Computational Intelligence

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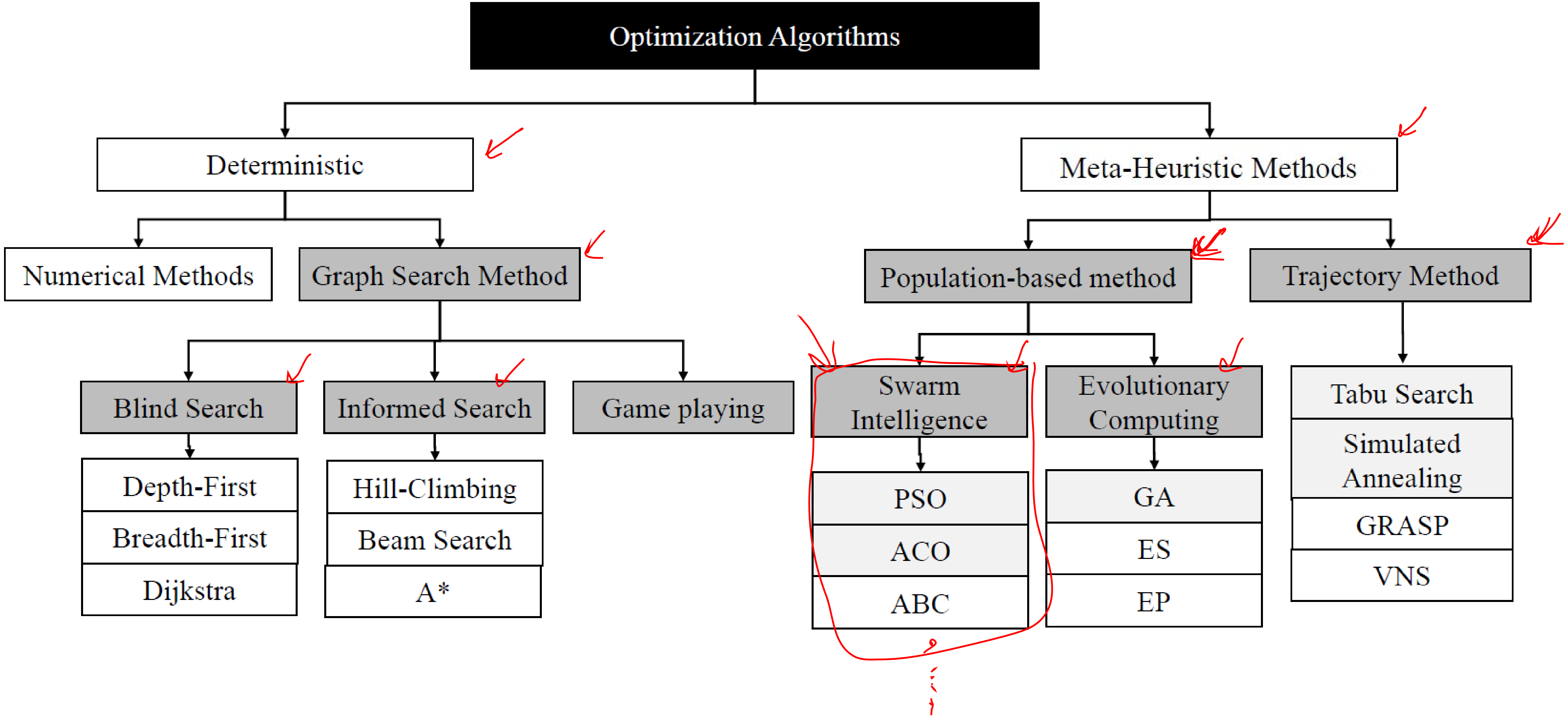
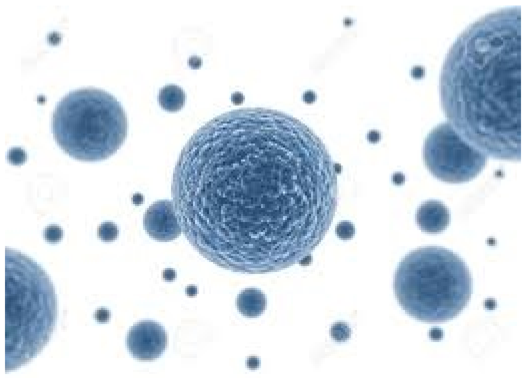
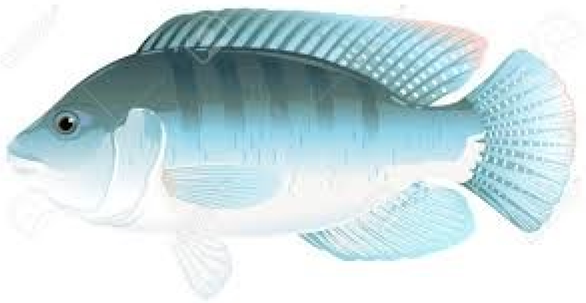
Optimization Algorithms



