# 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

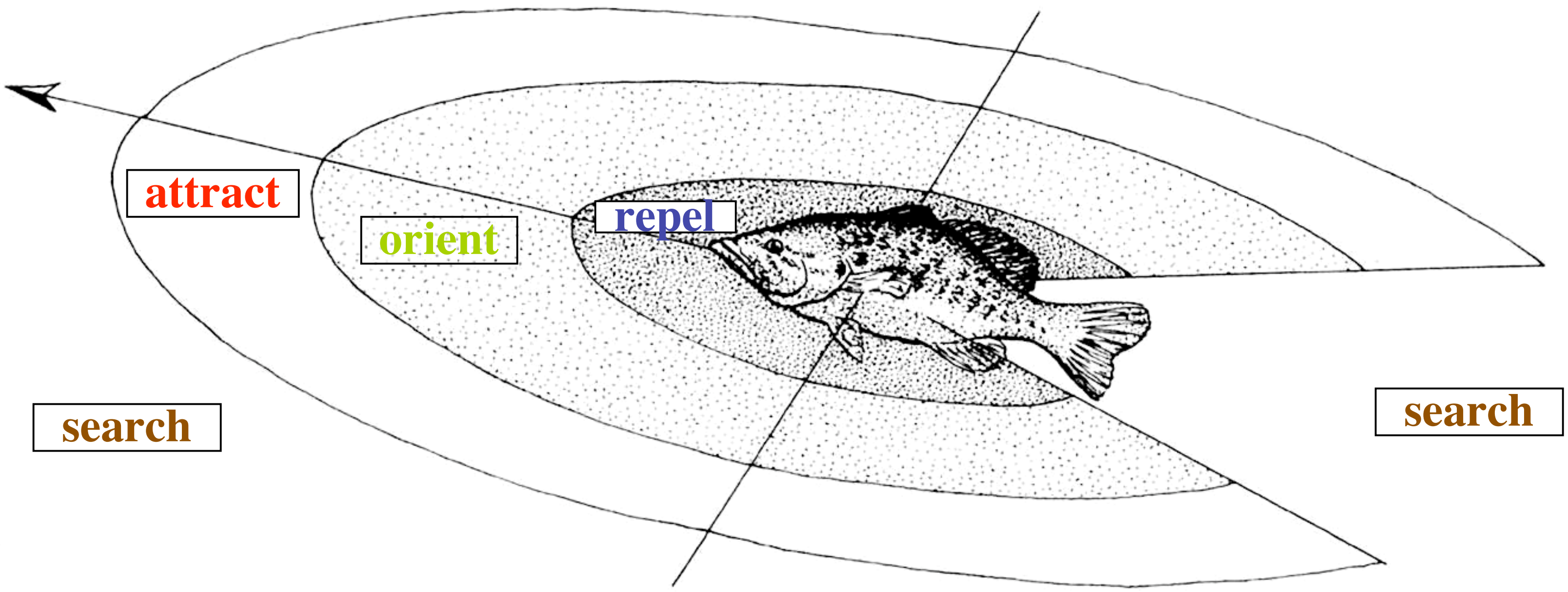





Fig. adapted from Camazine & al., *Self-Org. Biol. Sys.*

# 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

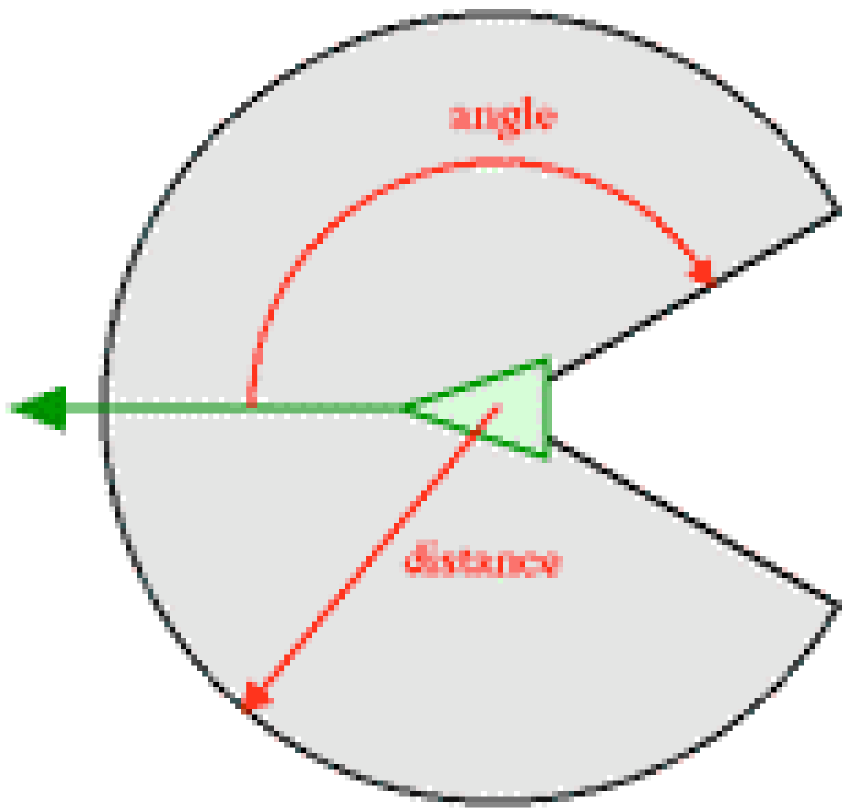
# Limitations of Model

- 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)

