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Bioinspired Collective Intelligence

Introduction to Machine Learning

Computer Science BSc Course, ELTE Faculty of Informatics

László Gulyás

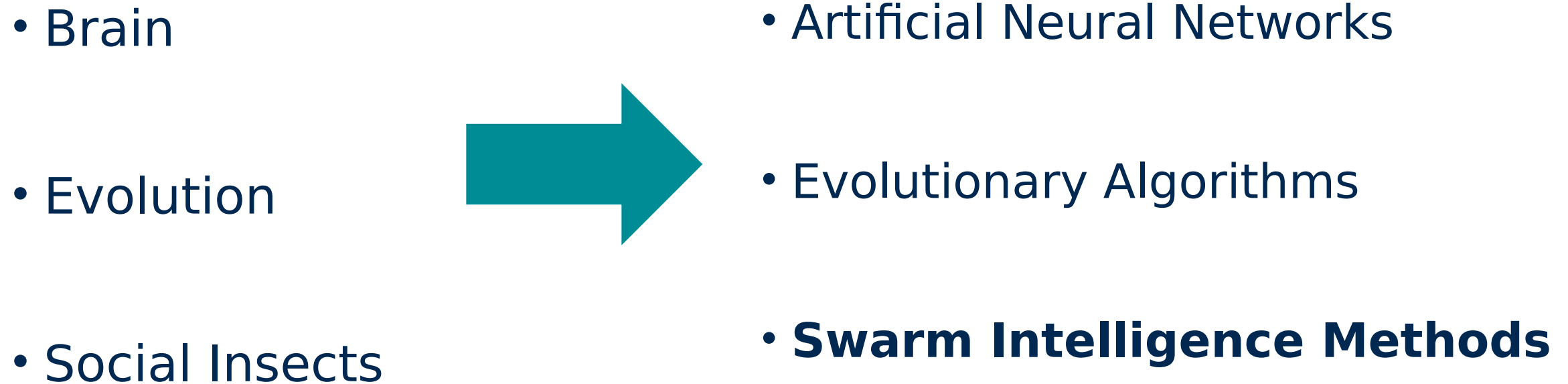
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Biologically Inspired Methods –



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”



Beehive Finding

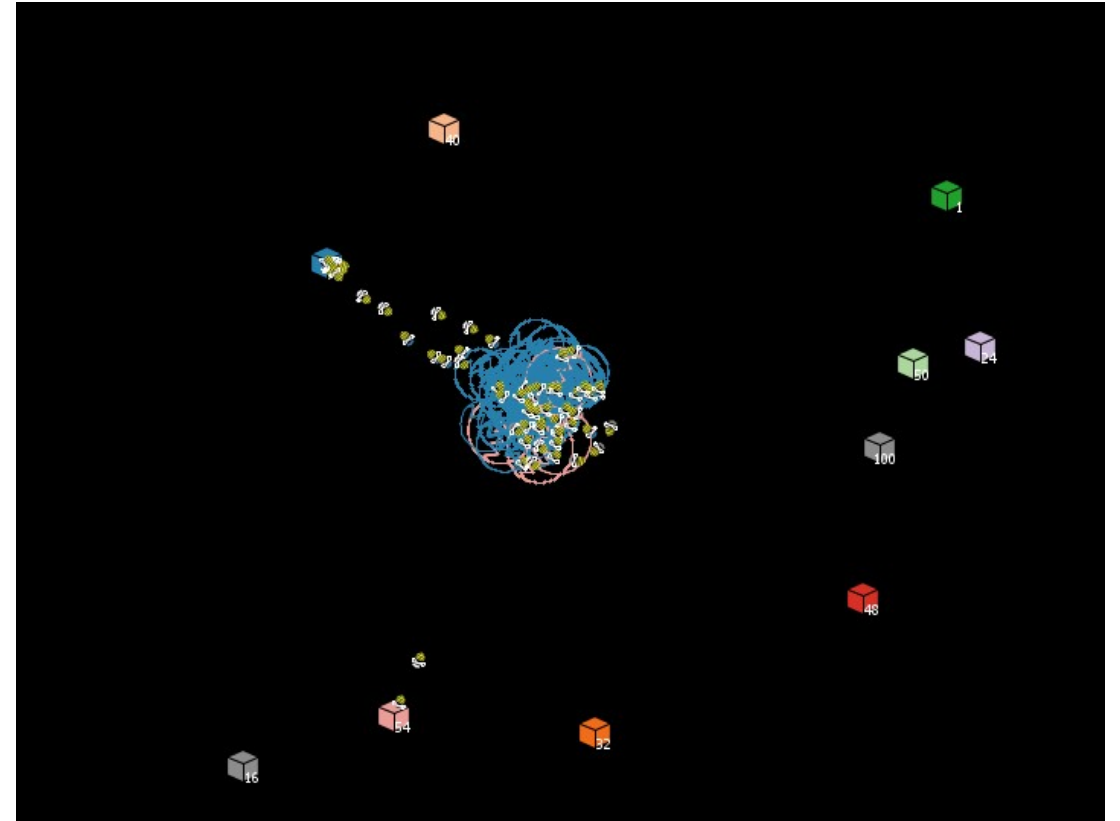
Louis Rosenberg (Unanimous AI)