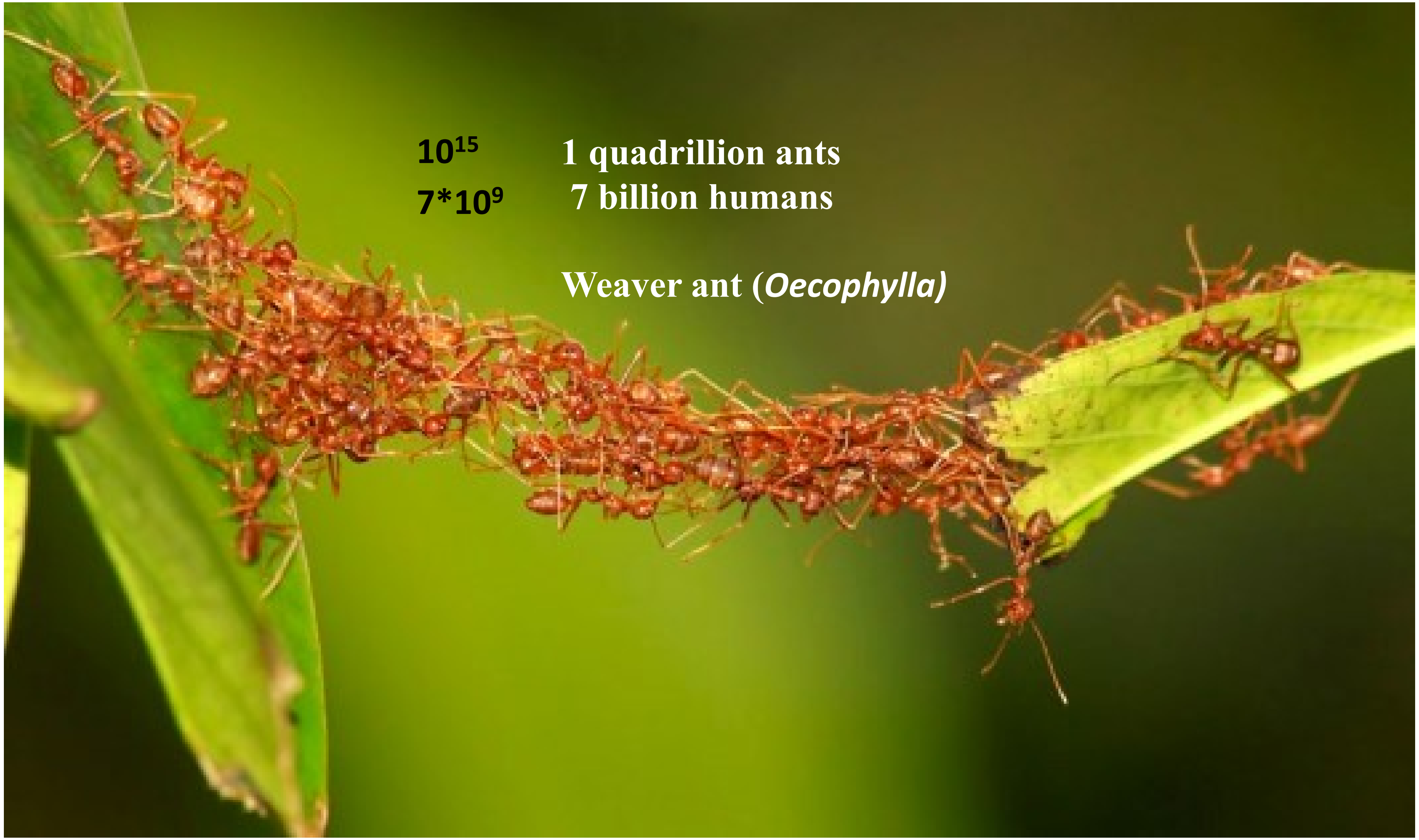
Intelligence in nature



Swarm Intelligence in nature

Robust collective behavior from cooperation of unreliable agents

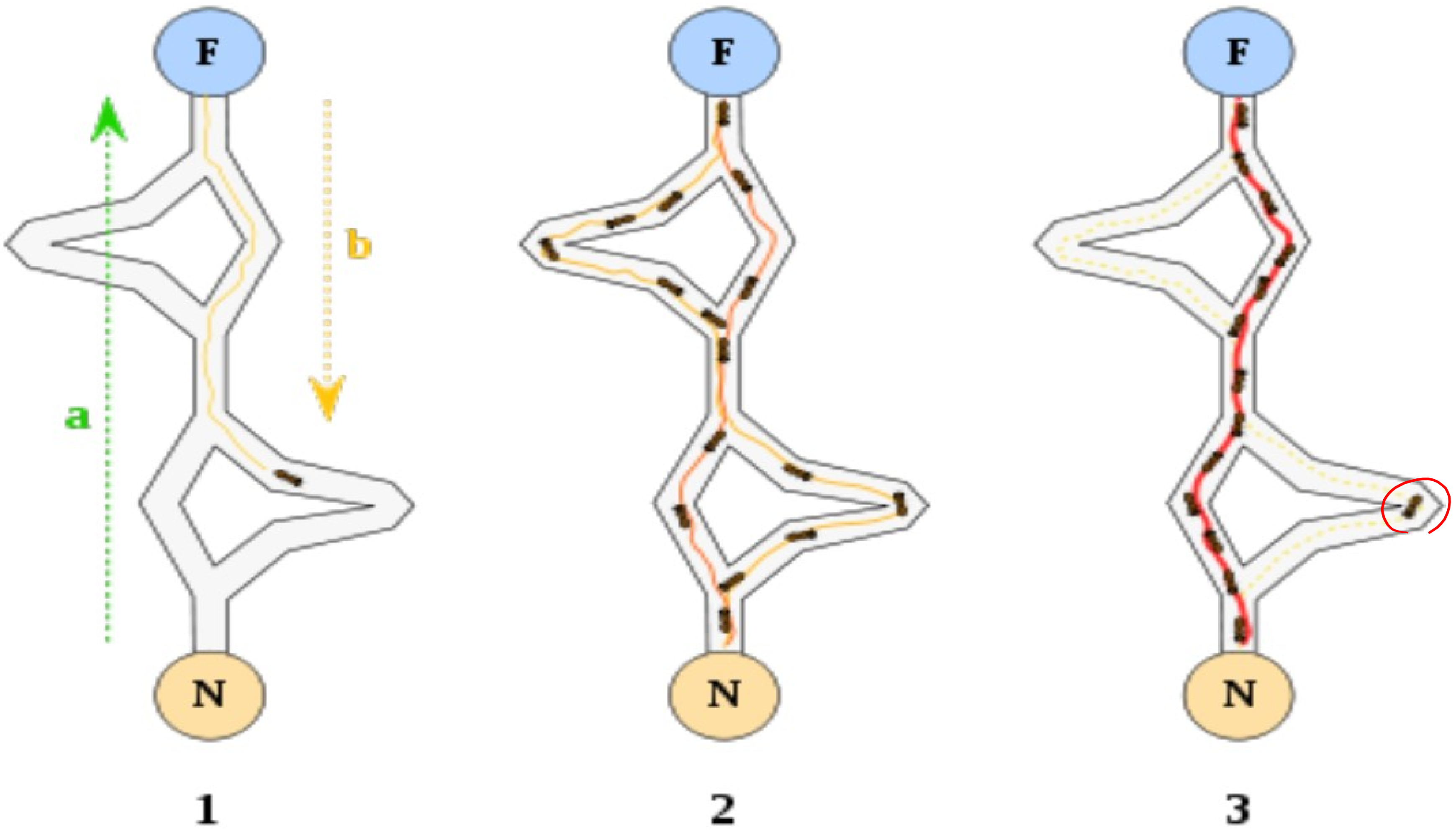


Robust collective behavior from cooperation of unreliable agents

- Biology hints :
  - Millions of cells cooperate to self-assemble a multicellular organism
  - Colonies of ants and bees cooperate to forage vast areas and construct complex nests without **supervisor** or predefined plan
  - Fish schools and bird flocks migrate with high efficiency and evade predators