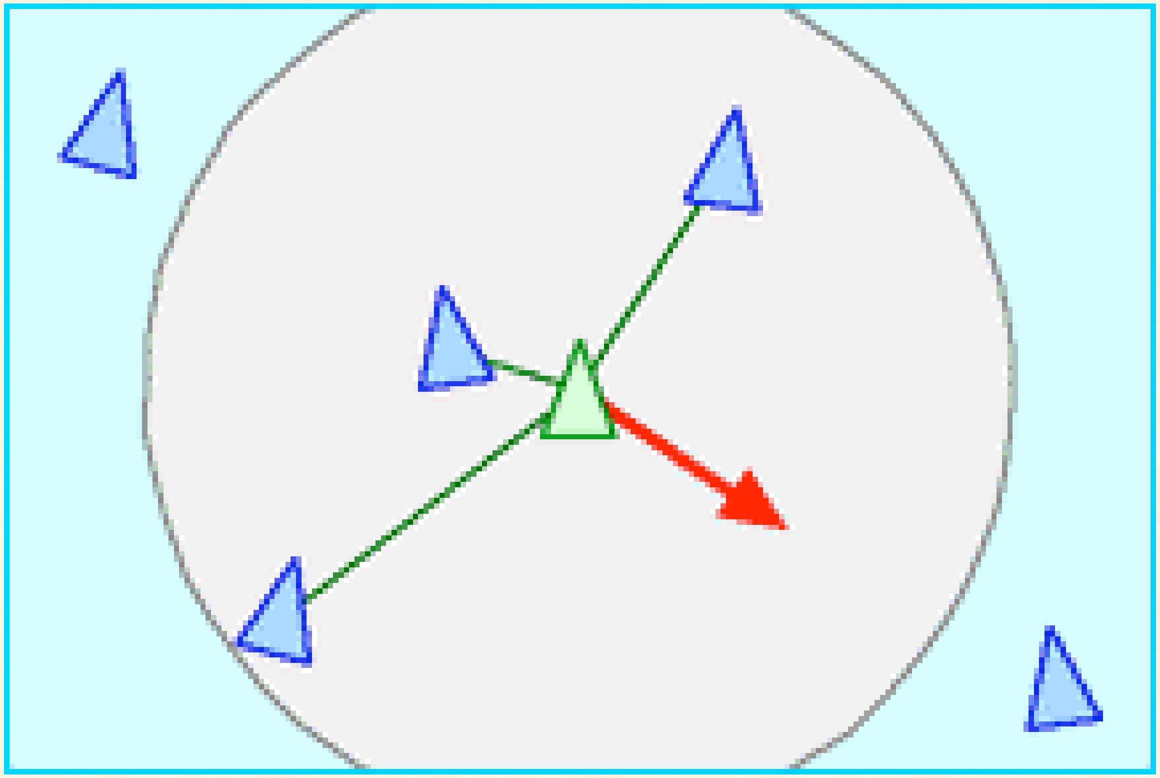
# Boid Neighborhood



# Steering Behaviors

- Separation
- Alignment
- Cohesion

# Separation

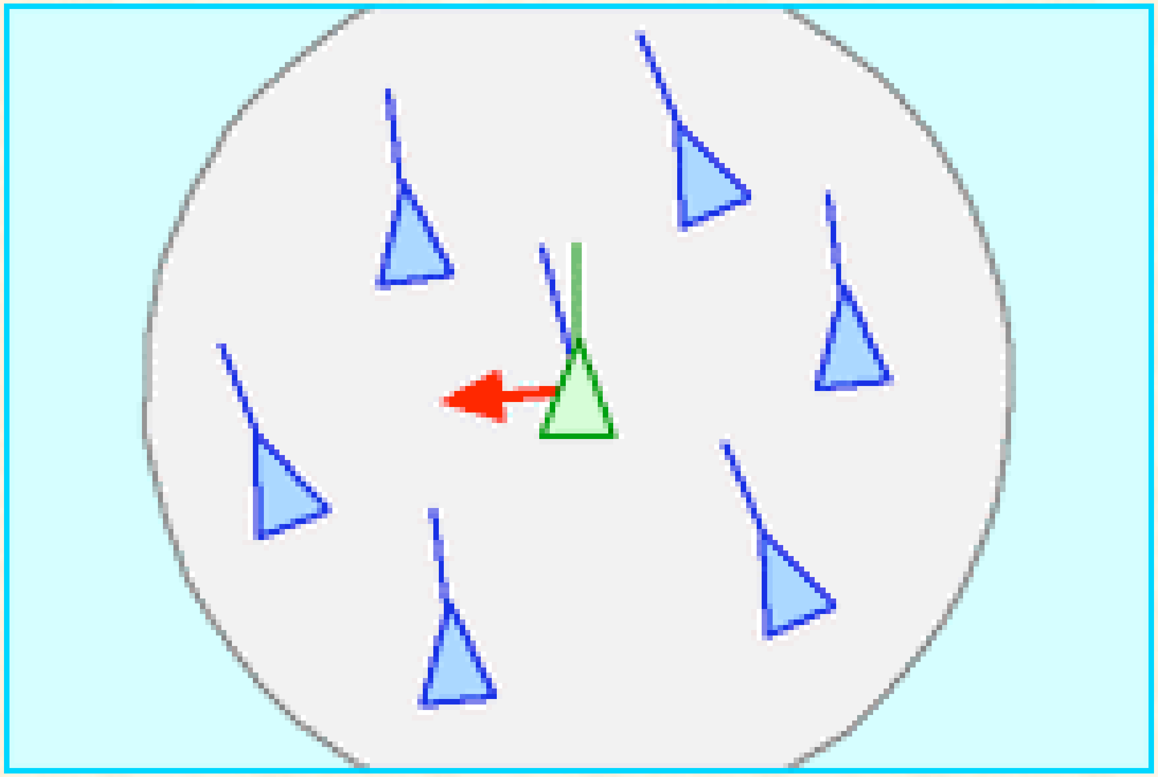


Steer to avoid crowding local flockmates



Fig. from Craig Reynolds

# Alignment

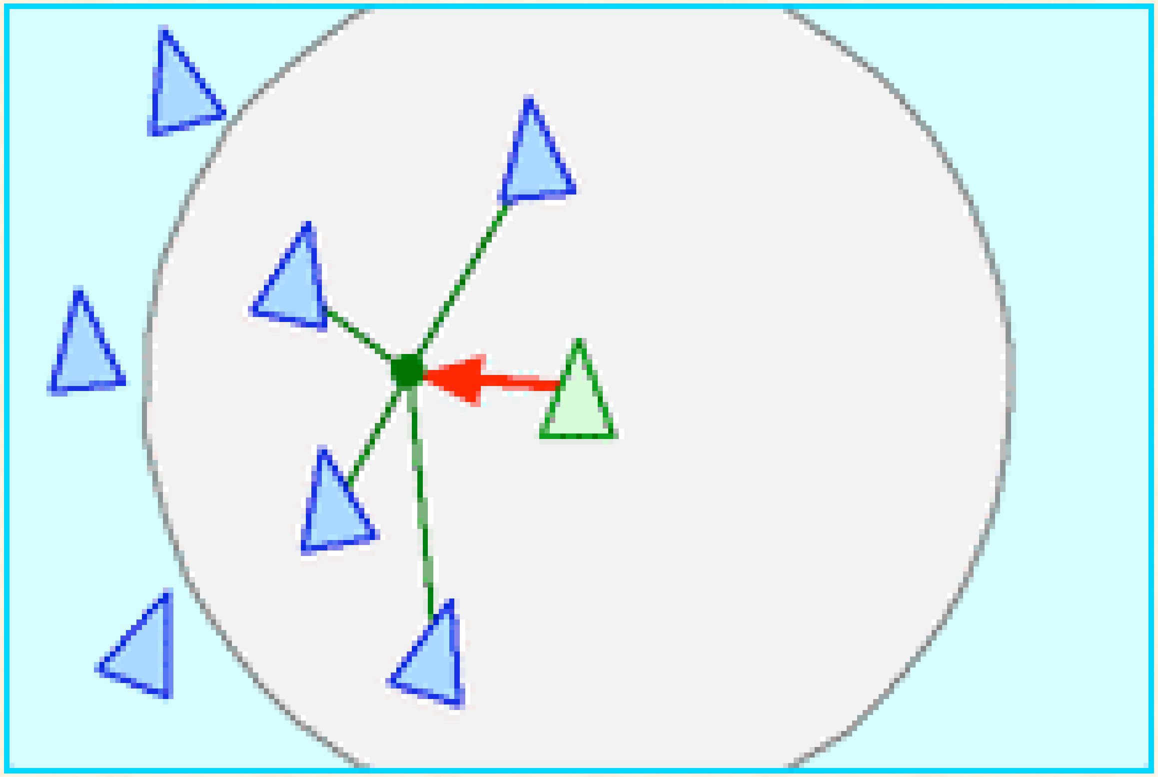


Steer towards average heading of local flockmates



Fig. from Craig Reynolds

# Cohesion



Steer to move toward average position of local flockmates



Fig. from Craig Reynolds

