CO3091 - Computational Intelligence and Software Engineering

Lecture 15

Image from: http://www.undet.com/wp-content/uploads/2014/03/ants-carrying-leaves2.jpg

Ant Colony Optimisation

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Overview

- Why are ants interesting for computer scientists?
- How can we improve on ants to produce better algorithms?
- What kinds of problems can be solved?

Stigmergy

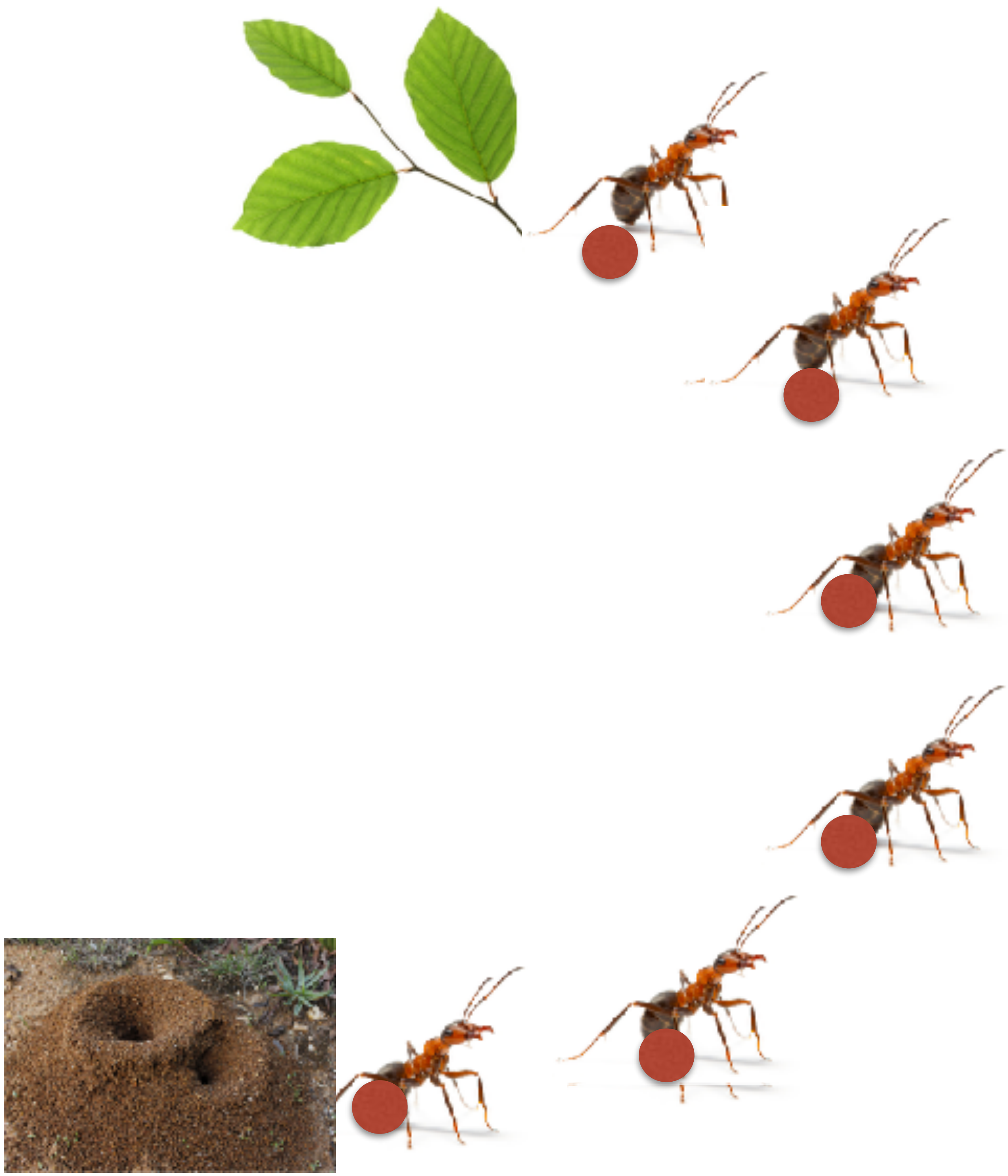
Stigmergy: communication by modifying the environment.

- Principle:
  - The trace left in the environment by an action stimulates the performance of a next action, by the same or a different individual.
- Effect:
  - Subsequent actions tend to reinforce and build on each other, leading to the spontaneous emergence of coherent, apparently systematic activity.