- High level of collective intelligence
- Individuals with simple rules and simple capabilities

Intelligence



Intelligence

Robust collective behavior from cooperation of unreliable agents

- Engineering provides many incentives for designing systems with these same properties

  - Computer networks embedded in smart buildings
  - Monitoring the environment
  - Multi-robot systems in applications from
    - Agriculture
    - search and rescue
    - Entertainment applications
    - Creating new computational substrates like self-assembling nano-structures.

Modeling collective behavior in social insects

- How to design adaptive, decentralized, flexible, and robust artificial systems, capable of solving problems, inspired by social insects?

- Uunderstanding the mechanisms that generate collective behavior in insects.

- Modeling (not designing) of an artificial system:
- Reproduce features of the natural system it is supposed to describe
- Consistent formulation with what is known about the considered natural system

Swarm Intelligence

Swarm of Ants

Swarm of robots

Swarm Intelligence

- Close research fields:
    - Self-organising computer systems
    - Biologically-inspired robotics
    - Biological multi-agent systems

Swarm Intelligence

- AI technique based on the collective behavior in decentralized, self-organized **multi-agent** Systems

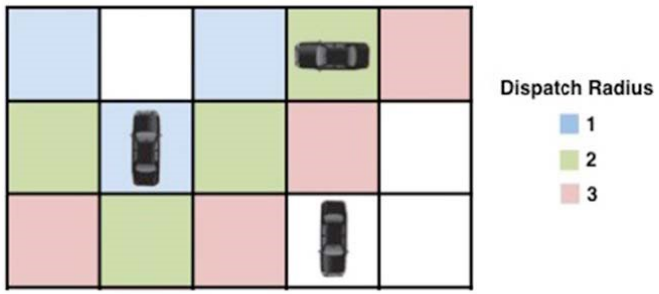
- Generally made up of agents who interact with each other and the environment
- **No centralized** control structures
- Characteristics
    - Composed of many individuals
    - Individuals are **homogeneous**
    - **Local** interaction based on **simple rules**
    - Self-organization

Swarm Intelligence History

Name	Pioneer	Year	Inspiration
ACO	M. Dorigo	1992	Ant colonies
PSO	J. Kennedy	1995	Group of birds
BFO	K. M. Passino	2002	E. Coli and M. Xanthus
TCO	M. Roth and S.Wicker	2003	Termite
ABC	D. Karaboga	2005	Honey bees
WASPCO	P. Pinto	2005	Wasp
BATCO	Xin-She Yang	2010	Bat
ASI	Rosenberg, Louis	2015	human groups