# Velocity Vector Update

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

$$w_{\text{separate}}\ \mathbf{v}_{\text{separate}}$$
$$+\ w_{\text{align}}\ \mathbf{v}_{\text{align}}$$
$$+\ w_{\text{cohere}}\ \mathbf{v}_{\text{cohere}}$$

momentum factor

- Let $\mathbf{v}_{\text{new}} = \square\ \mathbf{v}_{\text{old}} + (1 - \square)\ \mathbf{v}_{\text{change}}$

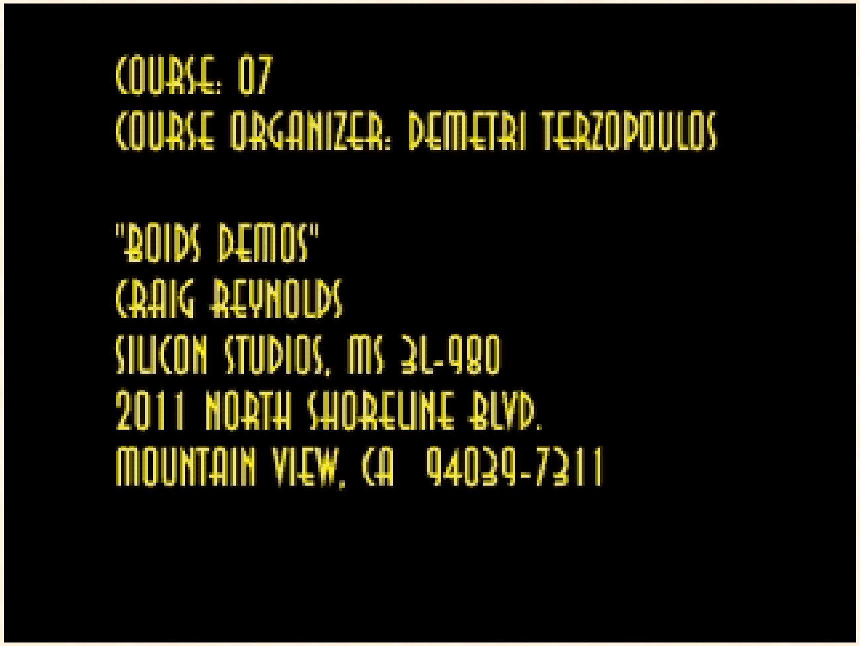
# Demonstration of boids

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)