Example of Stigmergy

Image from: https://upload.wikimedia.org/wikipedia/commons/3/34/Safari_ants.jpg

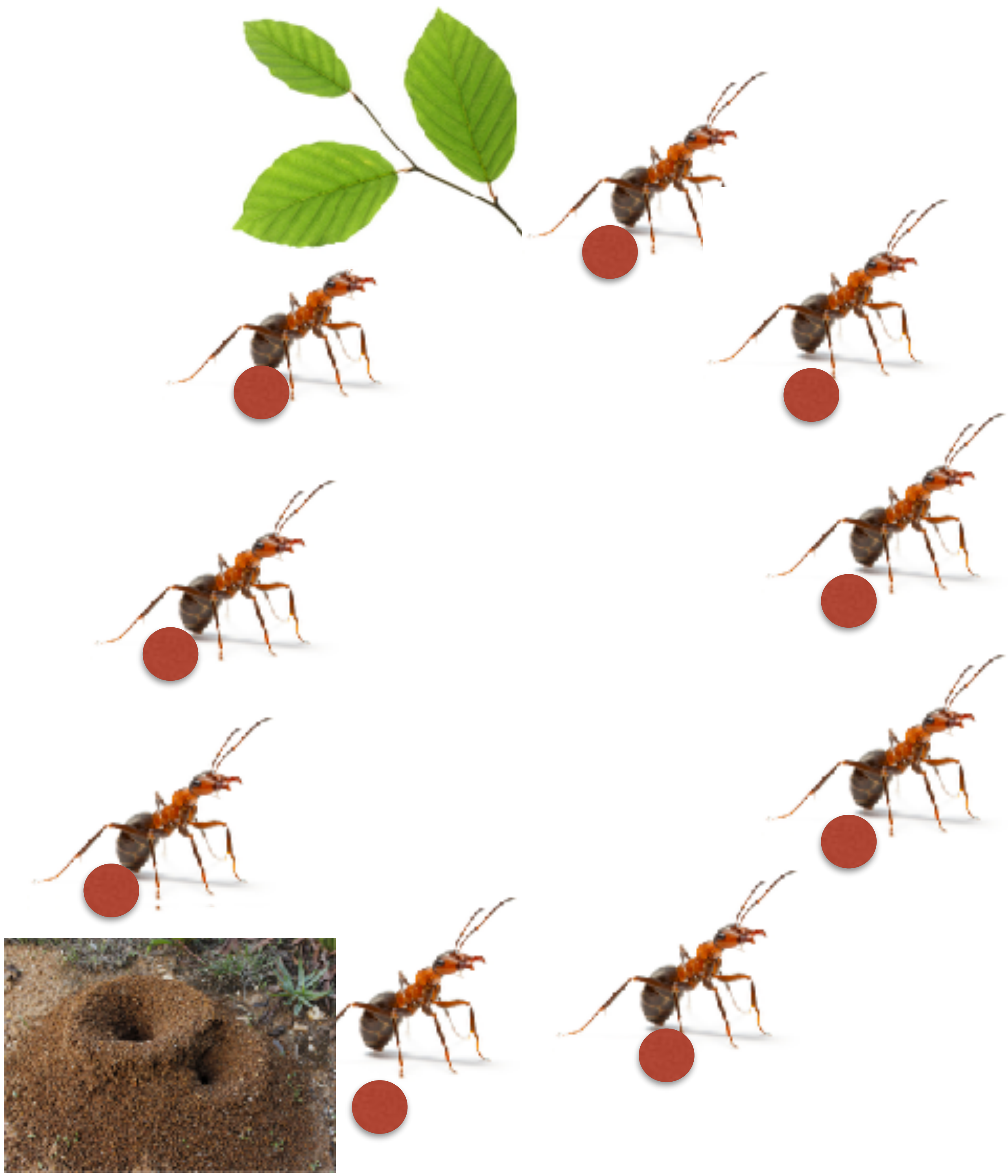
Ants Foraging



- Each ant tries to find a route between its nest and a food source.
- The behaviour of each ant is as follows:
  - Wander randomly at first, laying down a pheromone trail.
  - If food is found, return to the nest laying down a pheromone trail.
  - If pheromone is found, with some increased probability follow the pheromone trail.
  - Once back at the nest, go out again in search of food.
- Pheromones evaporate over time, such that unless they are reinforced by more ants, they will disappear.

Image from: http://www.2020site.org/trees/images/BeechLeaf_iStock_000013408445XSmall.jpg
Image from: http://www.peterandpaulspestcontrol.com.au/files/media/thumbcache/011/c11/60b/ant.jpg
Image from: https://homecheesemaker.files.wordpress.com/2013/08/ants-nest2.jpg

Ants Foraging



- Ants who took the shortest path will return to the nest earlier, causing that trail to contain more pheromone.
- A trail with more pheromone is more likely to be followed by ants.
- As this trail has more pheromone, ants are more likely to follow it, depositing even more pheromone in it.