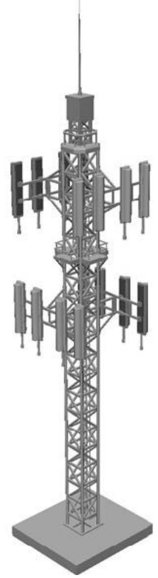
Complex problems

Sport Event Scheduling



Uber/Snap Dispatching

Unmanned vehicle Routing

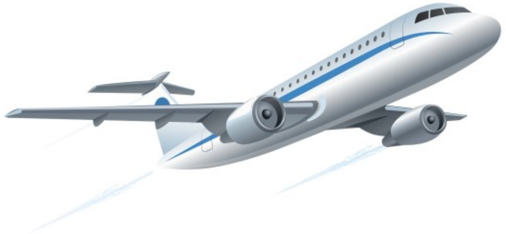


Cellular Tower Placement

Train Scheduling

Path Planning

Elevator Dispatching



Plane Scheduling

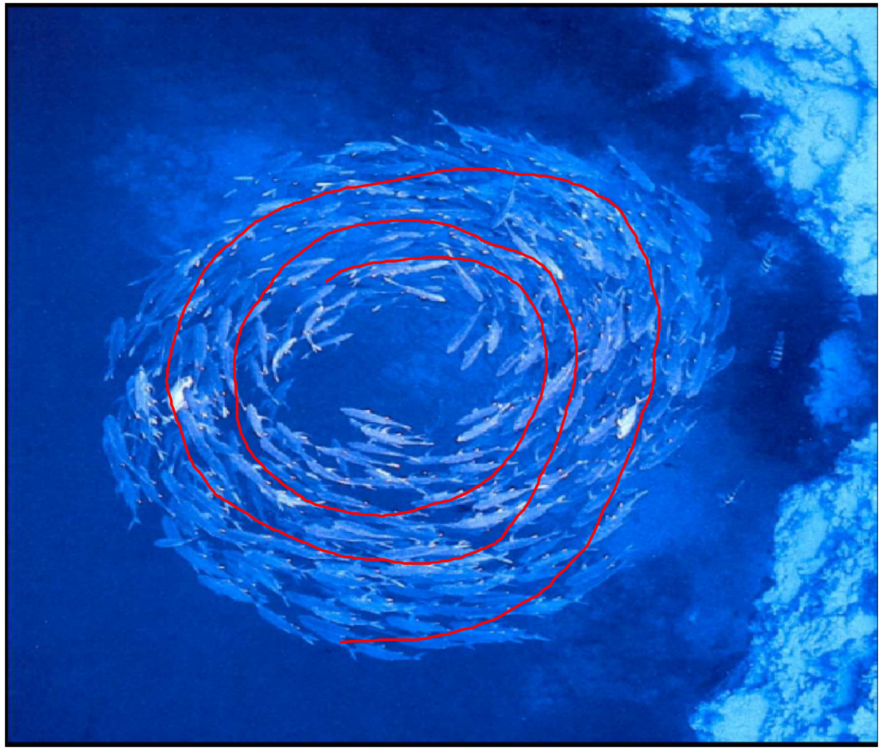
Particle Swarm Intelligence

Particle Swarm Optimization

- Introduction
- Motion
- PSO algorithms
- PSO neighborhoods
- PSO initialization
- Convergence
- PSO vs GA

Introduction

Bird flocking – V formation (© Soren Breitling)



Fish schooling (© CORO, CalTech)

Introduction

- The main idea is to ***simulate*** the collective behavior of social animals
- In particular, bird flocking and fish schooling behaviors
- Unlike some animal teams where there is a leader (e.g a pride of lions or a troop of baboons), the interest here in teams that has ***no leader***
- Individuals have **no knowledge of the global behavior** of the group
- They have the ability to move together based on **social interaction** between neighbours

Introduction

- The first computer program was written by Reynolds in 1986 [1] to simulate swarms for computer graphics and movies,

- The work took account of three behaviours:
  - Separation,
  - Alignment,
  - Cohesion.

Callision-avoidance

[illegible]