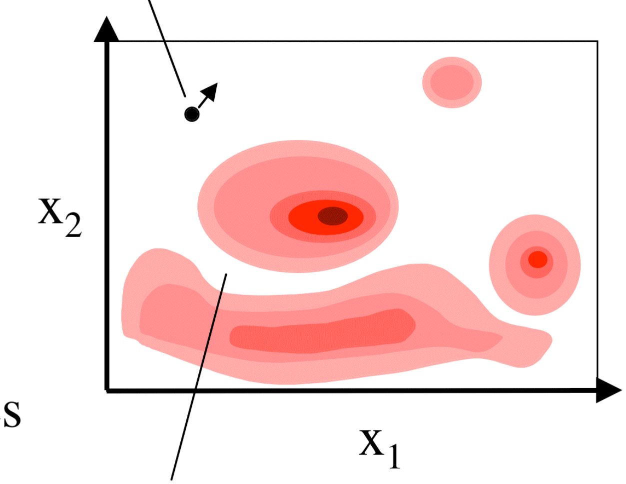
# Particle Swarms

## Idea

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

## What is a particle?

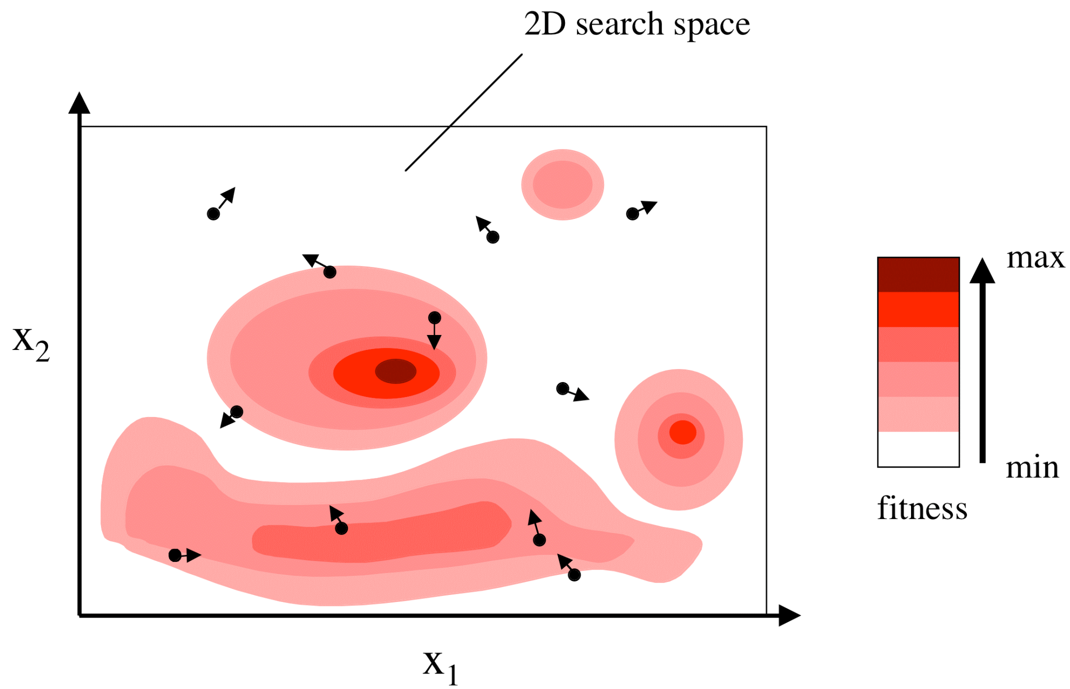
- a particle consists of:
  - $\vec{x}_i$ position
  - $\vec{v}_i$ velocity
  - $\vec{p}_i$ best position found so far
  - velocity and position update rules




(Kennedy and Eberhart, 1995)

