



ELTE | FACULTY OF  
INFORMATICS

# Bioinspired Collective Intelligence

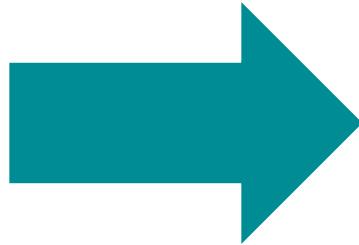
**Introduction to Machine Learning**  
Computer Science BSc Course, ELTE Faculty of Informatics

László Gulyás

Associate Professor  
Department of Artificial Intelligence  
[lgulyas@inf.elte.hu](mailto:lgulyas@inf.elte.hu)

# Biologically Inspired Methods –

---

- Brain
  - Evolution
  - Social Insects
- 
- Artificial Neural Networks
  - Evolutionary Algorithms
  - **Swarm Intelligence Methods**



# Swarm Intelligence

(Biologically inspired self-organisation)

---

- A collective system capable of performing complex tasks in a dynamic and changing environment without any external control or central coordination
  - Capable of achieving a collective performance that cannot normally be achieved by the organism alone
  - On this basis, we can build a natural model that is suitable for distributed problem solving



# Properties of Swarm Intelligence

---

- Distributed, massively parallel (many agents)
  - Individual agents are simple and disposable (‘cheap’)
  - Typically partially stochastic (i.e., non-deterministic)
- Intelligence ~ Optimising / Performing a task
  - Understood in a stochastic sense
    - Approximations
    - Different runs may give slightly different results
  - Typically **continuous optimisation** / performance of a series of tasks (no stopping)
- Robustness
  - Adapts to changing environments (and performs well)
    - Cf. Continuous optimisation
  - Graceful degradation
    - Withstands removal of agents (potentially many of them)



# „Collective Mind”



ELTE

FACULTY OF  
INFORMATICS

2023.12.31.

Introduction to ML, Bioinspired Collective Intelligence

5

# Beehive Finding

## Louis Rosenberg (Unanimous AI)

---



ELTE

FACULTY OF  
INFORMATICS

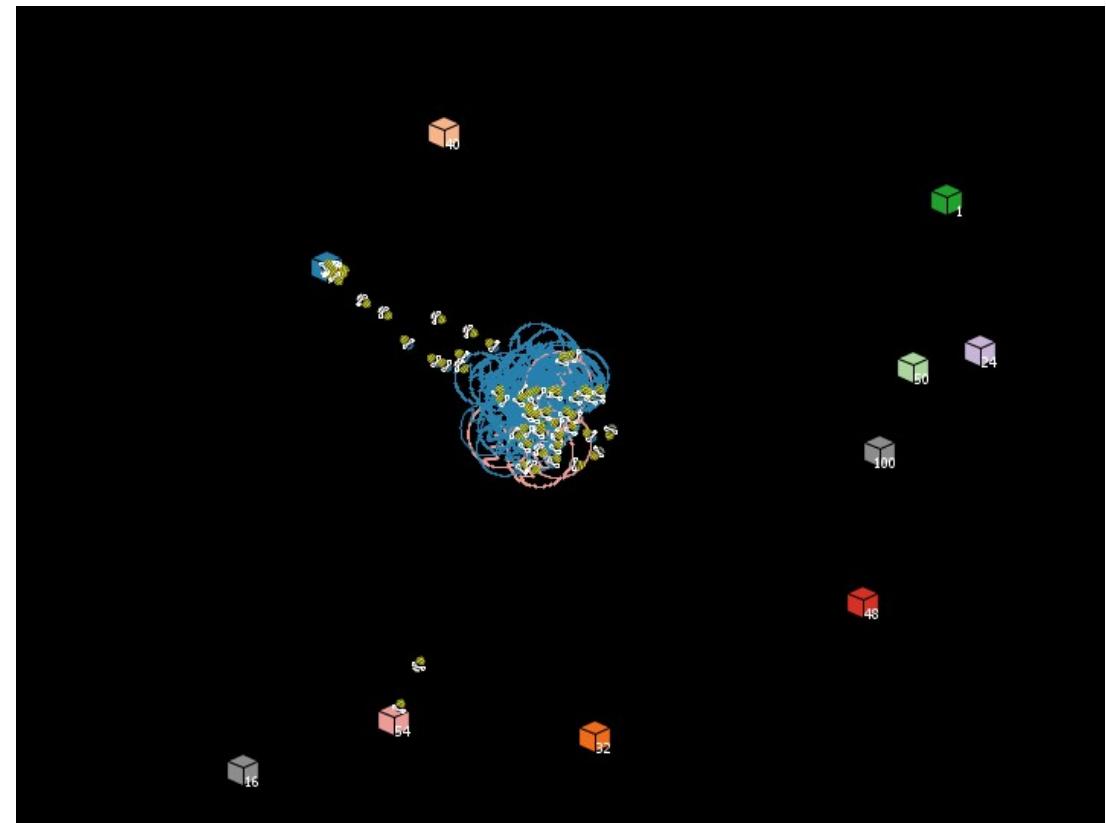
2023.12.31.