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

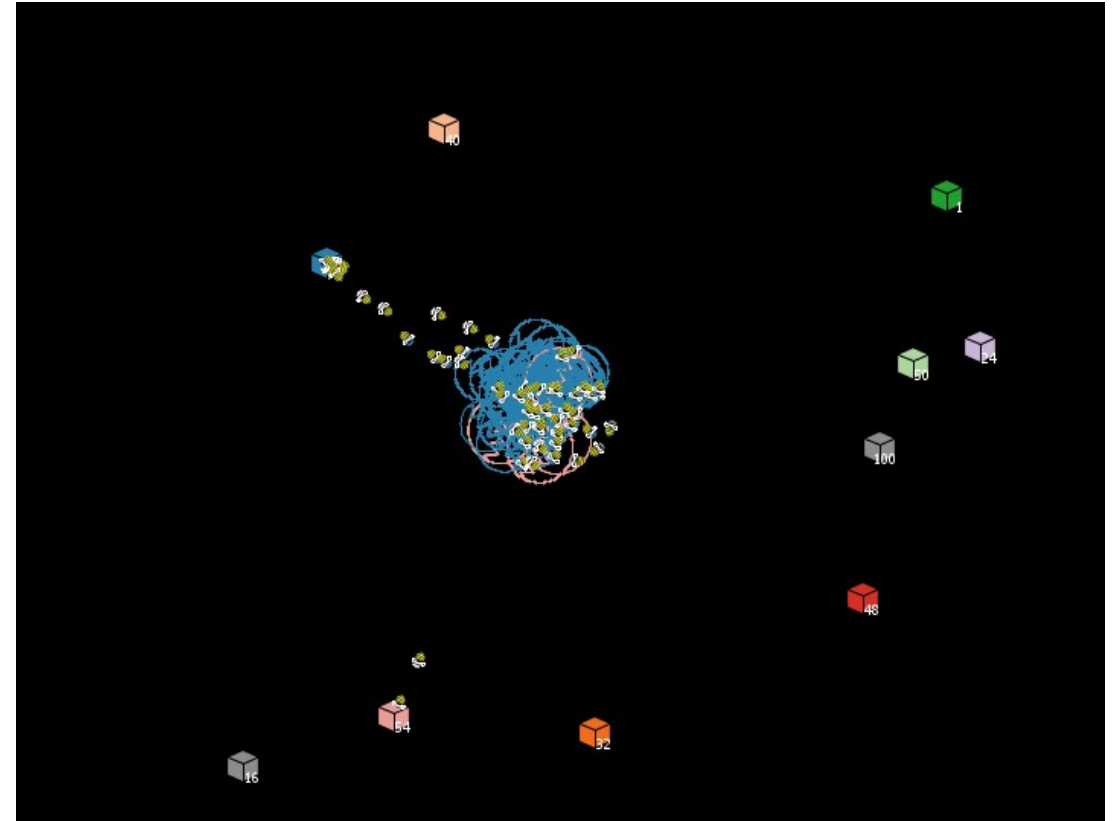


Beehive Finding (Decision Making)

