UNIVERSITY OF LIVERPOOL

COMP 532
Machine Learning and BioInspired Optimization

Lecture 22: Swarm Intelligence

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Overview

- What is Swarm Intelligence?
  - Inspirations from nature
  - Insects, birds, fish..
  - Common features of SI
- Particle Swarm Optimization
- Ant Systems and Ant Colony Optimization
- Bee Colonies and Swarm Robotics

What is Swarm Intelligence?

Swarm Intelligence is the complex global behavior shown by a **distributed system** that arises from the **self-organized local interactions** between its constituent agents.

Prof. Marco Dorigo
Inventor of Ant Colony Optimization

Insects, Social Insects, and Ants

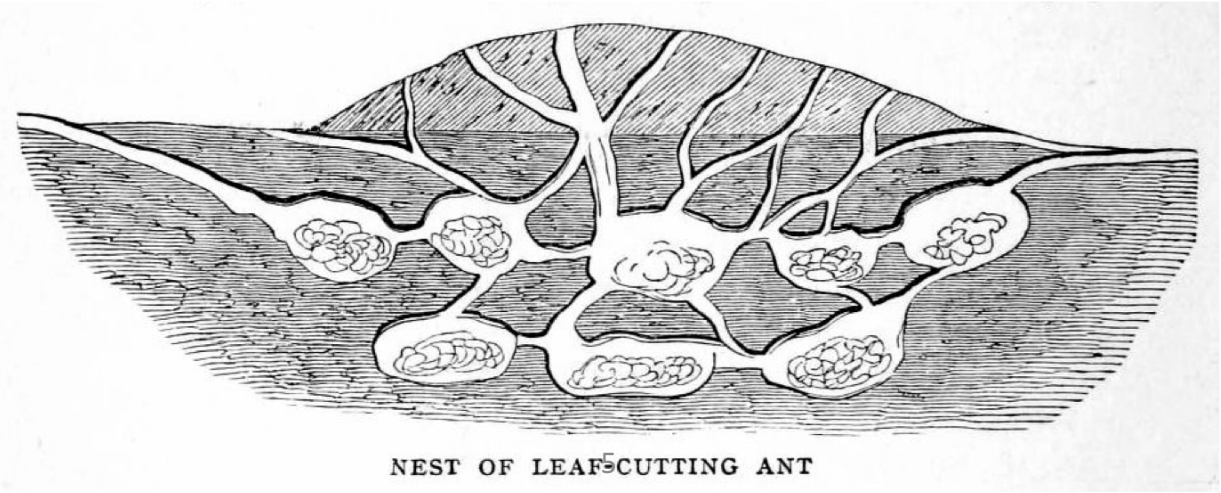
- 10^{18} living insects (rough estimate)
- ~2% of all insects are **social**
- Social insects are:
  - All ants
  - All termites
  - Some bees
  - Some wasps
- 50% of all social insects are ants
- Avg. weight of one ant between 1 and 5 mg
- Total weight ants ≈ Total weight humans
- Ants have colonized Earth for over 100 million years, *Homo sapiens* for approximately 50,000 years

Ants

Highly specialized

- Harvesting ants
- Fungus growers
- Breeding ants
- Army ants
- Weaver ants
- Slavemaker ants

Ants were the first farmers!