Introduction to ML, Bioinspired Collective Intelligence

6

# Beehive Finding (Decision Making) Model (Guo and Wilensky, 2014)

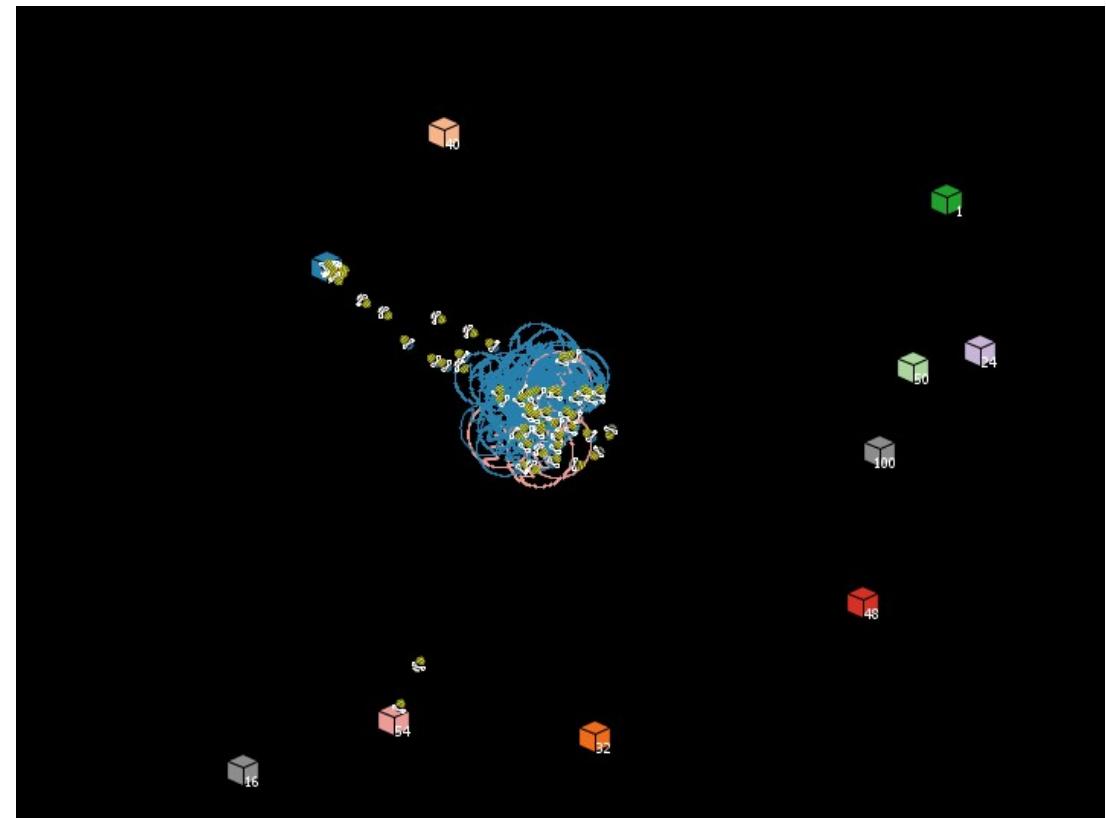
- Hive site attributes
  - Location, Color, Quality
- Waggle dance
  - Length proportional to site quality  
→ Higher chance idle bees see it  
→ follow to inspect the site
  - New visitors also advertise site (dance)
  - Upon revisits, interest in site decays
- When 'quorum' is observed at a site
  - Bees go home to 'pipe'
  - When piping heard, bees start to pipe, too
- signal to stop voting & move



# Beehive Finding (Decision Making) Model (Guo and Wilensky, 2014)

Typical progression of bee states

- Initial scouts:
  - Discover →
  - Inspect-hive →
  - Go-home →
  - Dance →
  - Re-visit →
  - Pipe
- Non-initial scouts:
  - Watch-dance →
  - Re-visit →
  - Inspect-hive →
  - Go-home →
  - Dance →
  - Re-visit →
  - Pipe



# Spatial Clustering

Ant Sort



ELTE

FACULTY OF  
INFORMATICS

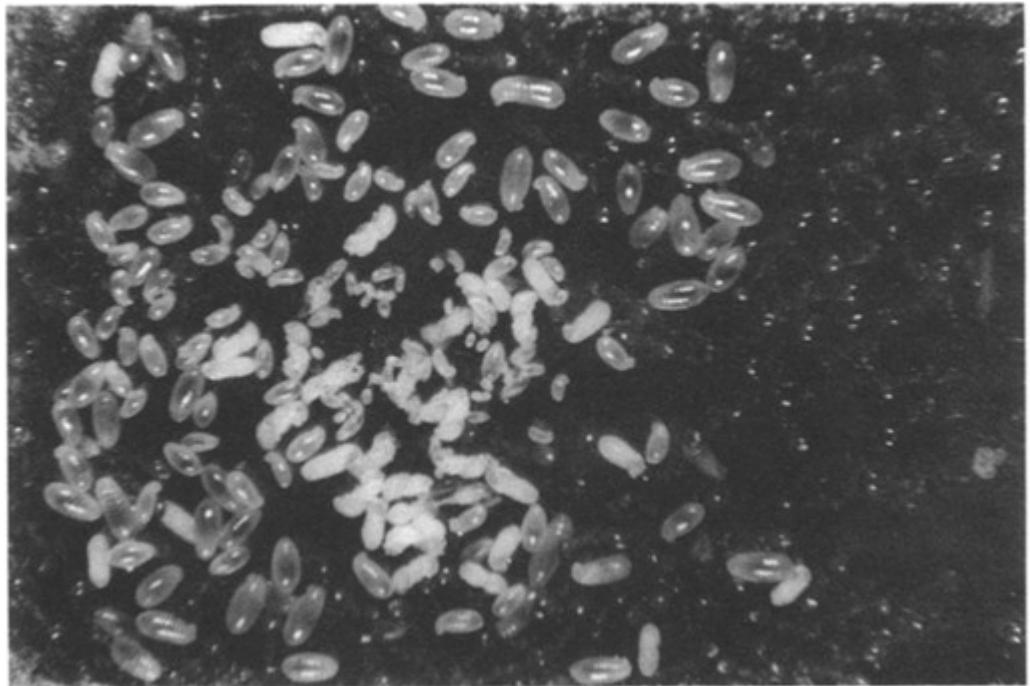
2023.12.31.