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



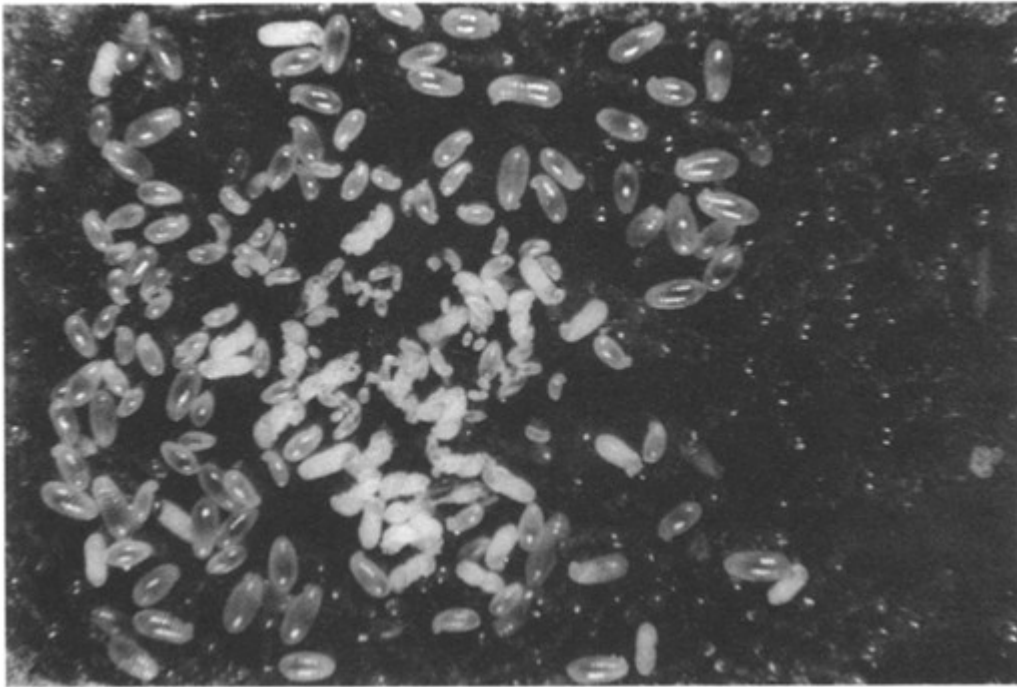
Spatial Clustering

Ant Sort

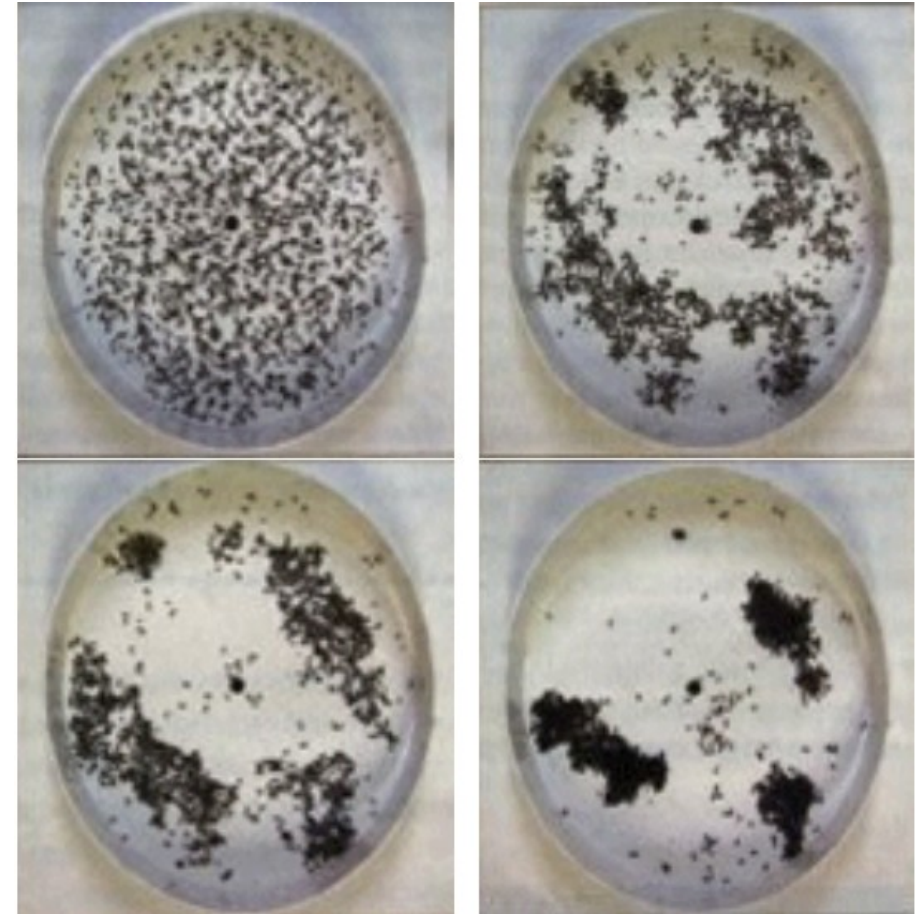


Brood Sorting / Cemetery organisation

Clustering by Ants



© Franks & Sendova-Franks (1992)



© Jost et al.
(2007)