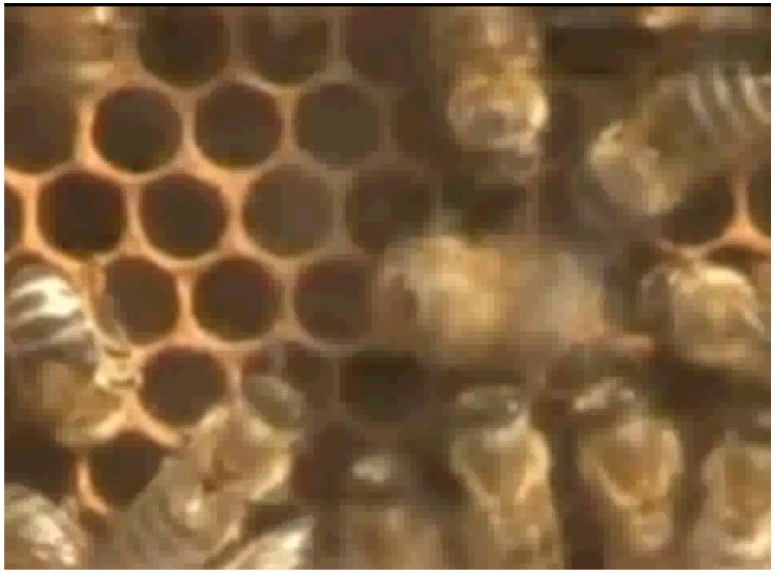


NEST OF LEAF-CUTTING ANT

Bees

Bees

- Colony cooperation
- Regulate hive temperature
- Efficiency = Specialization: division of labour in the colony



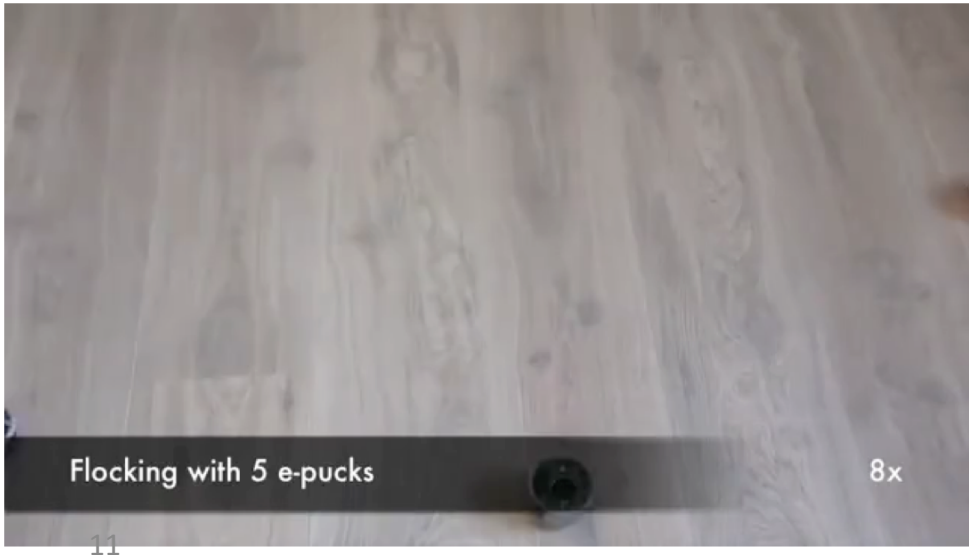
- Communication: food sources are exploited according to quality and distance from the hive

Not only insects

We sometimes exhibit swarm behaviour too

But we're mainly interested in animals and insects

Because we might learn something

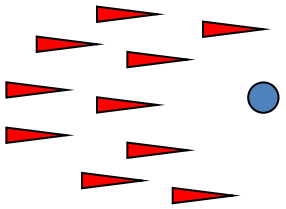


Why does flocking/swarming occur so much in nature?

- **Energy savings**: Geese in V formation have around a 70% greater range than in flying individually. Individuals can fly around 25% faster (why?)

- **Frightening and confusing predators**: avoiding being "picked off"

- **Helping to catch prey**: e.g. tuna school in a crescent shaped flock with the concave part forward
  - This is thought to help channel their prey to the "focus", and stop them from escaping



It might also help with migration

If we can assume that:

- An individual has an idea, but not a perfect one, of where to go … e.g. by itself it may go a few degrees off course.
- The "errors" of individuals are not correlated (i.e. they're all wrong in a randomly different way)
- An emergent result of the flocking is that the flock's direction is the average of its members' directions.

Then: basic statistics can show that the error in the flock's direction is probably very small. About $1/\sqrt{n}$ of the typical error of one of the n individuals.

So…

Flocking occurs so much because it is clearly useful. But how do they do it so well? Individual ants are not clever enough to understand the benefits.