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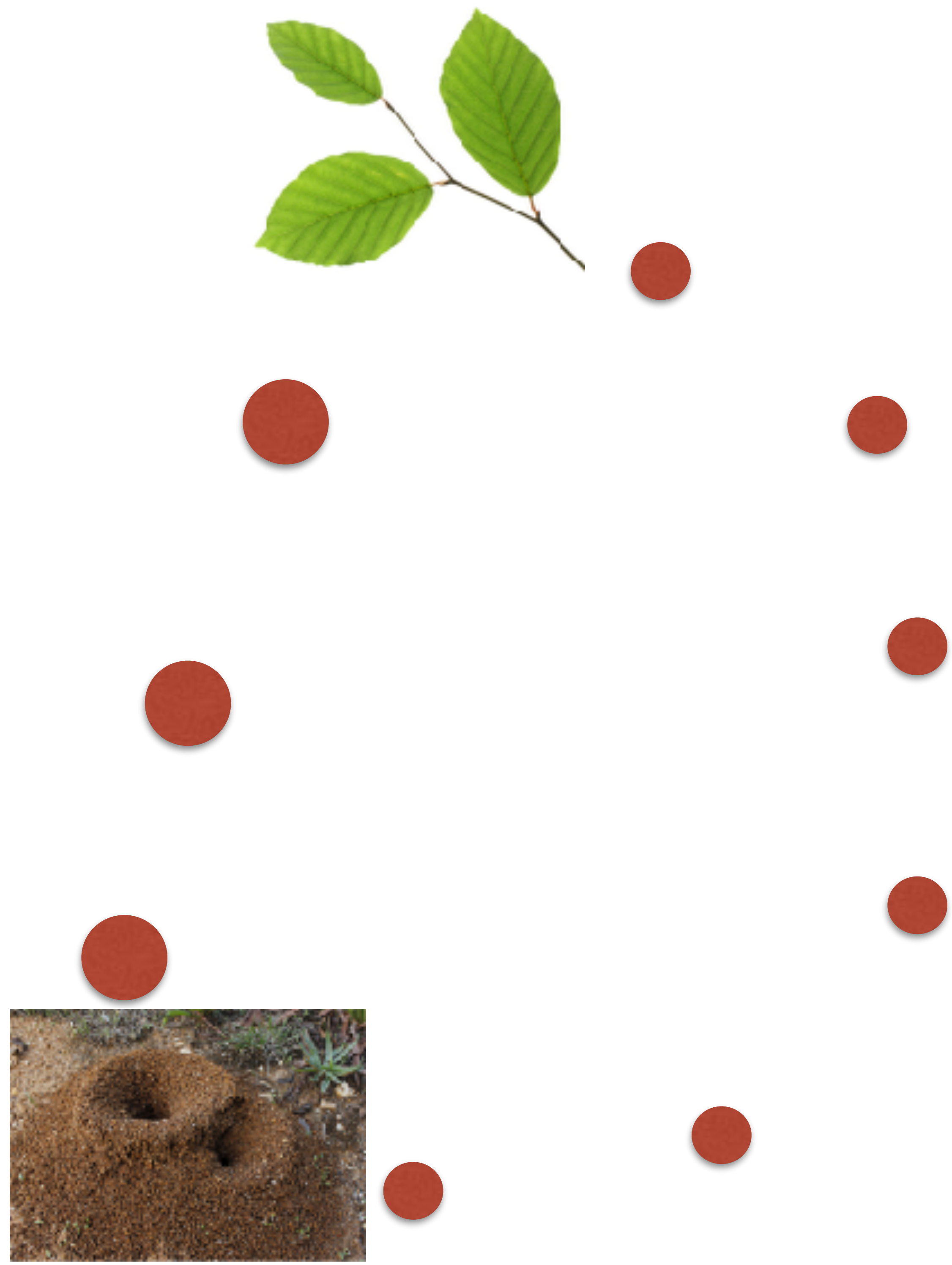
Ants Foraging



- Over time:
  - The shortest path becomes more and more likely to be followed.
  - Longer paths are less likely to be followed, and their pheromones evaporate.

