Swarm Intelligence
Ant Colony Optimization

Based on slides by Thomas Bäck, which were based on:
Marco Dorigo and Thomas Stützle: Ant Colony Optimization. MIT Press, Cambridge, MA, 2004.

Examples of Collective Intelligence in Nature

Termite hill

Nest of wasps

Bee attack

Flocking birds

Swarm Intelligence

- Originated from the study of colonies, or swarms of social organisms
- Collective intelligence arises from interactions among individuals having simple behavioral intelligence
- Each individual in a swarm behaves in a distributed way with a certain information exchange protocol

Communication

- **Point-to-point**: information between individuals or between an object and an individual is directly transferred
  - direct visual contact, antennation, trophallaxis (food or liquid exchange), chemical contact, …
- **Broadcast-like**: the signal propagates to some limited extent throughout the environment and/or is made available for a rather short time
  - generic visual detection, use of lateral line in fishes to detect water waves, actual radio broadcast
- **Indirect (stigmergy)**: two individuals interact indirectly when one of them modifies the environment and the other responds to the new environment at a later time
  - pheromone laying/following, post-it, web

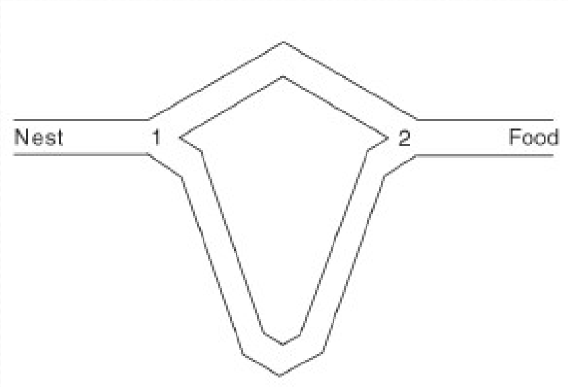
Ant Colony Optimisation

What is special about ants?

- Ants can perform complex tasks:
  - nest building, food storage
  - garbage collection, war
  - ***foraging*** *(to wander in search of food)*
- There is no management in an ant colony
  - collective intelligence
- They communicate using ***pheromones*** *(chemical substances)*, sound, touch

Double Bridge Experiments

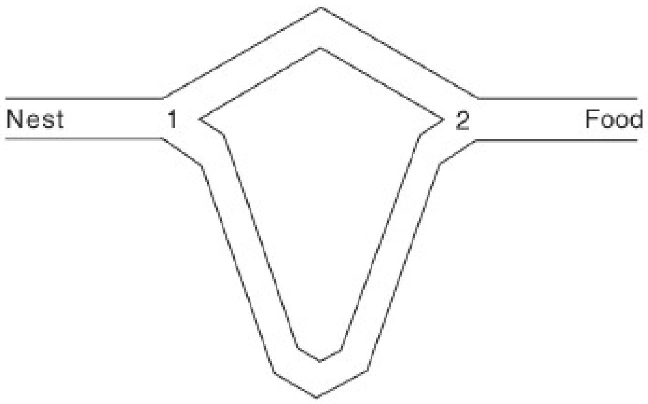
- A study on the pheromone trail-laying and –following behavior of Argentine ants
- A double bridge connects a nest of ants and a food source
- The ratio $r = L_{long} / L_{short}$ between the length of the two branches of the double bridge is varied
- Ants are free to move between the nest and the food

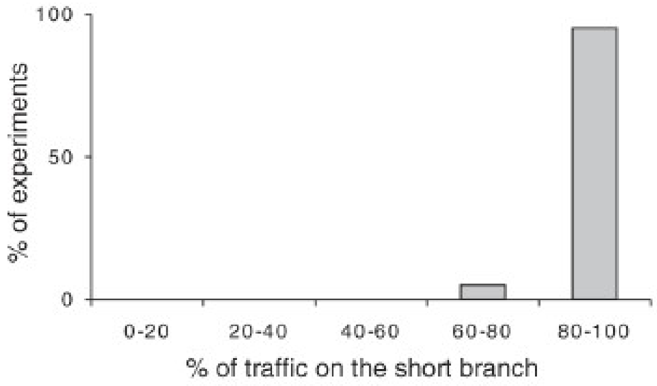


J.L. Deneubourg, S. Aron, S. Goss and J.M. Pasteels (1990). The self-organizing exploratory pattern of the Argentine ant. Journal of Insect Behaviour, 3, 159-168.