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,

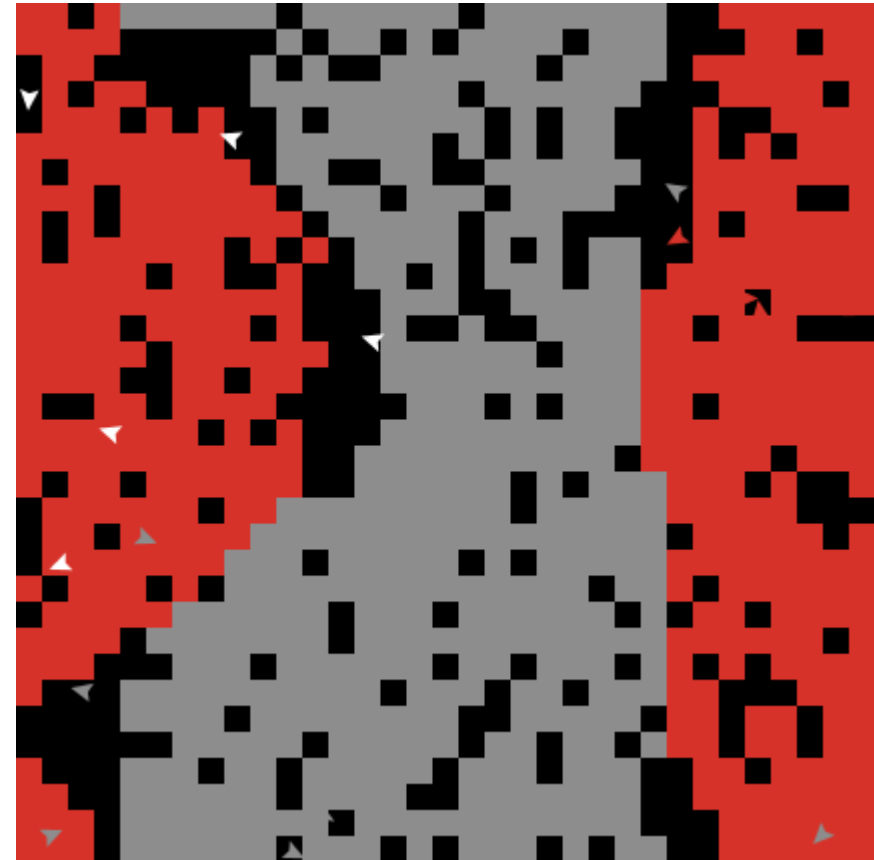
- workers form piles of corpses (cemeteries)

to clean the nests.

Brood Sorting / Cemetery organisation

Generic Description, variants

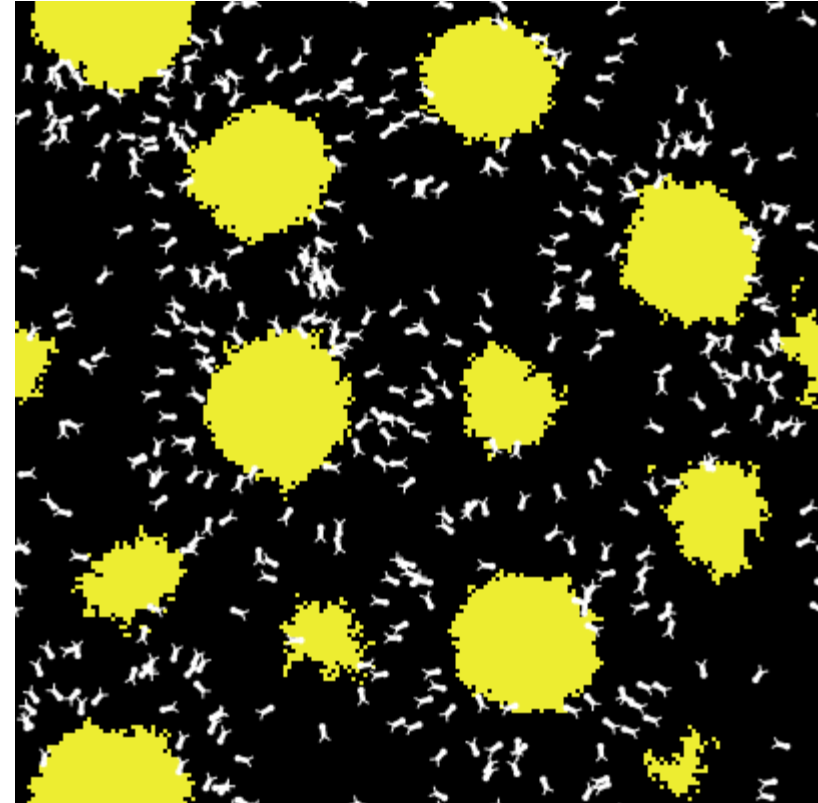
- 2D Grid
- One object at a place/cell or piles?
- #Types/Colors (1 or more)
- Ants can step on objects
- Multiple ants can occupy the same cell