# Example

## Particle Swarms



# Example

## Particle Swarms

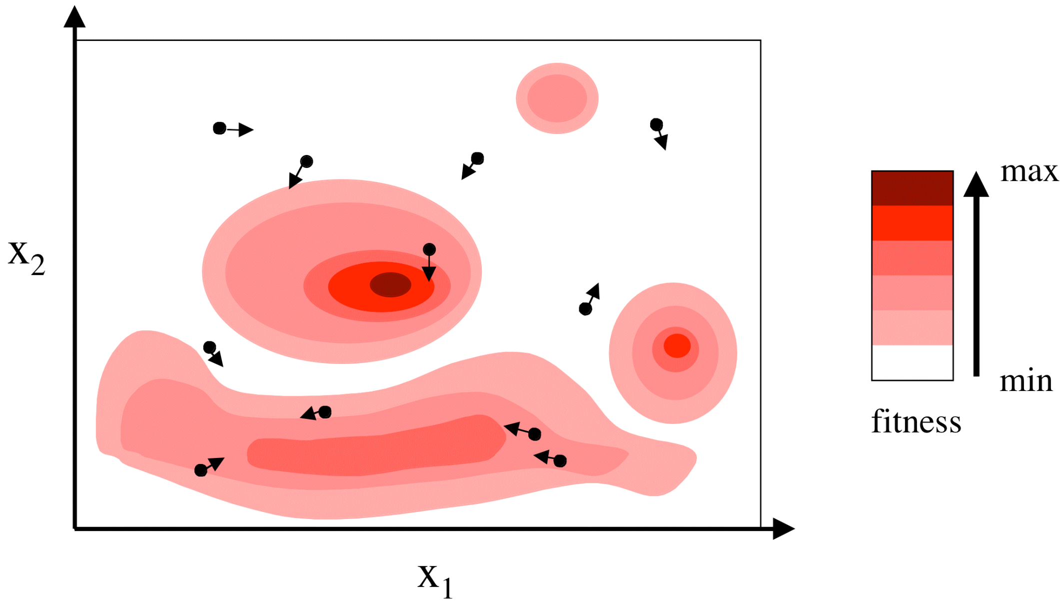





Fig. from EVALife site

# Example

## Particle Swarms

