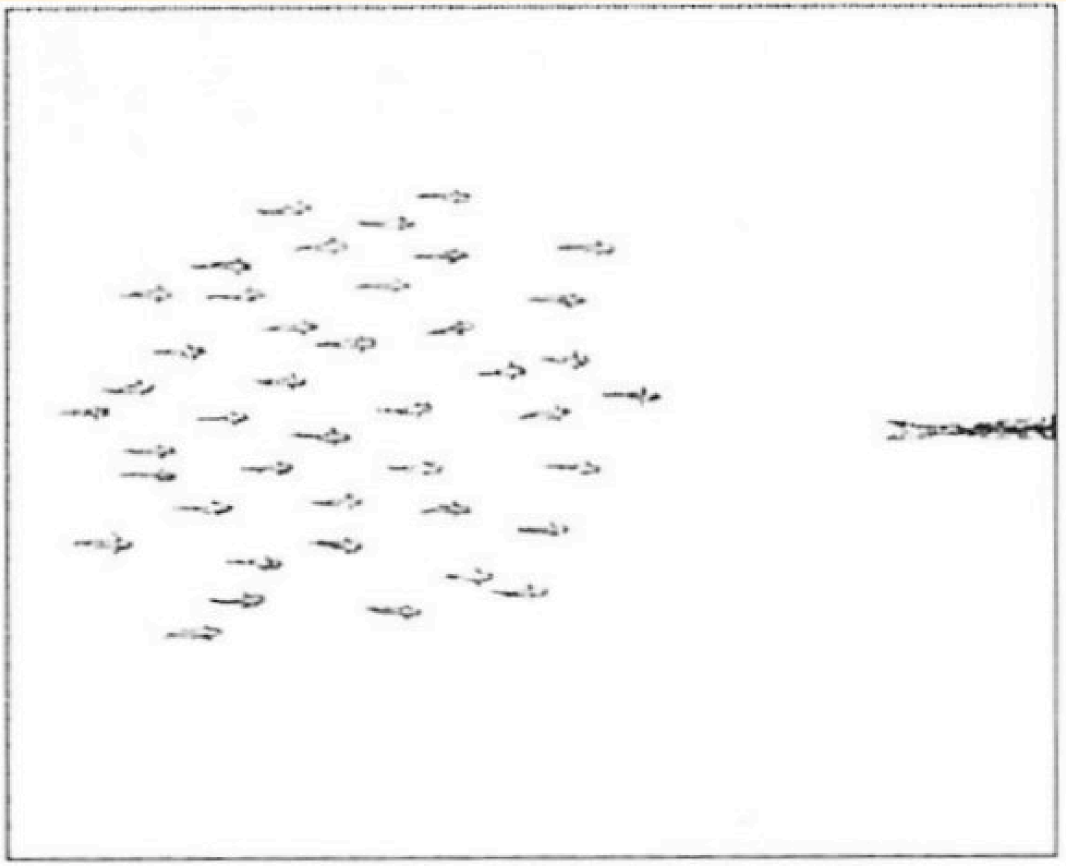


Fig. from Camazine & al., *Self-Org. Biol. Sys.*

# 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 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

# 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