It comes down to: **simple behaviours of individuals in a group can have useful emergent properties**. A theme we will continue to see a lot …

How do social insects coordinate?

Self-organization

- Set of dynamical mechanisms whereby **structure appears at the global level** as the result of **interactions among lower-level components**
  - The rules are executed on the basis of **purely local information**, without reference to the global pattern
  - Behaviour is an **emergent property of the system** rather than externally imposed

Self-Organization

Four basic ingredients:

- Multiple interactions
- Randomness (= exploration)
- Positive feedback
  - E.g., recruitment and reinforcement
- Negative feedback
  - E.g., limited number of foragers, pheromone evaporations

Again: Swarm Intelligence

- **Collective system** capable of accomplishing difficult tasks in dynamic and varied environments without any external guidance or control and with **no central coordination**

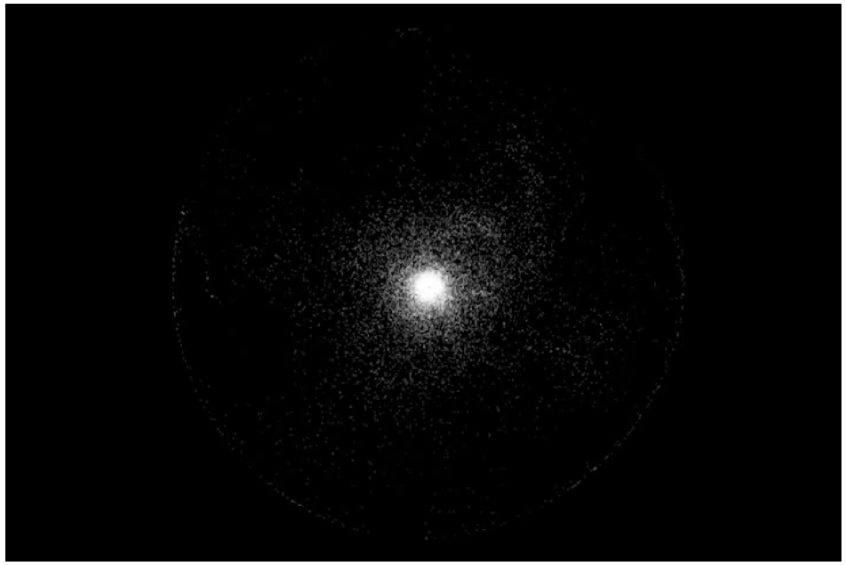
- Achieving a collective performance which could not normally be achieved by an individual acting alone

Constitutes a natural model particularly suited to distributed problem solving

Swarm Intelligence

Main features:

- Inherent parallelism
- Stochastic nature
- Adaptive
- Use of positive (and negative) feedback
- Autocatalytic in nature



Swarm Intelligence

A swarm can sometimes behave as if it is a single organism

- Ants or wasps on a hunt for food, or on the attack, behave as if with a single mind, co-ordinating different actions with different parts of the swarm.
- A swarm, of ants/bees/locusts/etc often exhibits behaviours that seem more intelligent than any of the individual members of it.
- The way in which swarms/flocks/schools in some species change direction is astoundingly well co-ordinated.
- The way in which swarms in some species avoid obstacles seems to be extremely well choreographed.

A key concept: Stigmergy

Stigmergy is:

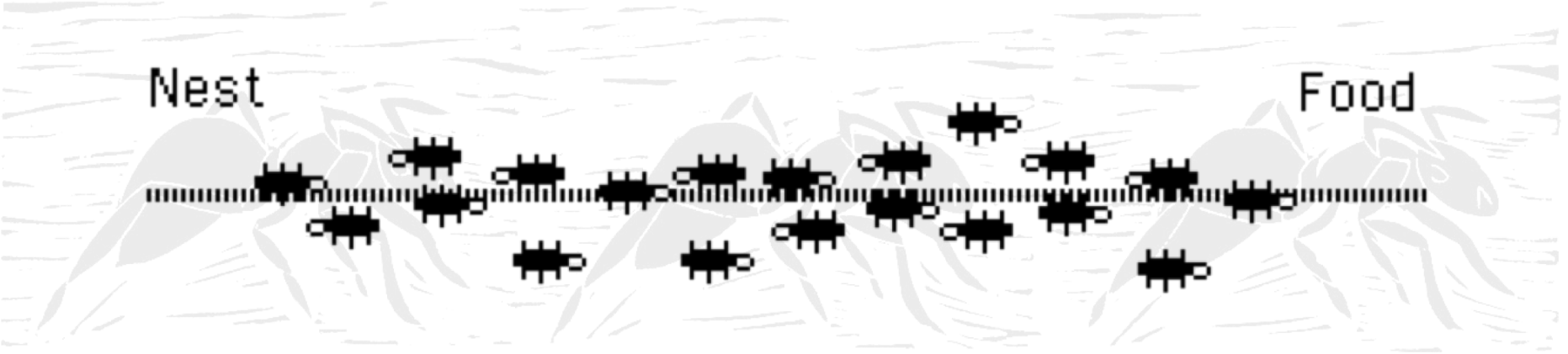
indirect communication via interaction with the environment

- A problem gets solved bit by bit
- Individuals communicate with each other in the above way, affecting what each other does on the task
- Individuals leave markers or messages – these don't solve the problem in themselves, but they affect other individuals in a way that helps them solve the problem
- E.g., as we will see, this is how ants find shortest paths

Stigmergy in Ants

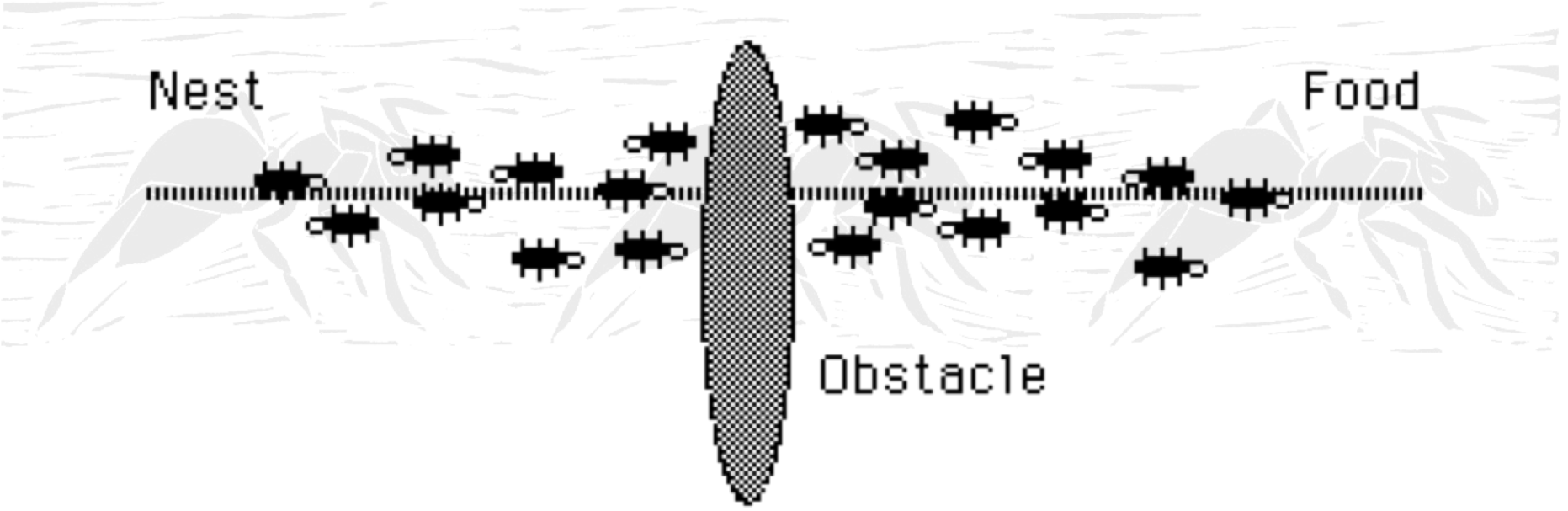
- Ants have sophisticated sign-based stigmergy
- They communicate using **pheromones**
  - While walking, they may deposit pheromones
  - They follow with high probability pheromone trails they sense on the ground
  - Pheromones evaporate over time
- What emerges is a form of **autocatalytic** behavior: the more ants follow a trail, the more attractive that trail becomes for being followed