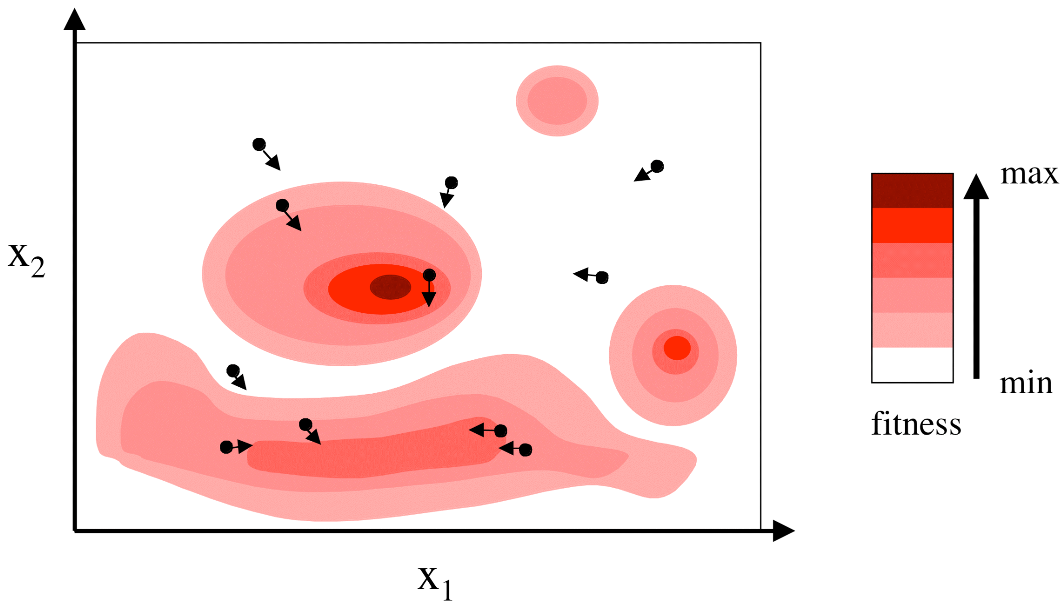





Fig. from EVALife site

# Example

## Particle Swarms

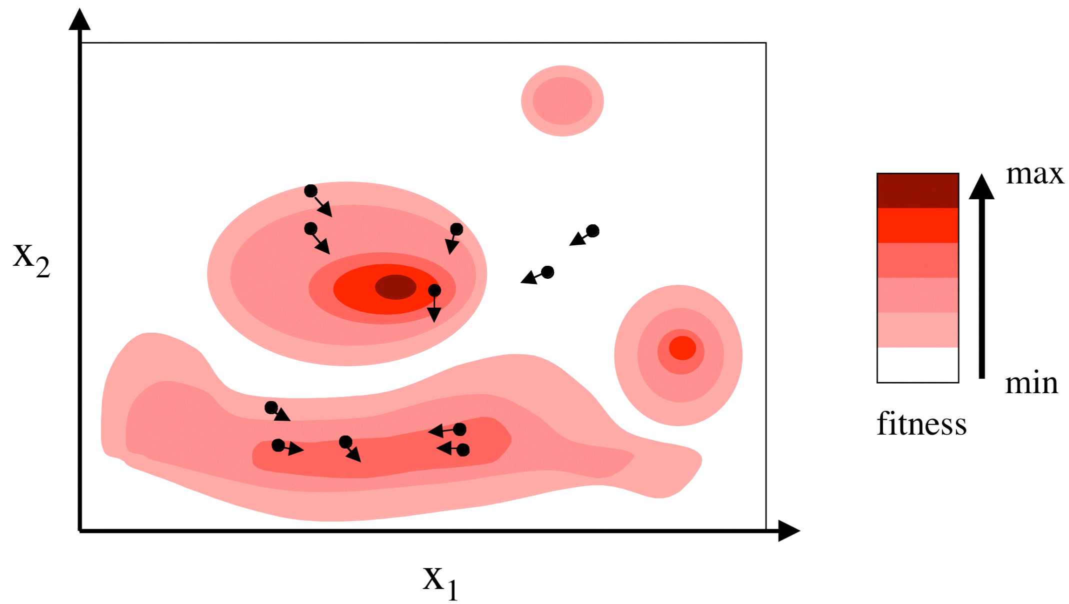
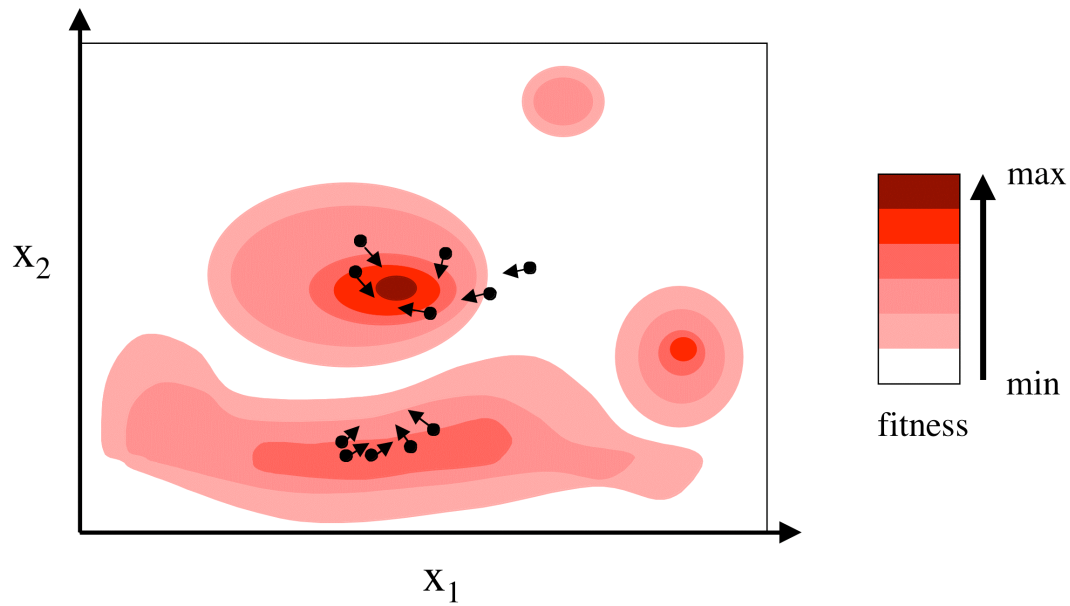