انسجام

- For online simulations, refer to http://www.red3d.com/cwr/boids/

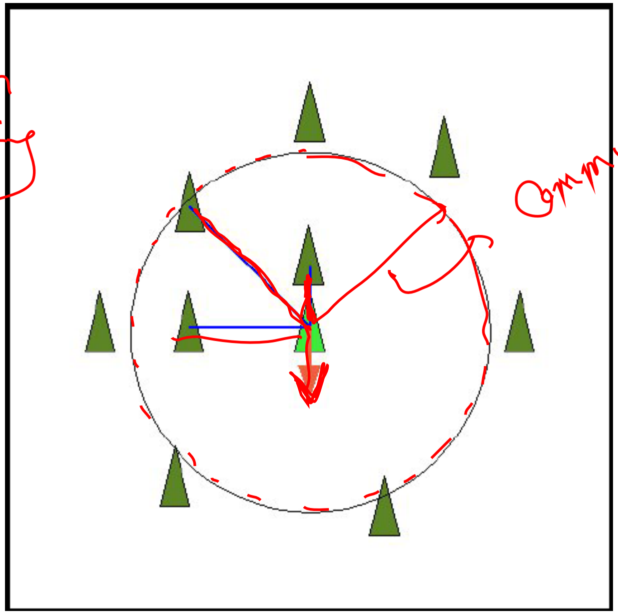
Introduction

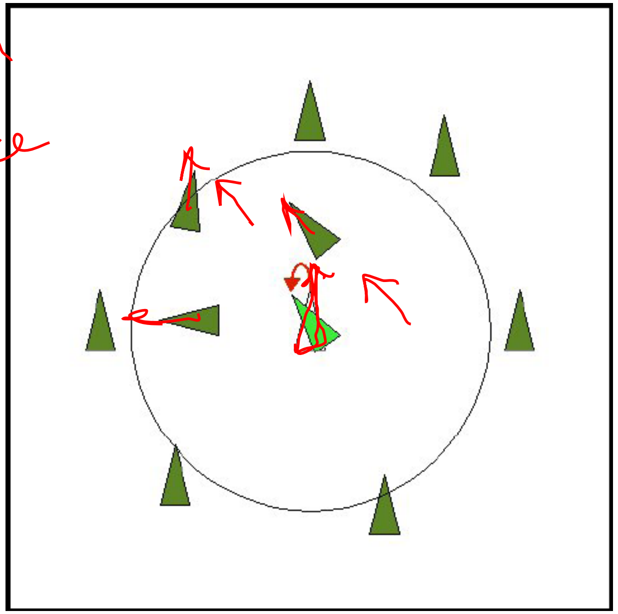
global – local

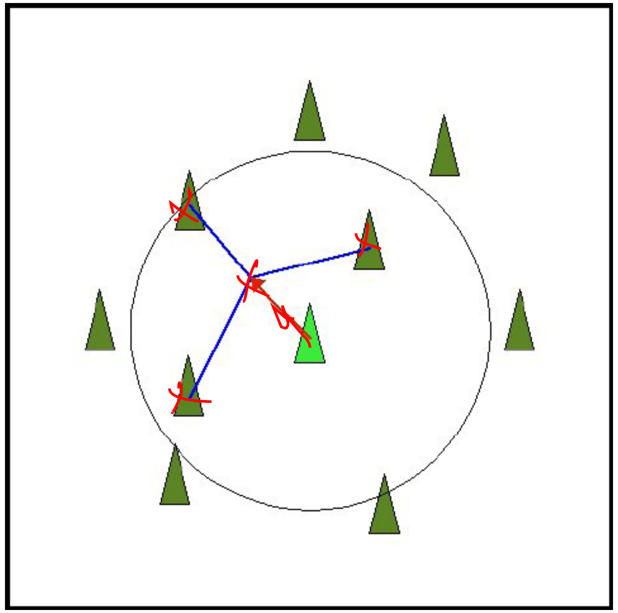
flocking

Position
velocity

Communication
distance







Separation: Each agent tries to move away from its nearby mates if they are too close (**Collision Avoidance**).

Alignment: Each agent steers towards the average heading of its nearby mates (**Velocity matching**).

Cohesion: Each agent tries to go towards the average position of its nearby mates (**Centering or position control**).

From [3]

Introduction

PSO ← ایده از حرکت پرندگان برای حل مسائل optimisations

Reinolds ← شبیه سازی حرکت پرندگان

- Heppner and Grenander [4] used a similar flocking model but added a roost (place for birds to rest) as an attractor of the birds.

لانه

- roost is a position on the pixel screen that attracted them until they finally landed there

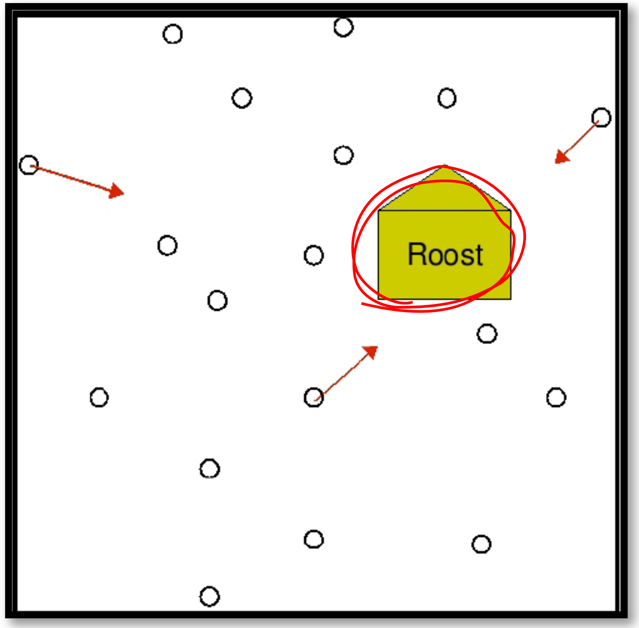
- The intent was to provide a computer simulation of a flock of birds to understand the underlying rules that enable synchronous flocking