Introduction to ML, Bioinspired Collective Intelligence

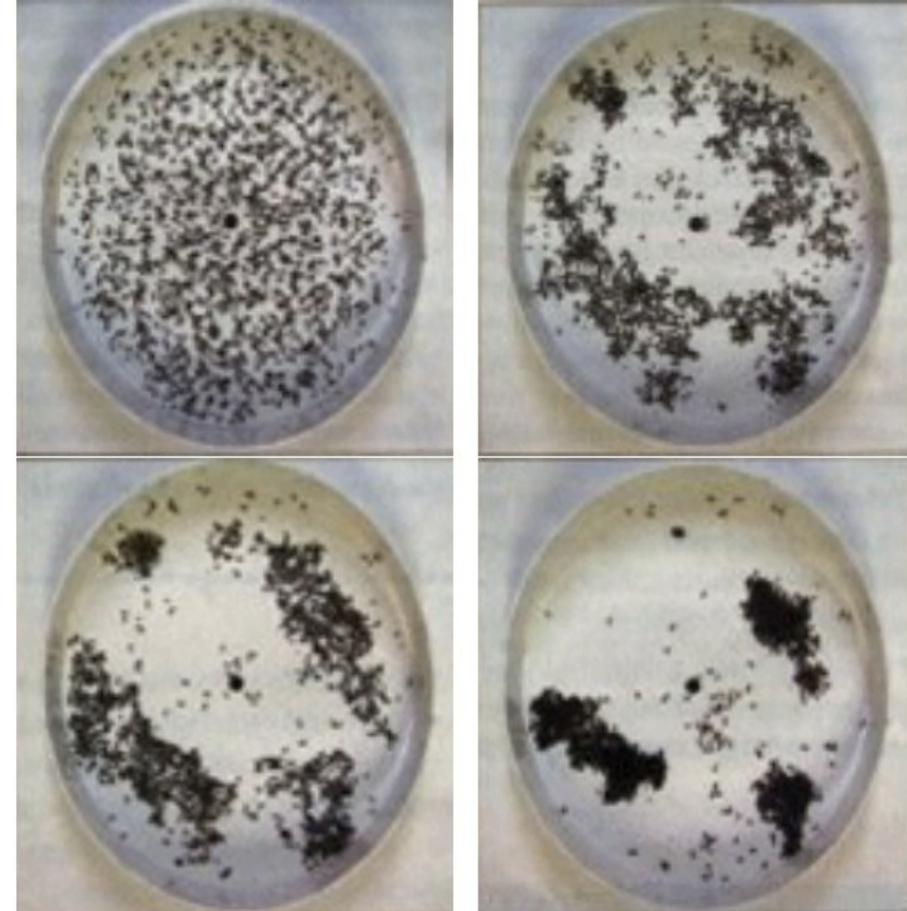
9

# Brood Sorting / Cemetery organisation

## Clustering by Ants



© Franks & Sendova-Franks (1992)



© Jost et al.  
(2007)



ELTE

FACULTY OF  
INFORMATICS

2023.12.31.

Introduction to ML, Bioinspired Collective Intelligence

10

# Brood Sorting / Cemetery organisation

## System Behavior

---

The ant colony keeps

- larvae, eggs, cocoons & food
- sorted by kind

E.g., an egg hatches, the larva is moved to the area for larvae

In several species of ants,

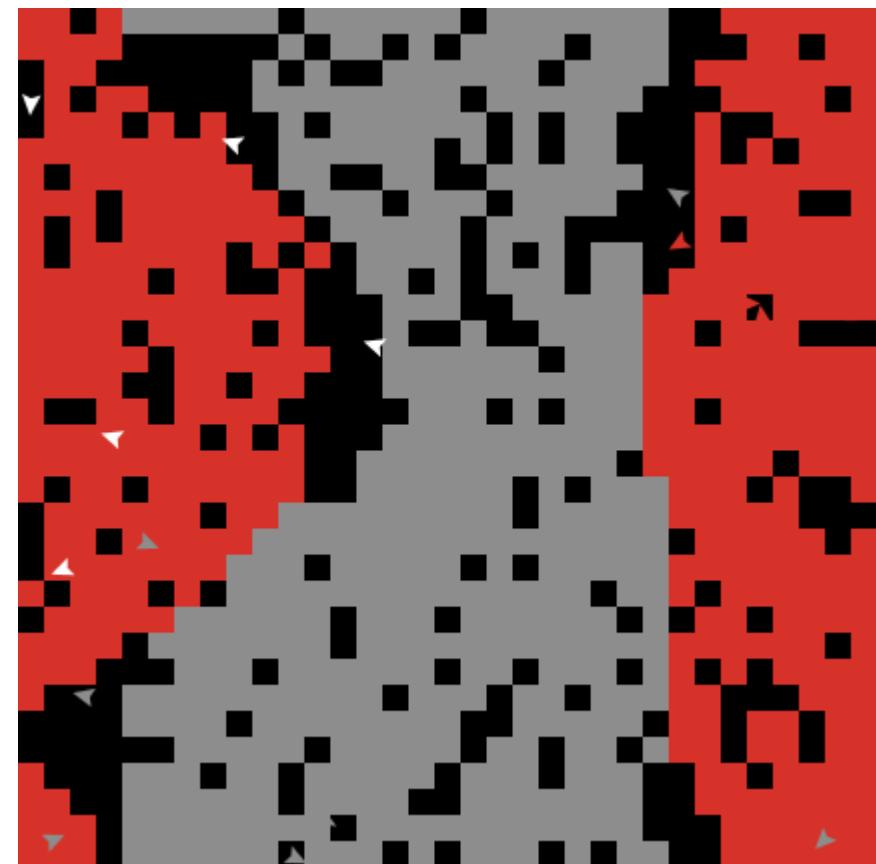
- workers form piles of corpses (cemeteries) to clean the nests.