Brood Sorting / Cemetery organisation

Simple Algorithm

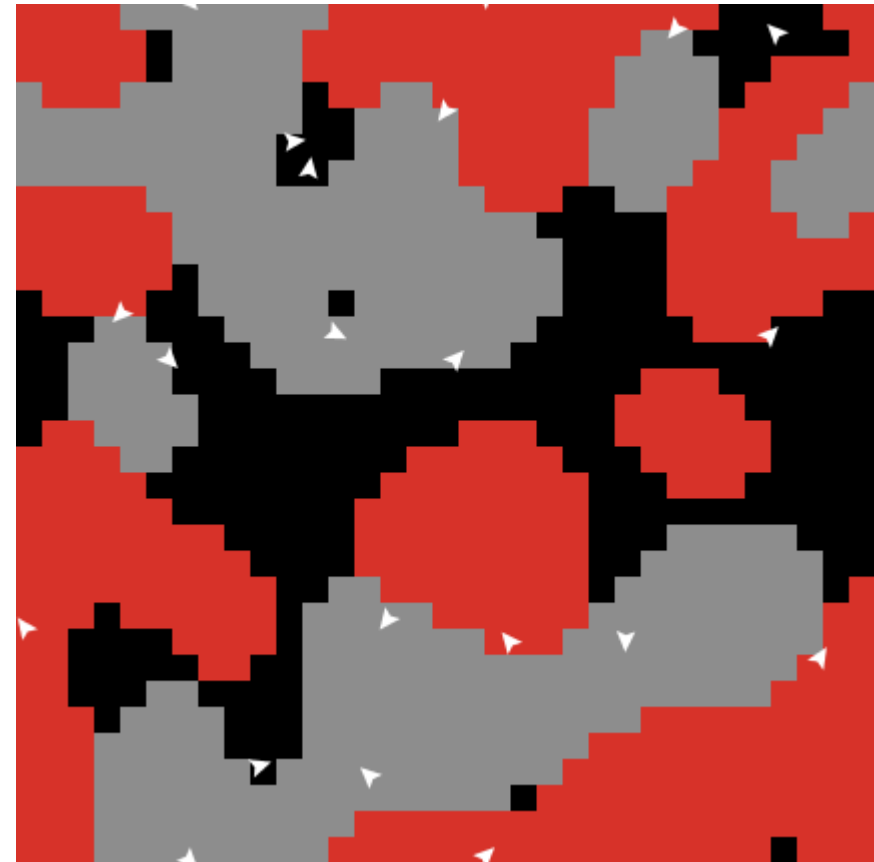
- Ants wander randomly on 2D grid
- They observe their immediate environment
- Pick up an object
 - From ,low-density' locations (when not carrying)
- Put it down
 - At ,high density' locations (if carrying)