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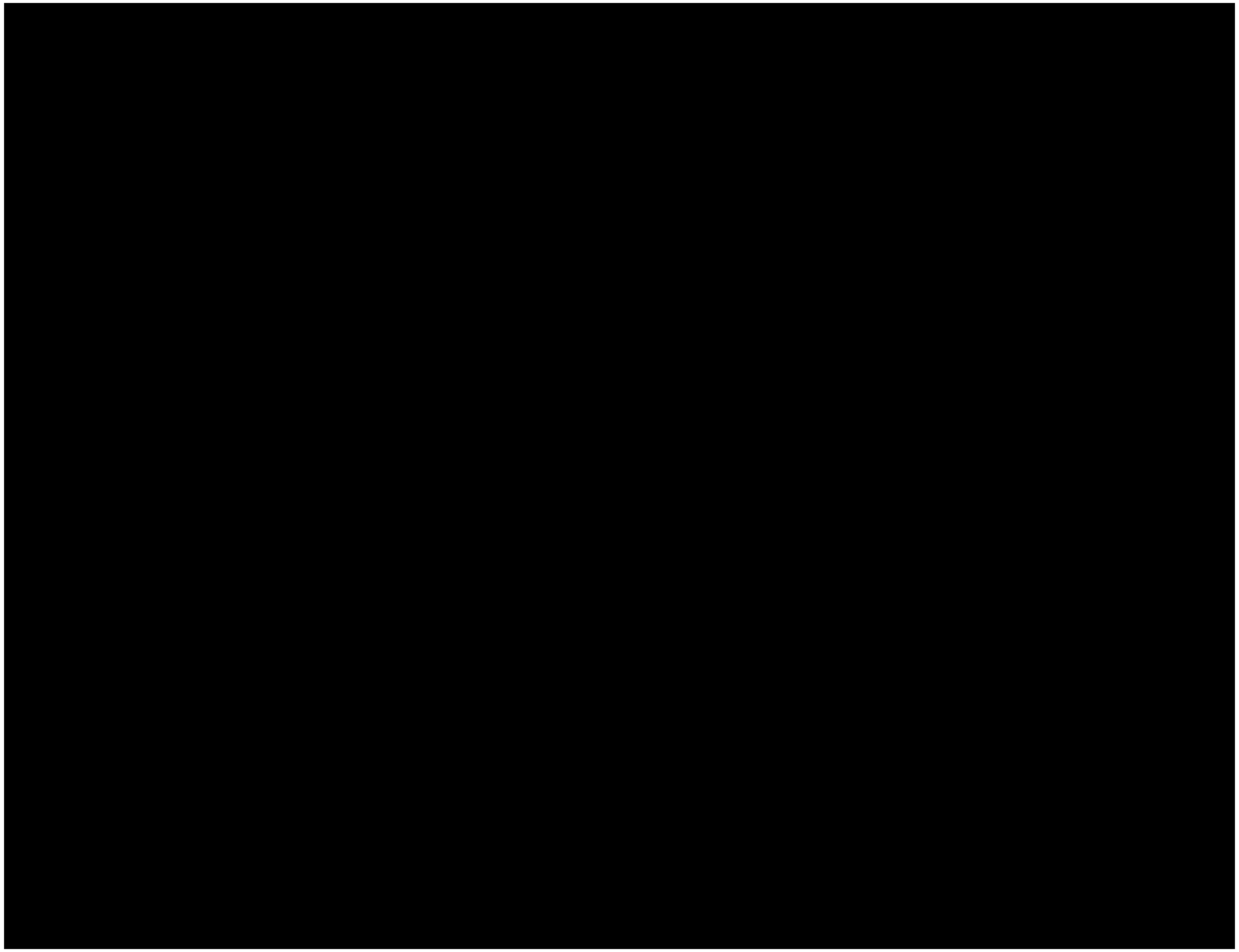
Image from: http://www.peterandpaulspestcontrol.com.au/files/media/thumbcache/011/c11/60b/ant.jpg
Image from: https://homecheesemaker.files.wordpress.com/2013/08/ants-nest2.jpg



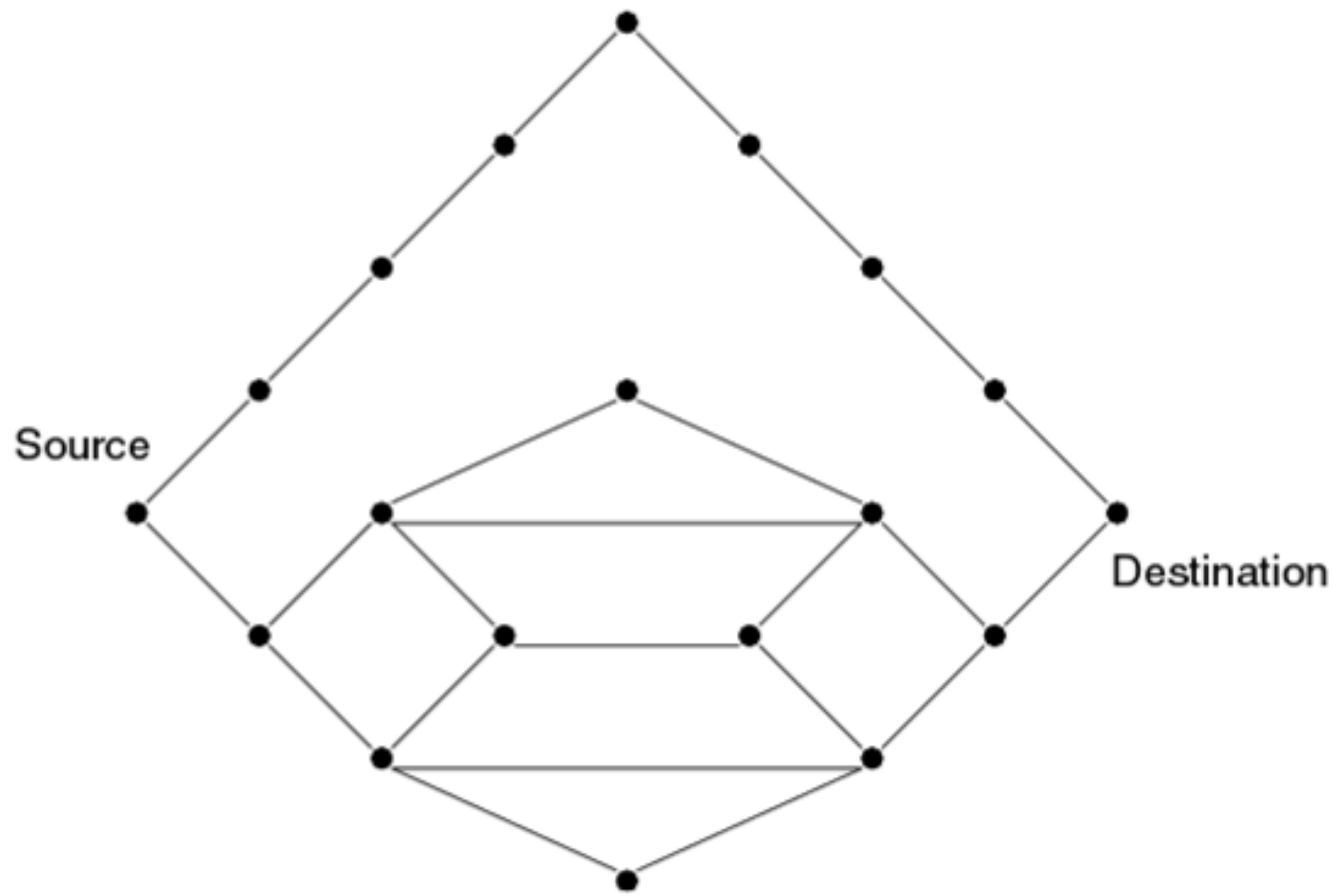
[YouTube video posted by Sandeep Kumar: https://youtu.be/3oCQ2DWAp4c]