# Brood Sorting / Cemetery organisation

## Generic Description, variants

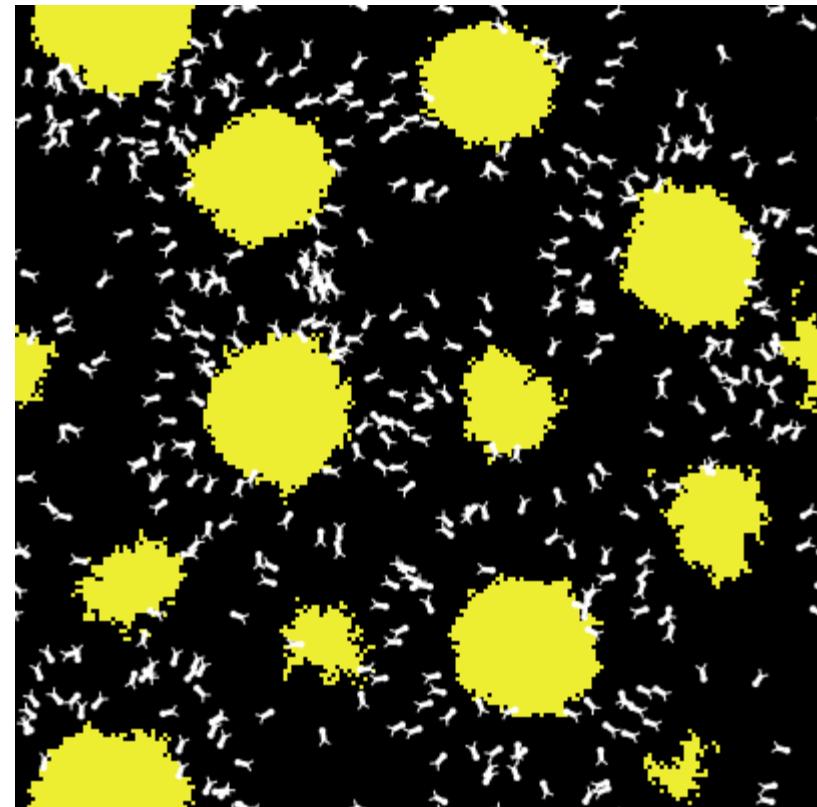
- 2D Grid
- One object at a place/cell or piles?
- #Types/Colors (1 or more)
- Ants can step on objects
- Multiple ants can occupy the same cell



# Brood Sorting / Cemetery organisation

## Simple Algorithm

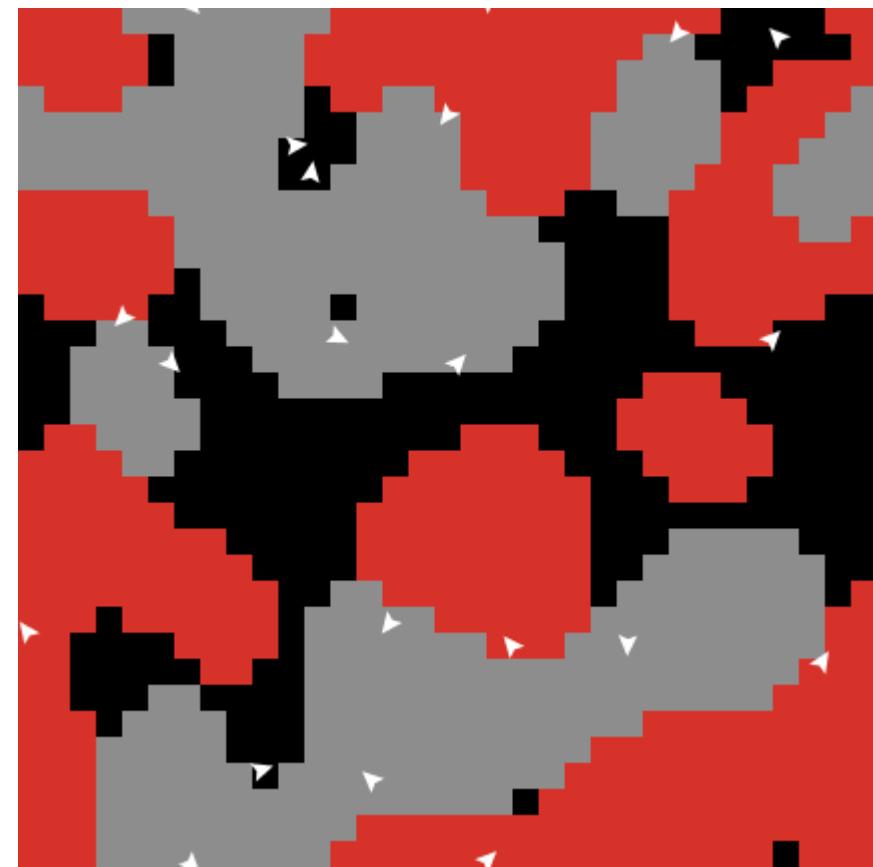
- Ants wander randomly on 2D grid
- They observe their immediate environment
- Pick up an object
  - From ,low-density' locations (when not carrying)
- Put it down
  - At ,high density' locations (if carrying)



# Brood Sorting / Cemetery organisation Model (Simple)

---

- One object at a place
- #Types: may vary
- Environment:
  - 8 Immediate cells (cf. Schelling)
- Decision making
  - #same color items (@location or carried)
  - Below / Above threshold (3, 4, 5)
- Tuning / Difficulty
  - Optimal threshold depends on
    - Density
    - #types
  - Non-optimal threshold
    - Early convergence (no clustering)
    - Ever-carrying ants



# Brood Sorting / Cemetery organisation Applications

---

- Distributed Data Mining
  - Data & Text retrieval
  - Graph partitioning
  - Mostly in networked environments
  - *Mostly before the Deep Learning boom*
- **Swarm robotics**
  - Most recent applications
- Edge computing
  - Mobile agents
- Using mostly variations of the classic model
  - Lumer and Faieta (1994)
  - Gutowitz (1993)
  - Etc.