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

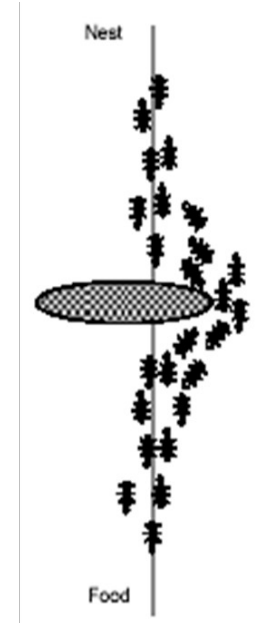
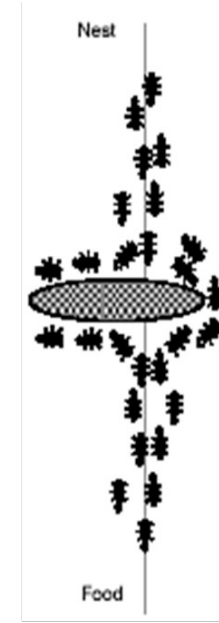
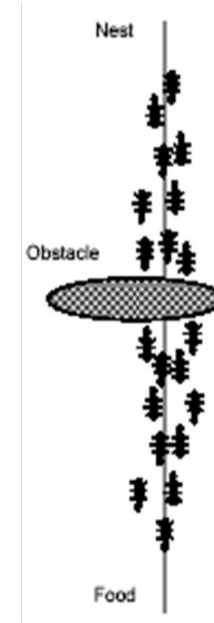
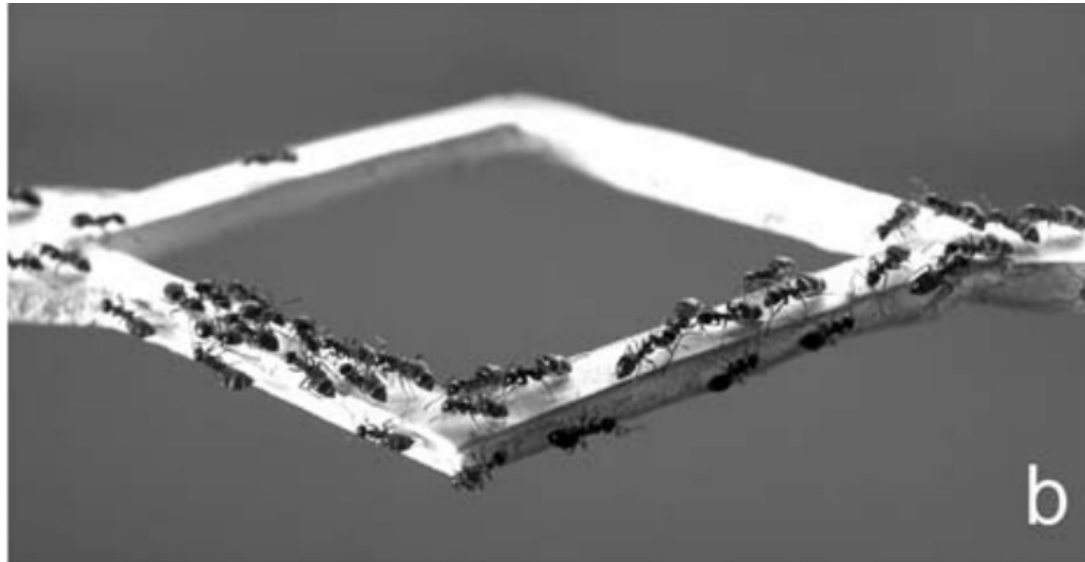