Ant Colony Optimisation

- Technique inspired on ants for solving optimisation problems which can be expressed as finding good paths through graphs, e.g., travelling salesman problem.

Nature	Computer Science
Natural habitat	Graph
Nest and food	Nodes in graph: start and destination
Ants	Artificial ants (individuals)
Pheromones	Artificial pheromones τ (numbers on edges)
Foraging behaviour	Random walk through the graph (guided by pheromones)

Example



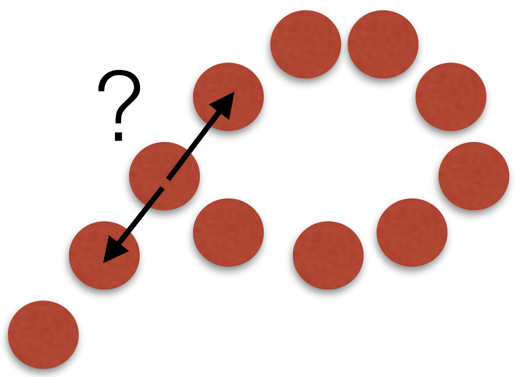
From: Dorigo's book M, Stutzle T. Ant Colony Optimization. The MIT Press; 2004

Inspiration ≠ Simulation

- ACO does not simulate real ants.
- Why?
  - Ants can get stuck in cycles!

[YouTube video posted by Milton Segura: https://youtu.be/mA37cb10WMU]

Why Ants Can Get Stuck In Cycles?



How Can We Solve This Problem?

Solution: use smarter ants!

- **Searching for food source:**
  - Ants search for destination without depositing pheromones.
  - Ants memorise the path they have traveled.
  - After reaching the destination they eliminate loops from their trail.
- **Return to nest:**
  - Walk back on trail and deposit pheromones.
  - Amount of added pheromone: inverse of path length (without loops).
- **Kill ants if they take too long.**

Scheme of Ant Colony Optimisation

Ant Colony Optimisation

Place a bit of pheromone on all edges.

Repeat:

1. Construct ant solutions (search for destination).
2. Update pheromones (evaporate pheromones and return to nest adding new pheromones).

Scheme of Ant Colony Optimisation

Ant Colony Optimisation

Place a bit of pheromone on all edges.

Repeat:

1. **Construct ant solutions.**
2. Update pheromones.

Construct Ant Solutions

- Leave nest and explore (memorising the path) until food source found.
- Choose next edge probabilistically according to amount of pheromone $\tau(e)$:

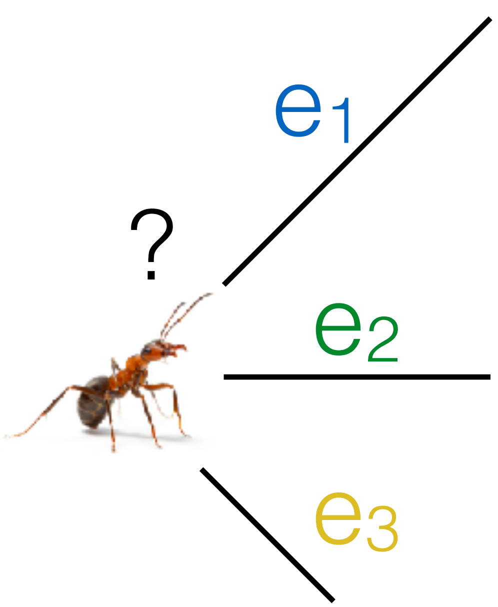
$$\uparrow \text{Prob(choosing edge } e\text{)} = \frac{\uparrow \tau(e)}{\sum_{available\ edges\ e'} \tau(e')}$$