# Shortest Path

Ant Foraging



ELTE

FACULTY OF  
INFORMATICS

2023.12.31.

Introduction to ML, Bioinspired Collective Intelligence

16

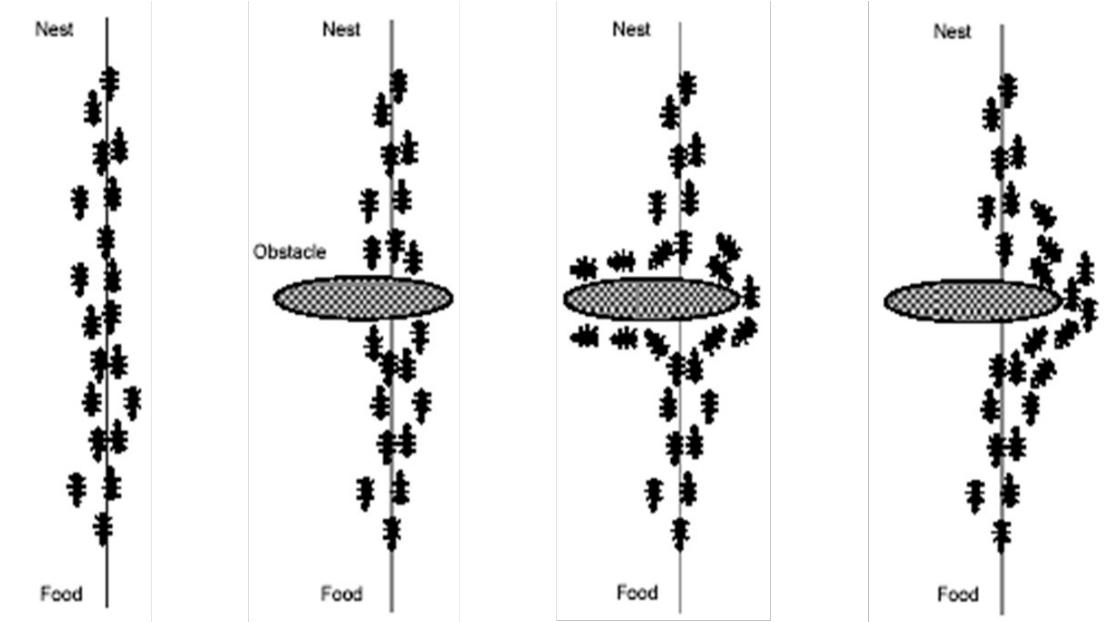
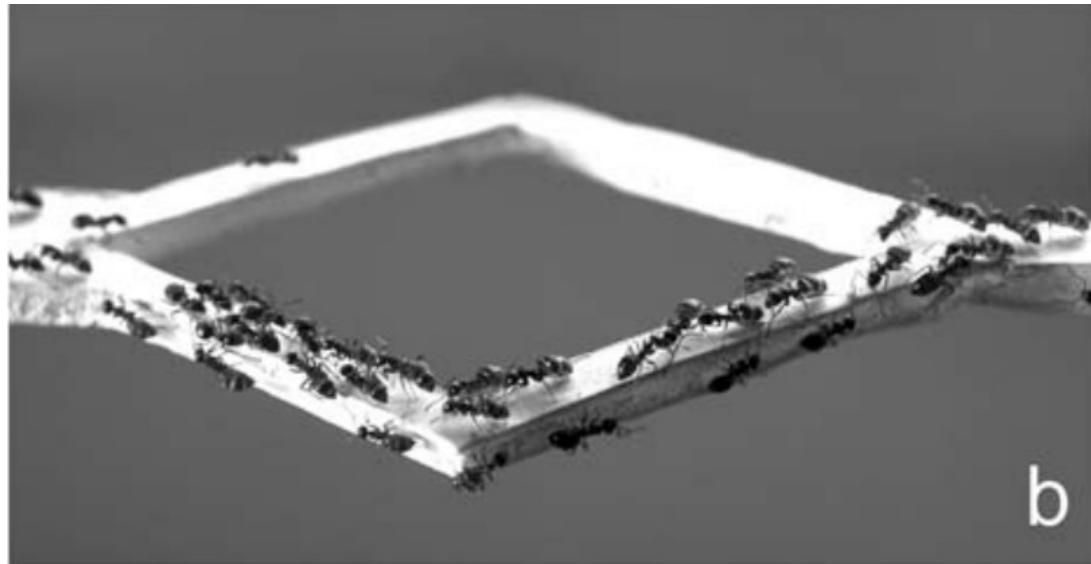
# Ant Foraging Observations

---

- Ants tend to 'march' in line
  - Carrying food
- They tend to pick the closest food source first
- Direct line is shortest
  - From food source to nest