Naturally Observed Ant Behavior



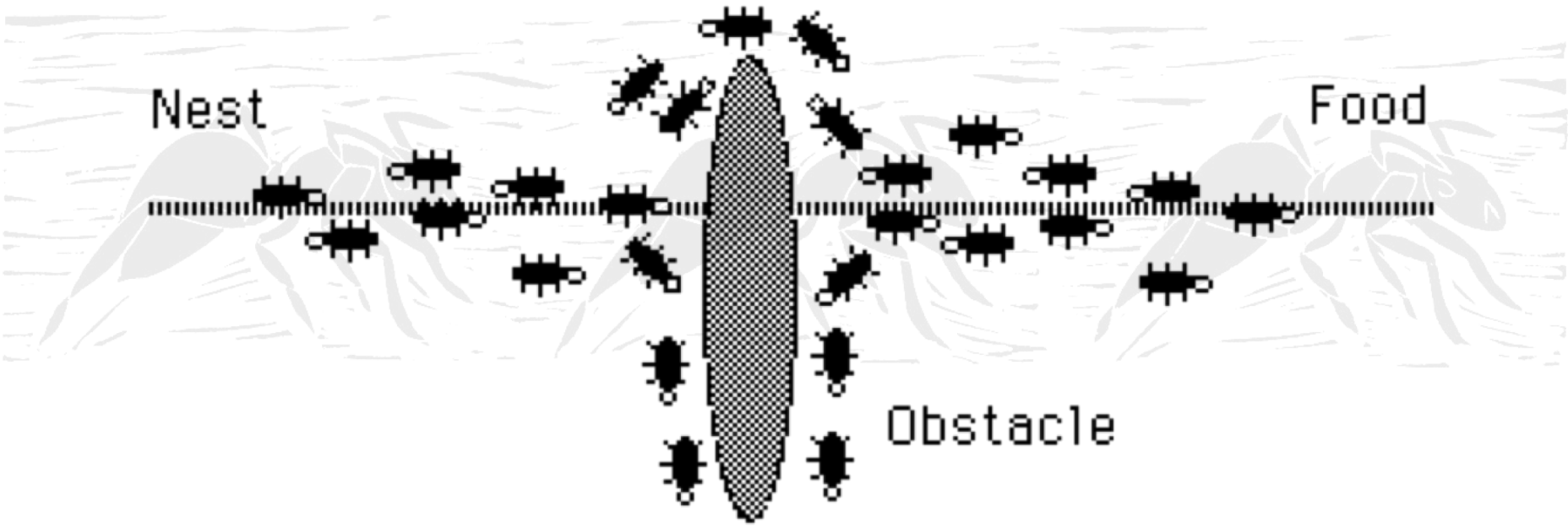
All is well in the world of the ant.