Fig. from EVALife site

# Example

## Particle Swarms



# Example

## Particle Swarms

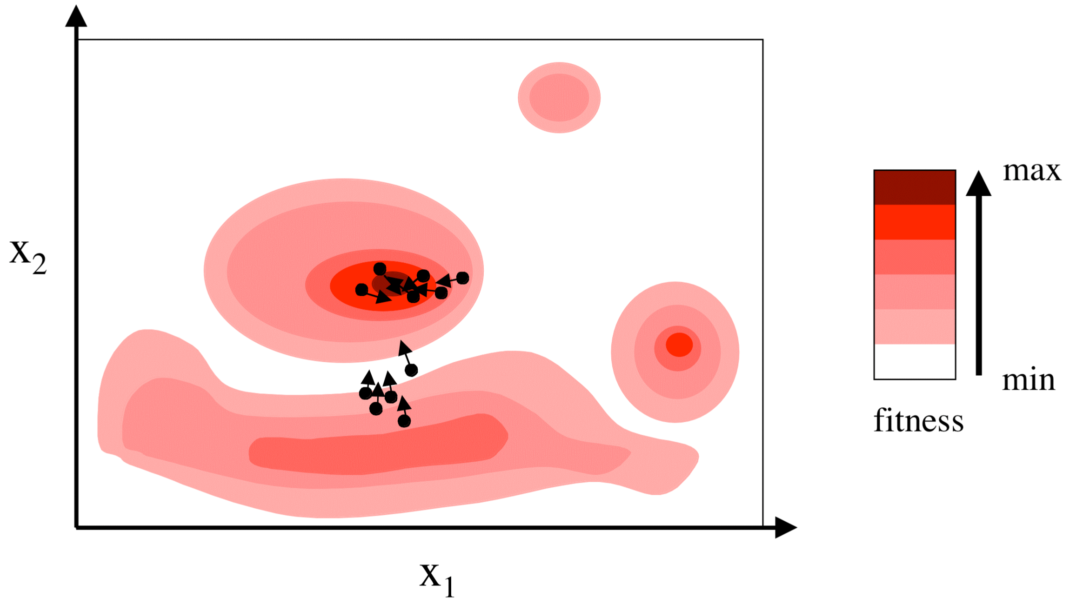
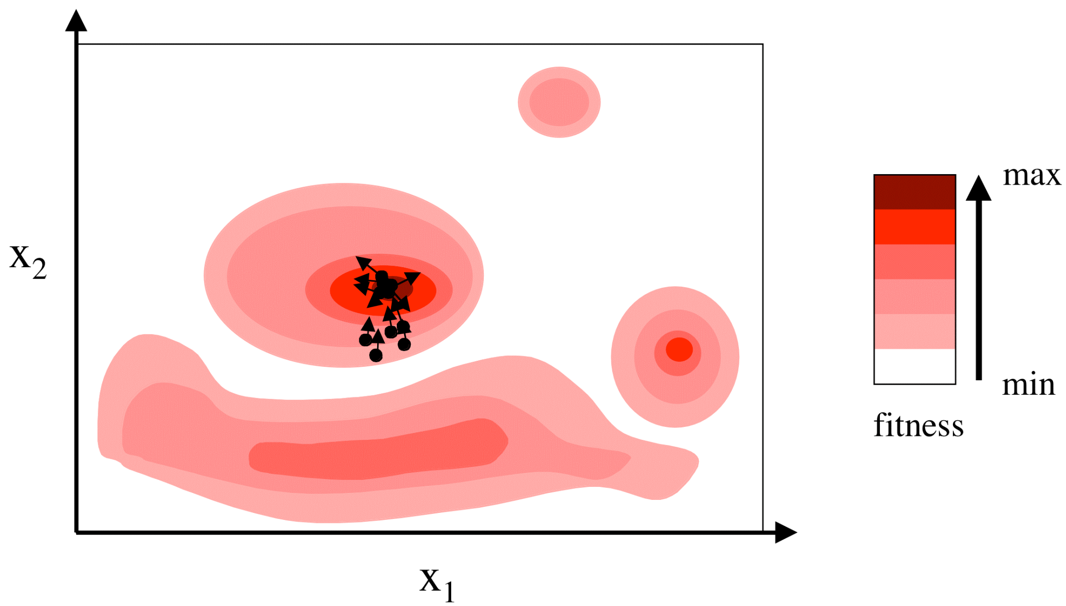