# Ant Foraging Observations



# Ant Foraging Observation (Workings)

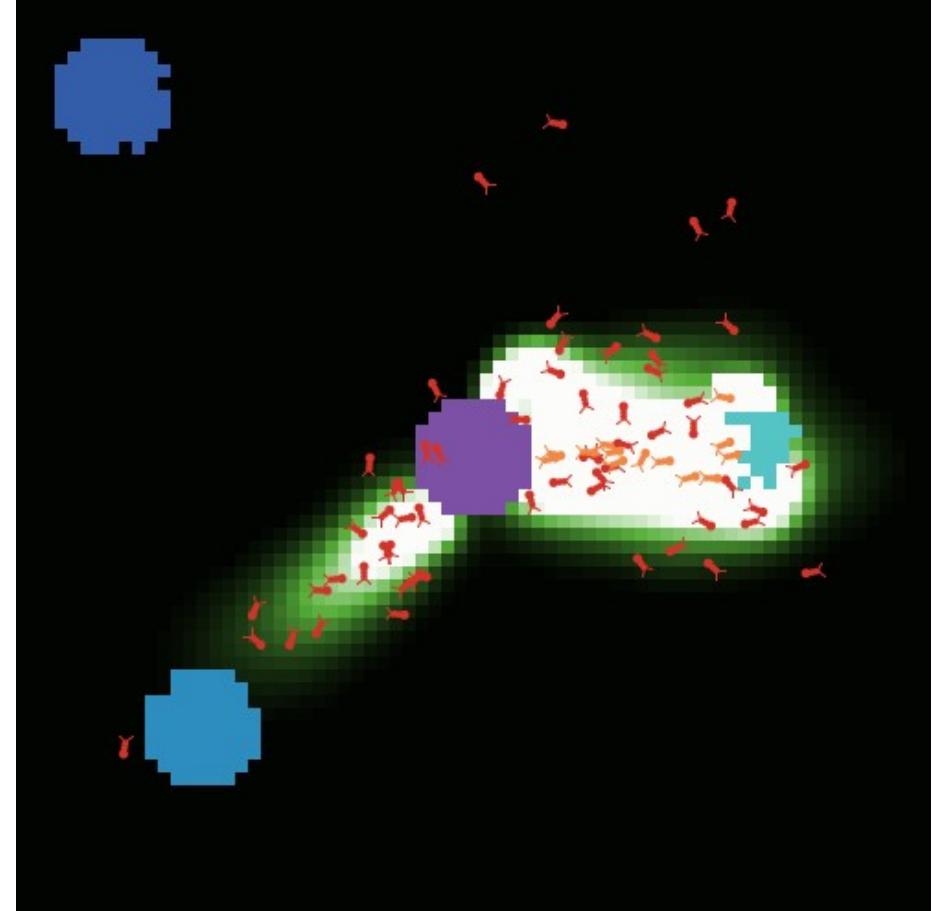
---

- It's all about **pheromones**
  - Fragrant, volatile substance
  - Triggers social response
  - In members of the same species
- Word coined by Peter Karlson & Martin Lüsche (1959)
  - From Ancient Greek φέρω (phérō) 'to bear' and hormone
- Ants lay 2 different pheromones
  - One when searching for food (,A')
  - One when carrying food (,B')
- Ants follow gradient (stochastically) of the ,other' pheromone
  - ,B' when searching for food
  - ,A' when homing
- Pheromone evaporates
  - Non-reinforced trails fade
  - Time/effort to reinforce trail is *proportional to length*



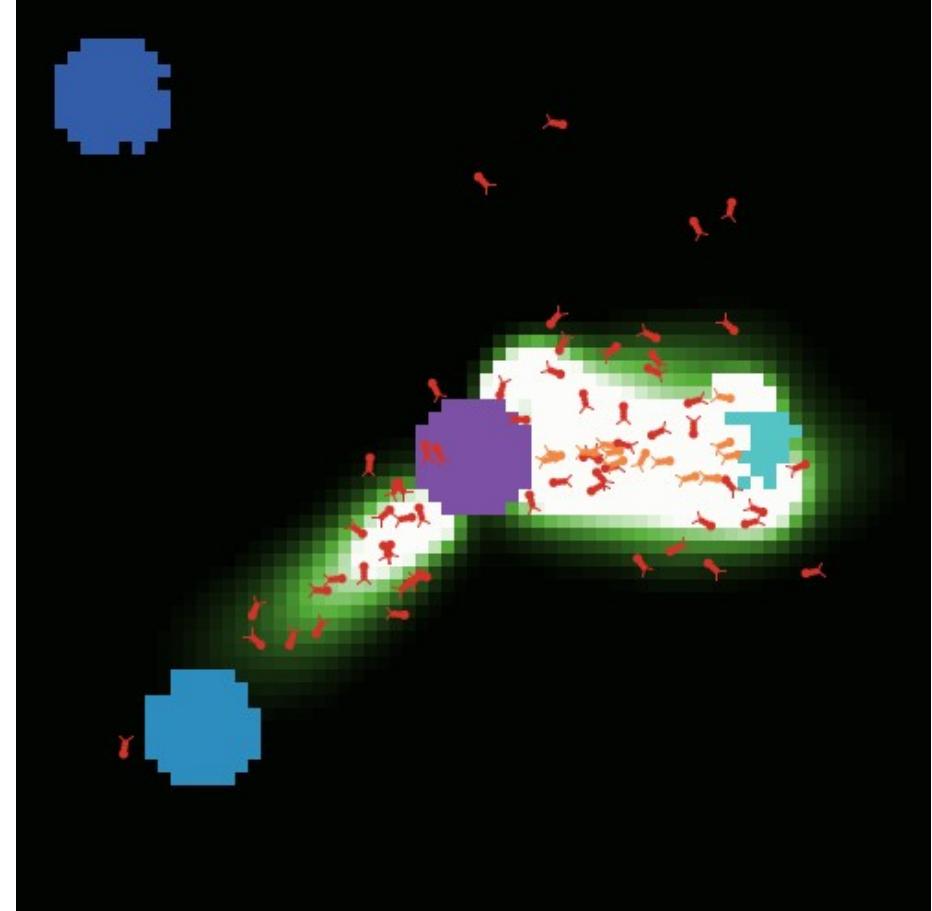
# Ant Foraging Model

- Ants wander around on 2D grid
  - Starting from nest
  - Avoid obstacles (if any)
  - Follow pheromone gradient (*probabilistically*)
- Pick up a piece of food
  - From their current location, if not carrying
- Put down food
  - If at nest and carrying
- Ants deposit a unit of pheromone
  - At current location
  - One when searching for food (,A')
  - One when carrying food (,B')
- Pheromone
  - Diffuses and evaporates
  - By constant rate, uniformly across space