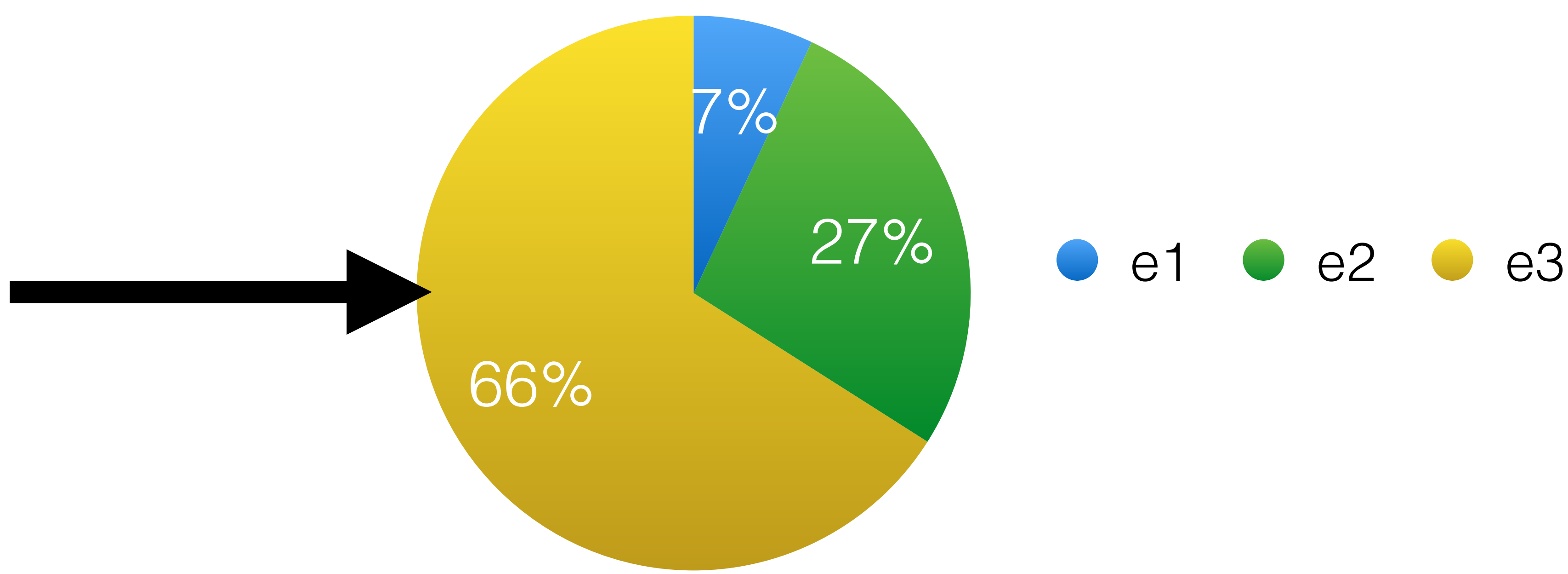
Construct Ant Solutions — Choosing an Edge

- This is similar to the roulette wheel parents selection in genetic algorithms.
  - Instead of selecting an individual using a probability proportional to the fitness,
  - we choose an edge based on a probability proportional to the amount of pheromone.

Construct Ant Solutions — Choosing an Edge

Edge	Pheromone	Probability
e1	1	1/15 = 0.07
e2	4	4/15 = 0.27
e3	10	10/15 = 0.66
Sum (Σ):	15	





Construct Ant Solutions — Eliminating Loops

- Once the food source is found, eliminate any loops from the path.

Scheme of Ant Colony Optimisation

Ant Colony Optimisation

Place a bit of pheromone on all edges.

Repeat:

1. Construct ant solutions.
2. **Update pheromones.**

Pheromone Update Rule

$$\tau(e) := \begin{cases} (1-\rho)\cdot\tau(e) & \text{if edge is not traversed} \\ (1-\rho)\cdot\tau(e) + \boxed{\text{new pheromone}} & \text{if edge is traversed} \end{cases}$$

total amount of new pheromone
e.g.: each ant would deposit an amount of pheromone inverse to its path length (without loops)

Where:

$\rho,\ 0 \leq \rho \leq 1$ is the evaporation rate

$\tau(e)$ is the amount of pheromone in edge e

Pheromone Update Rule

Evaporation

$$\tau(e) := \begin{cases} (1-\rho)\cdot\tau(e) & \text{if edge is not traversed} \\ (1-\rho)\cdot\tau(e) + \text{new pheromone} & \text{if edge is traversed} \end{cases}$$

Where:

$\rho,\ 0 \le \rho \le 1$ is the evaporation rate

$\tau(e)$ is the amount of pheromone in edge e

Exercise

- Consider three different values for ρ: 0, 0.1, 0.5 and 1.
- Consider that an edge *e* has not been traversed and has the following amount of pheromone: $\tau(e) = 1$.
- Calculate the new value for $\tau(e)$ after applying the pheromone update rule.