Ant Foraging Observations

- 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



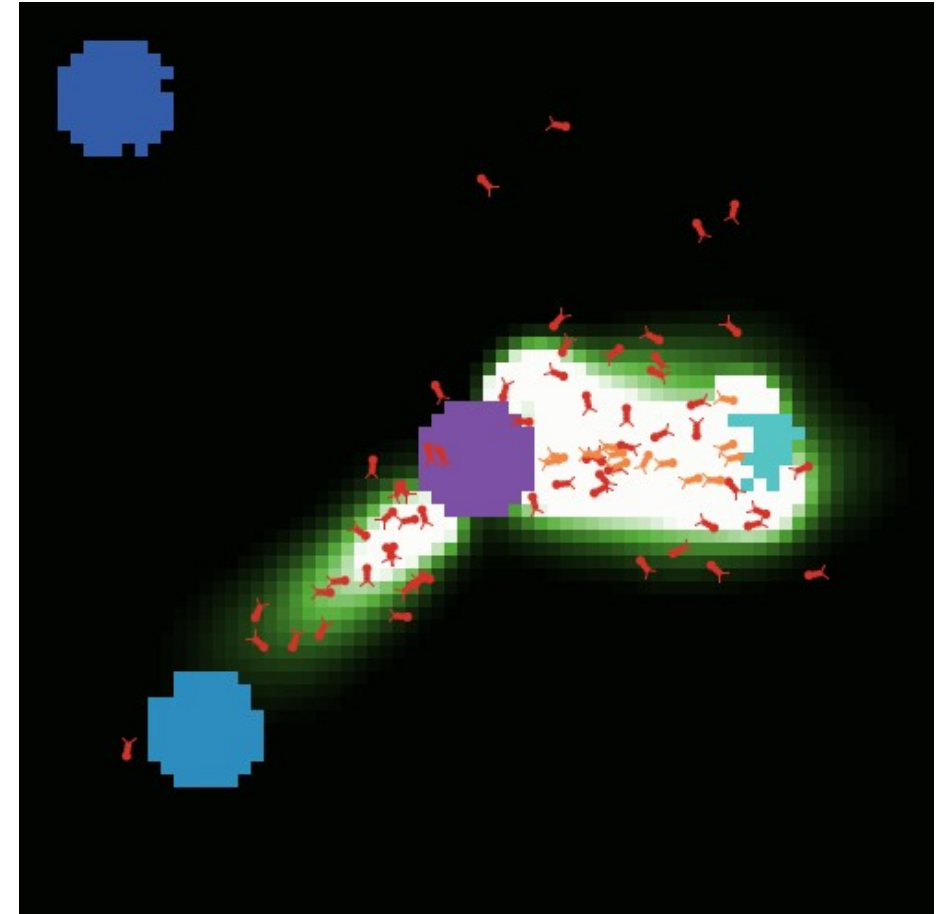
Ant Foraging

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*

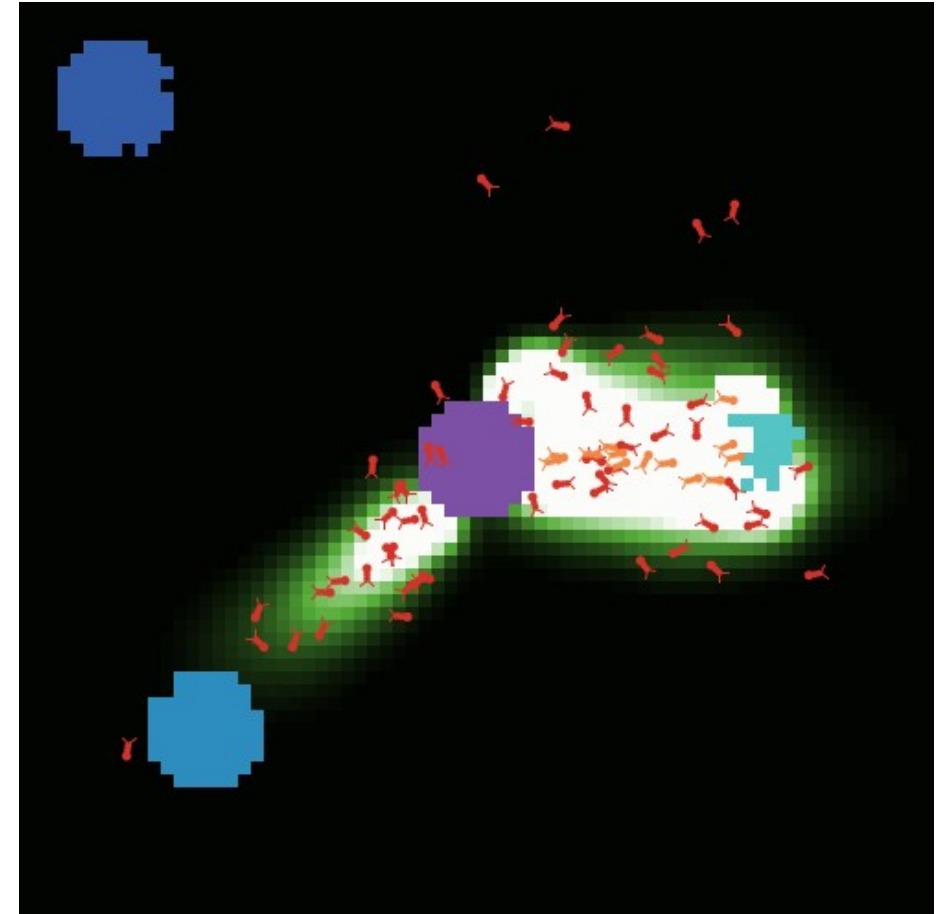
Ant Foraging Model

- 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



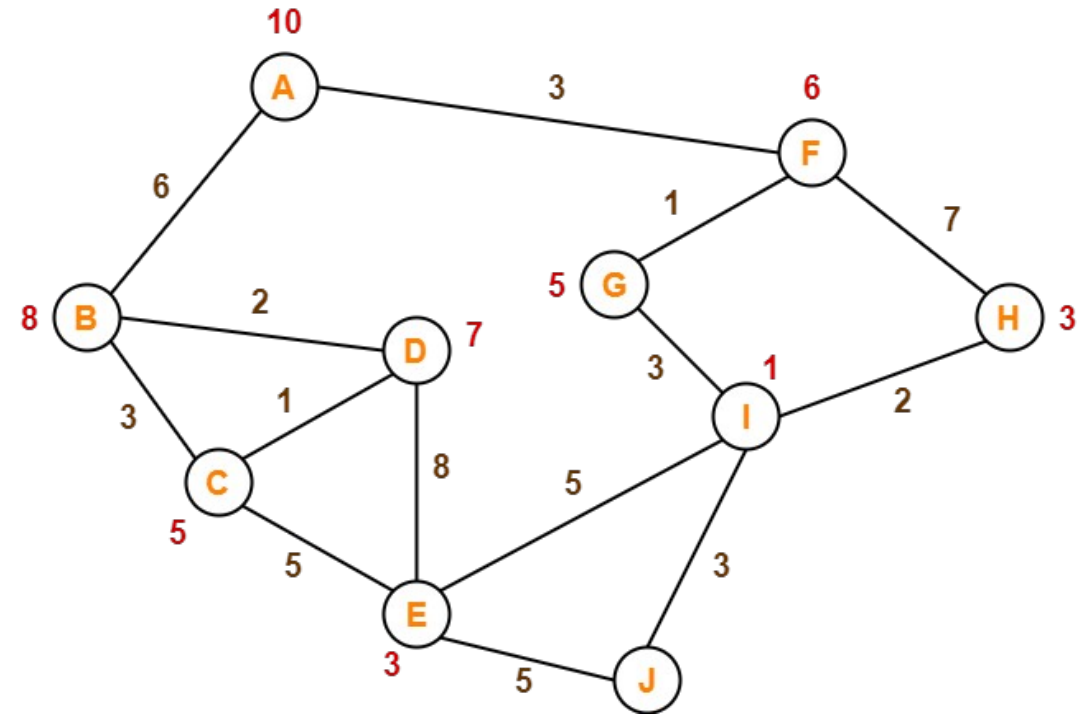
Ant Foraging Model (Alternative)

- 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



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Thank you!