# Ant Foraging Model (Alternative)

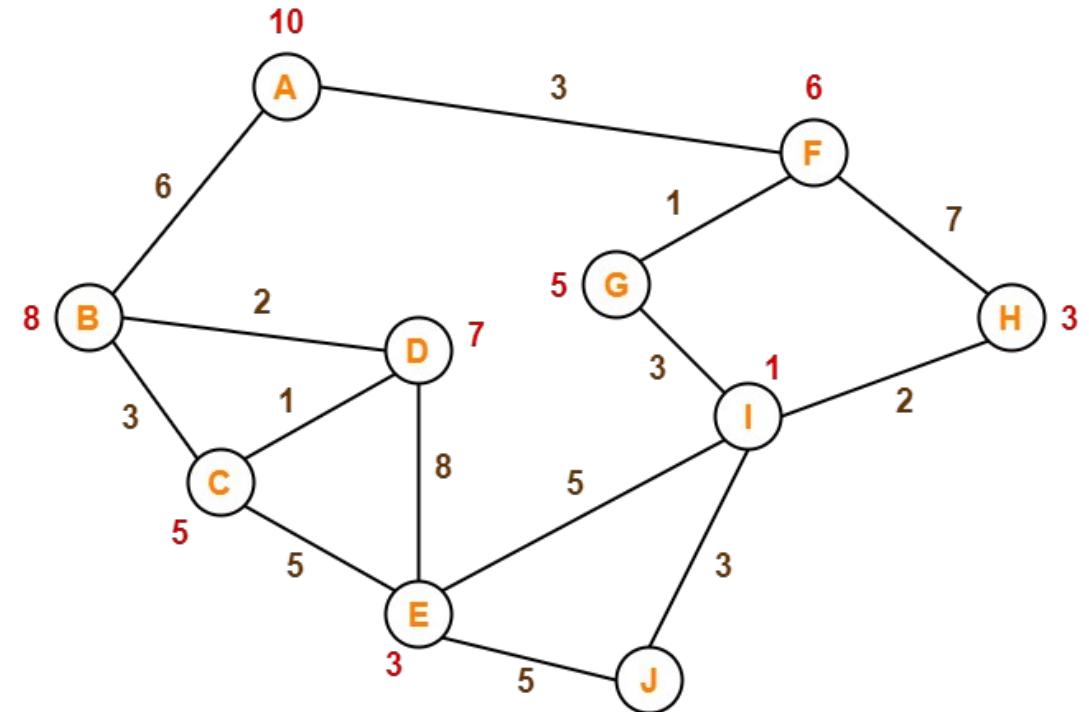
- Pheromone ,A' (nest scent)
  - Comes from the nest
  - Makes homing easier
  - But less general (i.e., hard to find nest from a larger distance)



# Ant Foraging Applications

---

- Many
- Finding shortest path is a very generic problem
  - Routing problems (telco, vehicles, etc.)
  - Finding approximate solutions (graph search) for large problems
  - Scheduling problems
  - Quadratic Assignment problems
  - Travelling Salesman Problem

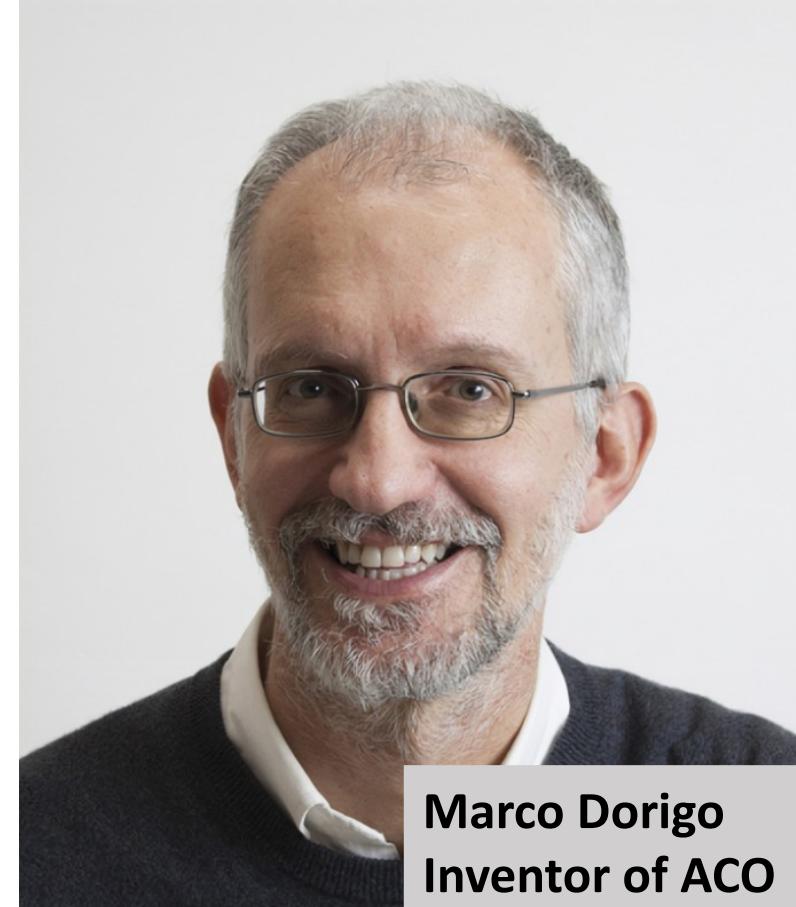


# Ant Foraging

Applications (Generalization: Marco Dorigo, 1992)