The Impact of ρ

What happens to the amount of pheromone with higher ρ?

higher ρ —> faster evaporation

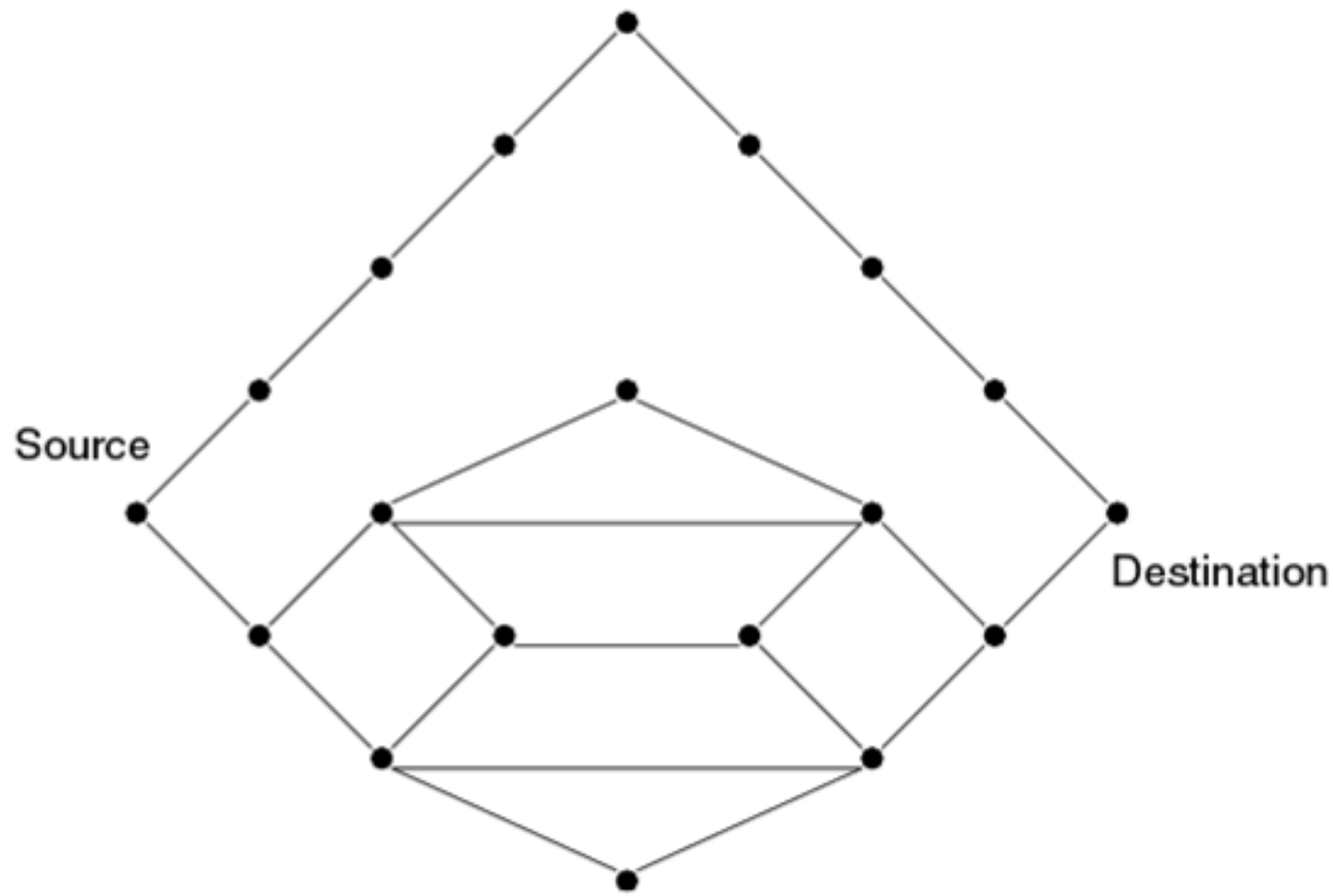
$\rho=1$, evaporates completely

What happens to the amount of pheromone with smaller ρ?