- Kennedy and Eberhart in 1995 [5, 6], introduced an optimization method based on the simple behavior of emulating the success of neighboring individuals.
  - Followed the same steps taken by Reynolds and adding a ***Roost*** as proposed by Heppner and Grenander

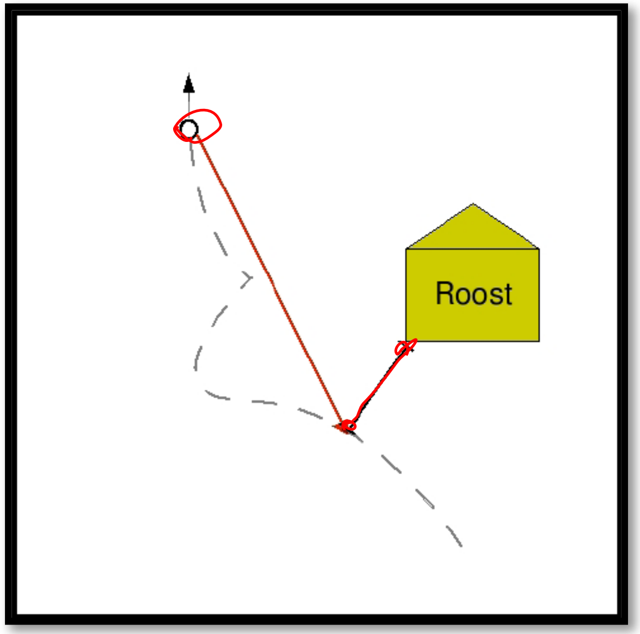
Introduction

- The ***roost*** is in the form of a memory of previous **own best and neighborhood best** positions (referred to ***cornfield***)
- These two best positions serve as attractor
- By adjusting the positions of the flock proportion to the distance from the best positions, they converge to the goal

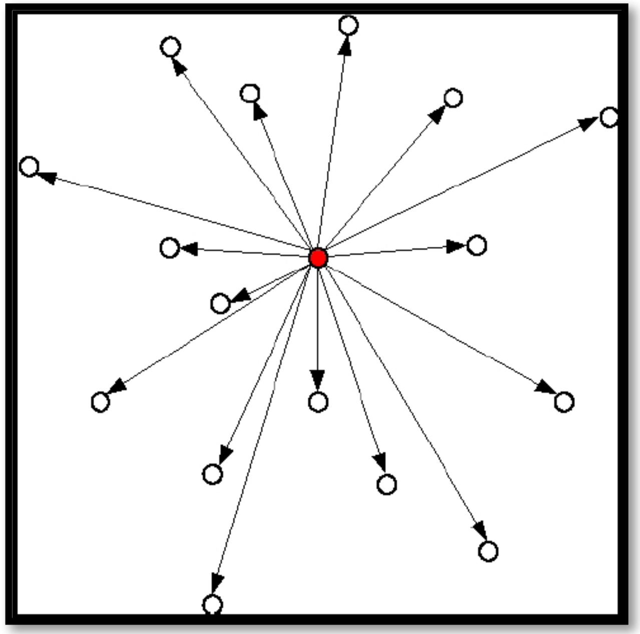
Introduction



All the individuals are attracted to the roost.



Each memorizes the position in which it was closest to the roost.



Each shares its information with all the others.

roost نسبت به: بهترین نقطه‌ای همه / lbest

From [3]

roost نسبت به: agent بهترین نقطه خود memory — Pbest

Introduction

- At the end of the simulation, all the individuals landed on the roost,

  agent - particle

- It was realized, this could be used to solve optimization problems,

- we want to minimize the distance to the roost

Introduction

- Kennedy and Eberhart called their model **Particle Swarm Optimization** (***PSO***)

potential solution

solution ← particle

- They choose the word ***particle*** to mean individual or candidate solution (in optimization terms) as they felt it is more appropriate for the the use with velocity and acceleration

- As their paradigm is a simplified version of bird flocking, they preferred the use of the word ***swarm*** to indicate the population.