Naturally Observed Ant Behavior



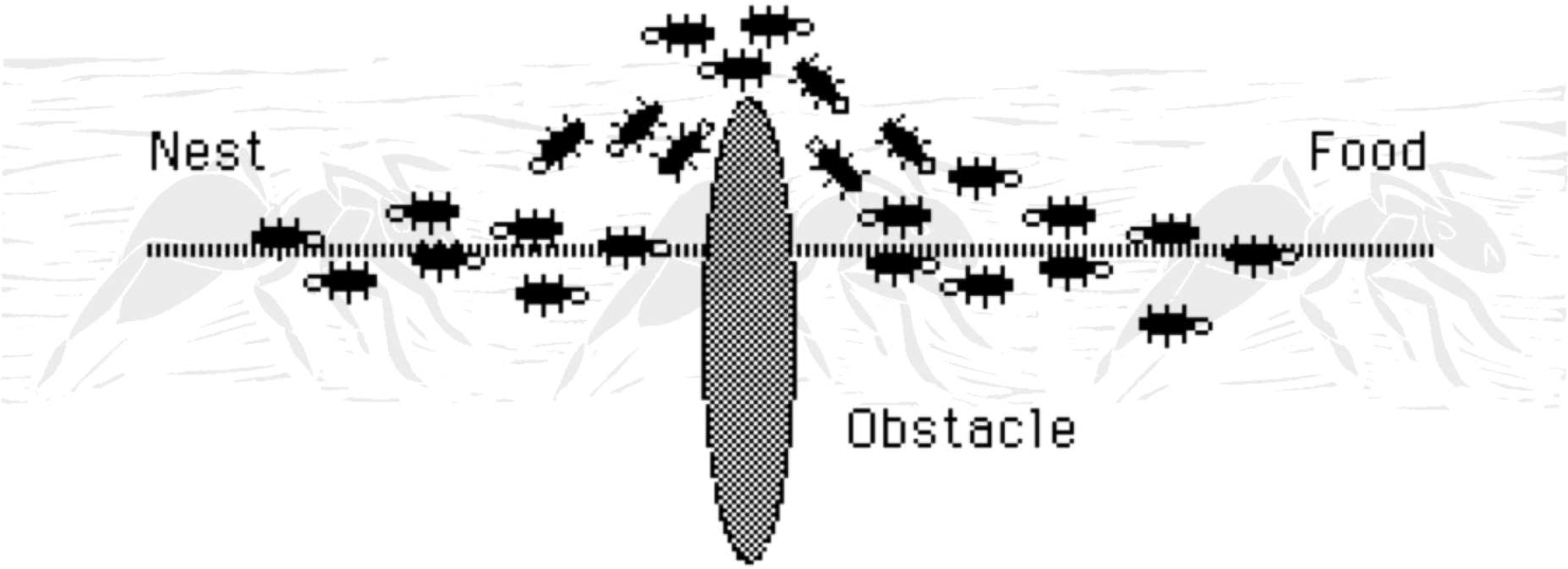
Oh no! An obstacle has blocked our path!

Naturally Observed Ant Behavior



Where do we go? Everybody, flip a coin.

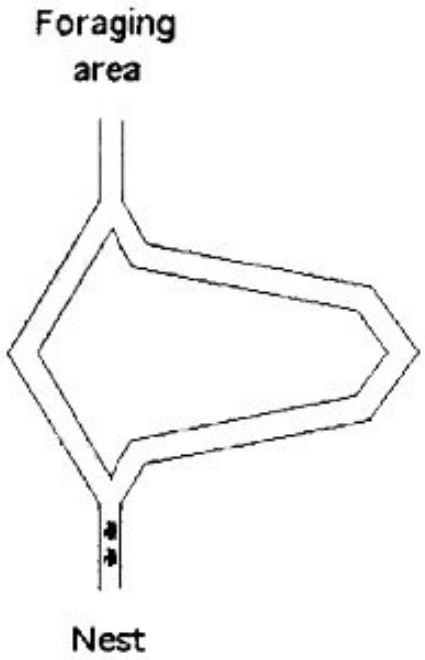
Naturally Observed Ant Behavior

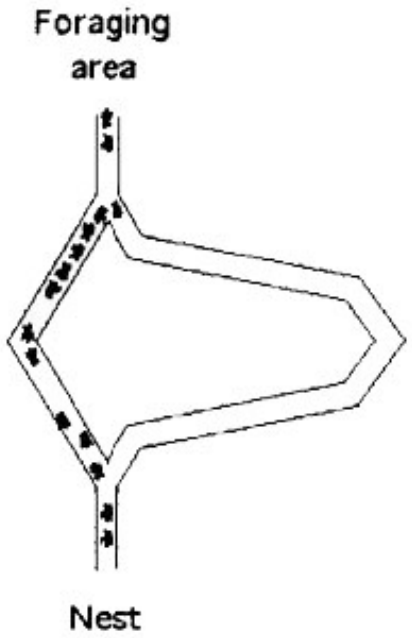


Shorter path reinforced.