lower ρ —> slower evaporation

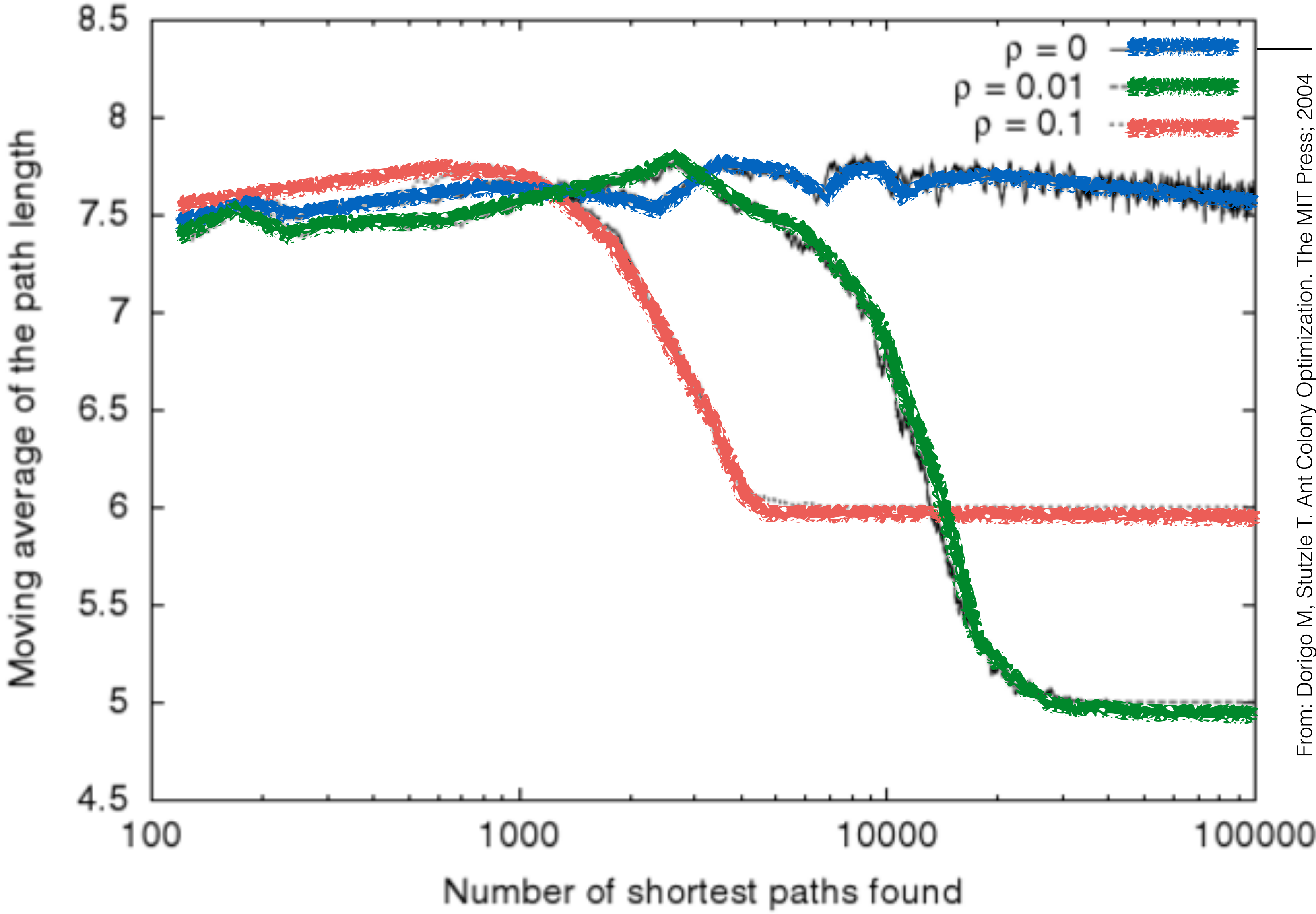
$\rho=0$, no evaporation

Example



From: Dorigo M, Stutzle T. Ant Colony Optimization. The MIT Press; 2004

Example



—> no evaporation

From: Dorigo M, Stutzle T. Ant Colony Optimization. The MIT Press; 2004

higher ρ —> faster evaporation —> faster adaptation
lower ρ —> slower evaporation —> slower adaptation

Pheromone Update Rule

$$\tau(e) := \begin{cases} (1-\rho)\cdot\tau(e) & \text{if edge is not traversed} \\ (1-\rho)\cdot\tau(e) + \boxed{\text{new pheromone}} & \text{if edge is traversed} \end{cases}$$

total amount of new pheromone
e.g.: each ant would deposit an amount of pheromone inverse to its path length (without loops)

Where:

$\rho,\ 0 \leq \rho \leq 1$ is the evaporation rate

$\tau(e)$ is the amount of pheromone in edge e

Exercise

- Consider $\rho = 0.01$.
- Consider that an edge *e* has been traversed by an ant whose path has length 4.
- Edge *e* currently has the following amount of pheromone: $\tau(e) = 1$.
- Calculate the new value for $\tau(e)$ after applying the pheromone update rule.

[Demo]

Applications

- Applicable to various problems where decisions on paths can be mapped to decisions for constructing problem solutions. Examples:
    - Routing problems (e.g., traveling salesman problem).
    - Assignment and scheduling problems (e. g. project scheduling problem).
    - Subset problems (e.g., lorry problem).
    - Etc.
- Ants are adaptive — potentially useful for dynamic environments.
    - Evaporation rate plays again a key role. It may need to be increased after a change in the environment.

Further Reading

Dorigo M., Stutzle T.

Chapters 1.

In: Ant Colony Optimization. The MIT Press; 2004.

http://site.ebrary.com/lib/leicester/detail.action?docID=10229602