- PSO is a population based approach similar to GA and other EC approaches

PSO vs GA

PSO		GA
Swarm	⟷	Population
Particle	⟷	Individual
Fitness	⟷	Fitness
Uses past experience (pbest) and relationship to neighbours (lbest)	⟷	Uses crossover and mutations

Particle Swarm Optimization

Motion

PSO - Introduction

- A stochastic optimization approach that manipulates a number of candidate solutions at once,

  Particle

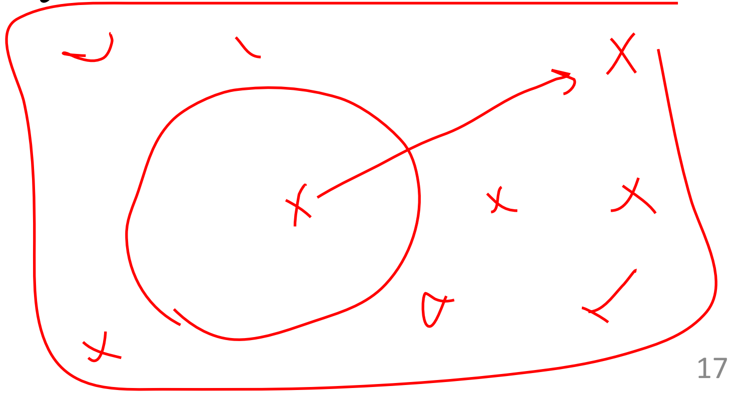
- A solution is referred to as a ***particle***, the whole population is referred to as a ***swarm***,

- Each particle holds information essential for its movement.

PSO - Motion

- Each particle holds:
  - Its current position x_i, i ام particle محل جاری
  - Its current velocity v_i, → 〃 〃 سرعت فعلی   بهترین محل P_i نسبت به goal
  - The best position it achieved so far, personal best, *pbest$_i$* (sometimes p_i for short), بهترین محل همسایه‌های P_i نسبت به goal
  - The best position achieved by particles in its neighbourhood *Nbest$_i$* or *lbest$_i$* (or p_l)
  - If the neighbourhood is the whole swarm, the best achieved by the whole swarm is called *global best*, *gbest$_i$* (sometimes p_g for short).

Nbest → gbest



PSO - Motion

- Each particle adjusts its velocity to move towards its personal best and the swarm neighbourhood best,

$v_{t+1} \leftarrow \boxed{v_t , \ldots}$

- After the velocity is updated, the particle adjusts its position.

$x_{t+1} \leftarrow \boxed{v_{t+1} \text{ و } x_t}$

۱- بروزرسانی سرعت هر Particle

۲- بروزرسانی مکان " "

PSO - Motion

- **Equations of motion:**

$$v_{t+1}^{id} = w * v_t^{id} + c_1 r_1^{id}\left(pbest_t^{id} - x_t^{id}\right) + c_2 r_2^{id}\left(Nbest_t^{id} - x_t^{id}\right) \quad (1)$$

$$x_{t+1}^{id} = x_t^{id} + v_{t+1}^{id} \quad (2)$$

w

c_1

c_2

$v = \frac{\Delta x}{\Delta t}$

x_t^{id}

$pbest^{id}$

$v = x_{t+1} - x_t$

- **Where**
  - v is the velocity of particle *id,*
  - w is the inertia weight,
  - c_1, c_2 are the acceleration coefficients,
  - r_1,r_2 are randomly generated numbers in [0, 1],
  - x is the position of the particle
  - t is the iteration number,
  - i and d are the particle number and the dimension.
  - Δt is the time step length which, for simplicity,commonly is set to 1

PSO - Motion

$$
\begin{aligned}
v_{t+1}^{id} = \quad & w * v_t^{id} && \longrightarrow \textbf{Inertia} \\
& + c_1 r_1^{id}\left(pbest_t^{id} - x_t^{id}\right) && \longrightarrow \textbf{Cognitive component} \\
& + c_2 r_2^{id}\left(Nbest_t^{id} - x_t^{id}\right) && \longrightarrow \textbf{Social component}
\end{aligned}
$$

- The inertia component accommodates the fact that a bird (particle) cannot suddenly change its direction of movement,

- The c_1 and c_2 factors balance the weights in which each particle:
  - Trusts its own experience, *cognitive component*,
  - Trusts the swarm experience, *social component*.

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