Fig. from EVALife site

# Example

## Particle Swarms



# Example

## Particle Swarms

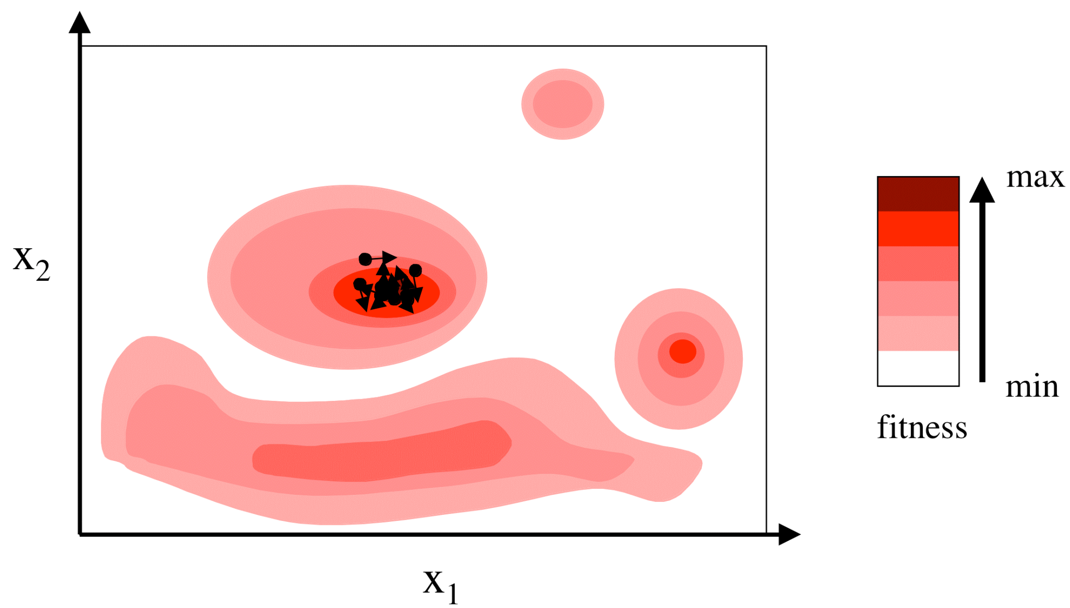





Fig. from EVALife site

# Variables

$\mathbf{x}_k$ = current position of particle $k$

$\mathbf{v}_k$ = current velocity of particle $k$

$\mathbf{p}_k$ = best position found by particle $k$

$Q(\mathbf{x})$ = quality of position $\mathbf{x}$

$g$ = index of best position found so far

i.e., $g = \text{argmax}_k\, Q(\mathbf{p}_k)$

$\square_1$, $\square_2$ = random variables uniformly distributed over [0, 2]

$w$ = inertia

# Velocity & Position Updating

$\mathbf{v}_k' = w\,\mathbf{v}_k + \varphi_1\,(\mathbf{p}_k - \mathbf{x}_k) + \varphi_2\,(\mathbf{p}_g - \mathbf{x}_k)$

$w\,\mathbf{v}_k$ maintains direction (*inertial* part)

$\varphi_1\,(\mathbf{p}_k - \mathbf{x}_k)$ turns toward private best (*cognition* part)

$\varphi_2\,(\mathbf{p}_g - \mathbf{x}_k)$ turns towards public best (*social* part)

$\mathbf{x}_k' = \mathbf{x}_k + \mathbf{v}_k$

- Allowing $\varphi_1, \varphi_2 > 1$ permits overshooting and better exploration (*important!*)
- Good balance of *exploration* & *exploitation*
- Limiting $\mathbf{v}_k < \mathbf{v}_{\max}$ controls resolution of search