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Flocking / Schooling



Flocking / Swarming / Schooling

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Collective Intelligence

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Flocking / Swarming / Schooling

System Behavior

Flocks of birds, shoals of fish

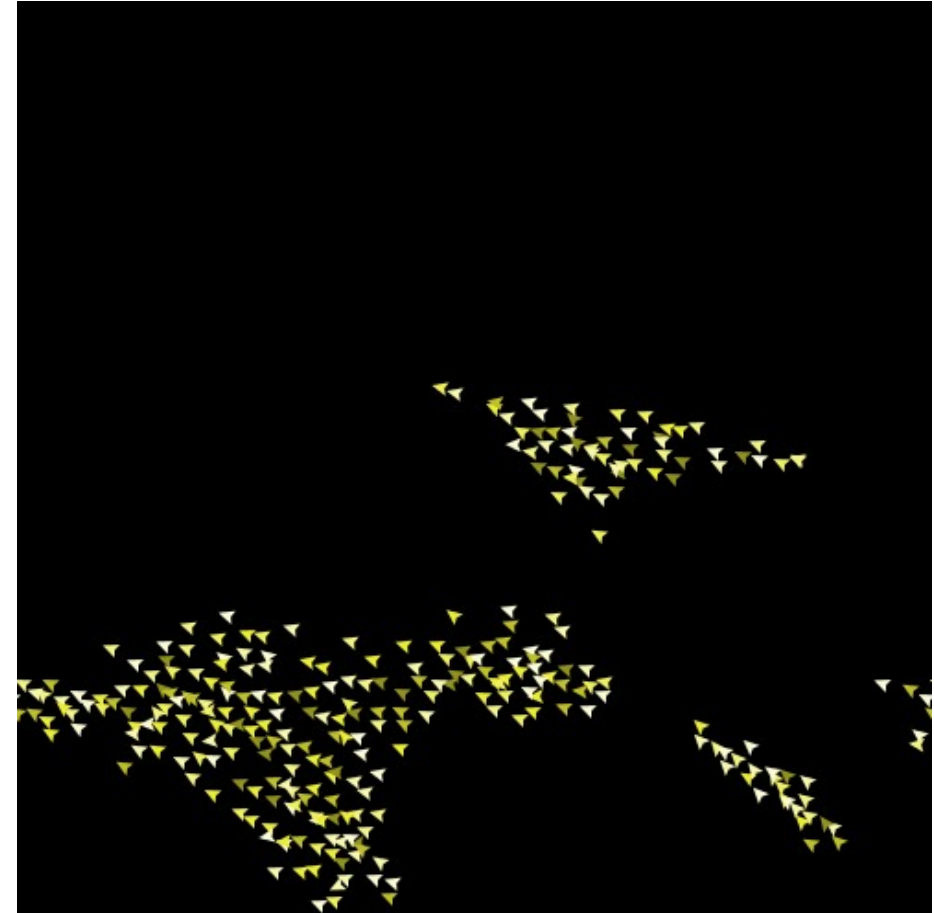
- stay together,
- coordinate turns, and
- avoid collisions with obstacles and each other



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**