## Ant Colony Optimization (ACO)

- Graph (network) instead of 2D grid
  - Pheromone accumulates on edges
- Starting node selected at random
  - Next node is selected *probabilistically* following edge pheromone gradient
- When a solution is found
  - Pheromone amounts on path are adjusted: proportionally to quality
- Stopping condition
  - When most ants select the same solution



**Marco Dorigo**  
**Inventor of ACO**



# Summary: Swarm Intelligence

---

- Surveyed collective, massively multi-agent algorithms for specific problems
  - Biologically inspired
  - Cheap and simple individual behaviours
  - Massive number of agents
  - Continuous operations, graceful degradation
- Simple behavior may be enough for emerging intelligent behavior





ELTE | FACULTY OF  
INFORMATICS

# Thank you!

László Gulyás

Associate Professor  
Department of Artificial Intelligence

[lgulyas@inf.elte.hu](mailto:lgulyas@inf.elte.hu)



DEPARTMENT OF  
ARTIFICIAL  
INTELLIGENCE



ELTE | FACULTY OF  
INFORMATICS

# BACKUP



DEPARTMENT OF  
ARTIFICIAL  
INTELLIGENCE

# Flocking / Schooling



ELTE

FACULTY OF  
INFORMATICS

2023.12.31.

Introduction to ML, Bioinspired Collective Intelligence

27

# Flocking / Swarming / Schooling

---

© Hakai Institute



ELTE

FACULTY OF  
INFORMATICS

2023.12.31.

Collective Intelligence

28

# Flocking / Swarming / Schooling

## System Behavior

Flocks of birds, schools of fish

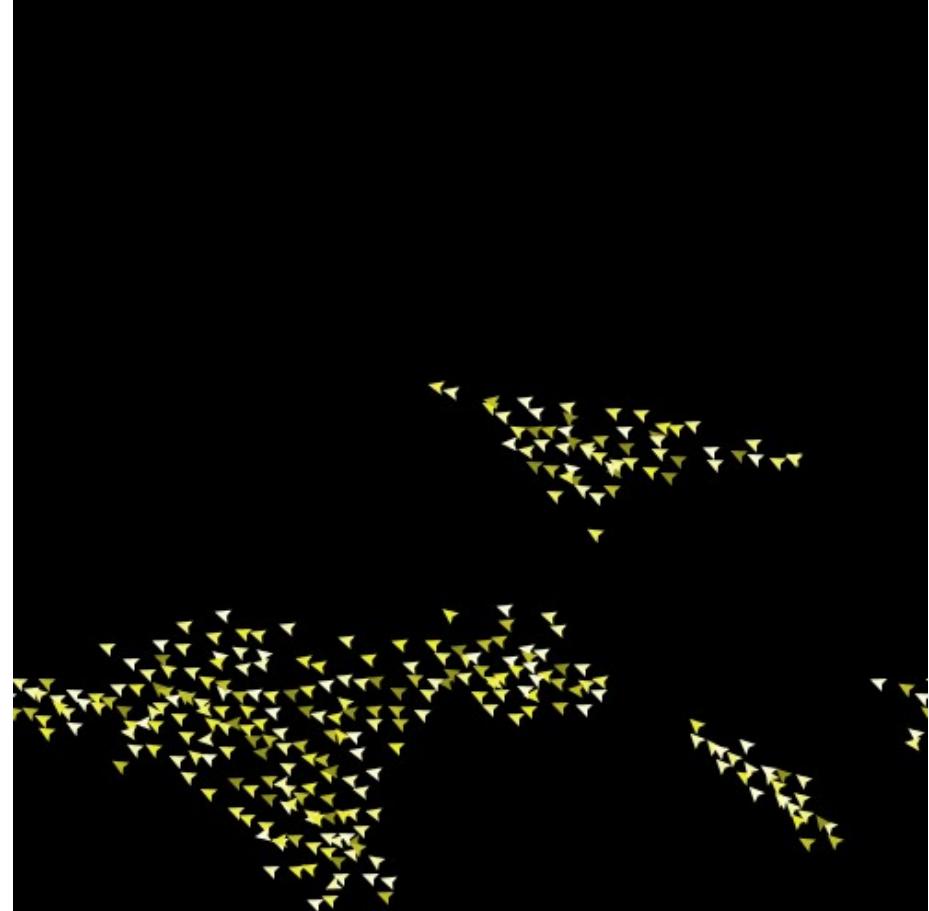
- stay together,
- coordinate turns, and
- avoid collisions with obstacles and each other



# Flocking / Swarming / Schooling Model

Three simple rules:  
[Reynolds 1987, Heppner 1990]

1. Maintain a specified minimum separation from the nearest object or other birds
2. Match velocity (magnitude and direction) to nearby birds
3. Stay close to the center of the flock



# Flocking / Swarming / Schooling Applications

---

In human societies similar problems

- in air-traffic control,
- convoys of ships,
- **movement of robots, drones!**

Conventional solutions depend on

- sophisticated communication and
- central coordination, plus
- **cannot handle the density of coordinated entities**