Deneubourg Bridge Experiment

Initially, ants choose either path with equal probability

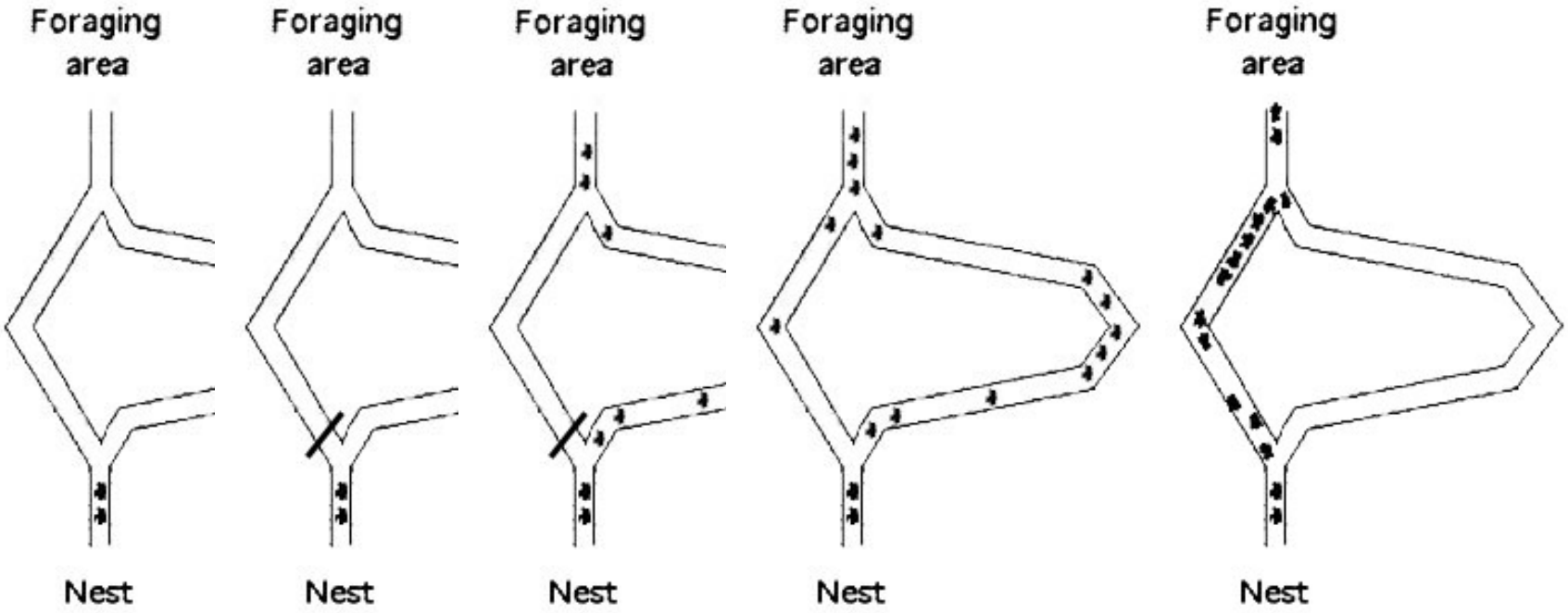




Eventually, all ants take the shorter path: pheromones have less time to evaporate!

Deneubourg Bridge Experiment

Highly adaptable to changes in the environment



Finally: Swarm Intelligence

Swarm intelligence:

"Any attempt to design algorithms or distributed problem-solving devices **inspired** by the collective behavior of **social insect colonies** and other animal societies"

Bonabeau E., M. Dorigo & G. Theraulaz, *Swarm Intelligence: From Natural to Artificial Systems*, Oxford University Press, 1999, page 7.