S. Goss, S. Aron, J.L. Deneubourg and J.M. Pasteels (1989). Self-organized shortcuts of the Argentine ant. Naturwissenschaften, 76, 579-581

Double Bridge Experiments





- In most of the trials, almost all the ants select the short branch (exploitation)
- Not all ants use the short branch, but a small percentage may take the longer one (exploration)

Foraging Behavior of Argentine Ants

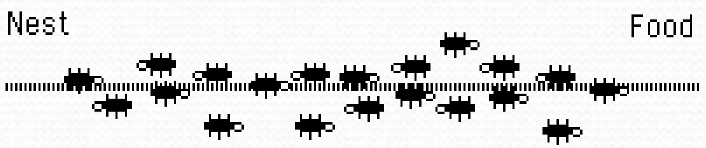
- Ants initially explore the area surrounding their nest randomly
- Argentinian ants deposit pheromones everywhere they go
- When choosing their way, ants prefer to follow strong pheromone concentrations
- Pheromones defuse over time

Foraging Behavior of Argentine Ants

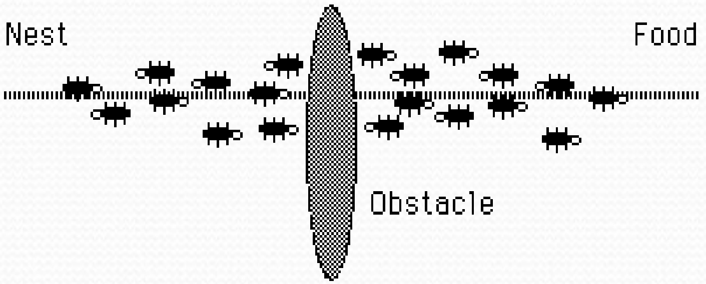
- How do Argentine ants find the shortest path?
  - The ants that take the shortest path arrive at the food source first
  - They return over the path that they took to get there, reinforcing the pheromones they deposited when going to the food source
  - Other ants notice the trail and follow it, reinforcing it further
- Hence, during the “start” of the experiment the advantage that ants on the shortest path had is reinforced

Alternative experiment

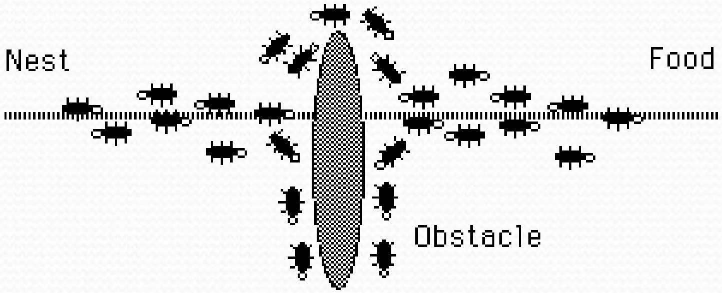
- An obstacle is put in the path of ants



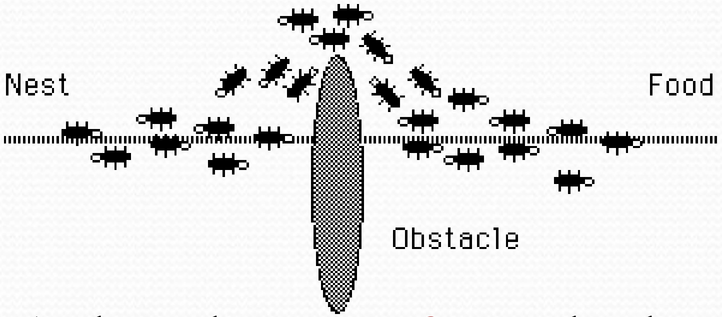
a) - Ants **follow path** between the Nest and the Food Source



b) - Ants go around the obstacle following one of two different paths with **equal probability**



c) Ants on the shortest path arrives at the food source first; on the way back they will follow the phero-mones on the shortest path again



d) – At the end, **all ants follow** the shortest path.

Simple Ant Colony Optimisation: Shortest Paths

- Artificial ants going “forward”
  - choose probabilistically the next node on their path, exploiting pheromones
  - do not drop pheromones
  - memorize the path they take
- Artificial ants going “backward”
  - deterministically follow the path they took earlier
  - drop pheromones proportionally to the quality of the path taken earlier

Simple ACO: Shortest Paths

```
initialize pheromones
for each iteration do
    for k = 1 to number of ants do
        set out ant k at start node
        while ant k has not build a solution do
            choose the next node of the path
        end while
    end for
    update pheromones
end for
return best solution found
```

Simple ACO: Shortest Paths

- For an ant located at node v_i the probability p_{ij} of choosing v_j as the next node is:

$$p_{ij}^k = \begin{cases} \frac{(\tau_{ij})^\alpha}{\sum_{m \in N_i^k} (\tau_{im})^\alpha} & \text{if } j \in N_i^k \\ 0 & \text{if } j \notin N_i^k \end{cases}$$

where

- τ_{ij} is the amount of pheromones on edge $i \rightarrow j$
- N_i^k is the set of neighbors of node i not visited by ant k yet (tabu list)

Simple ACO: Shortest Paths

- Change in pheromone for an ant k on edge i → j

$$\Delta\tau_{ij}^{k} = \begin{cases} Q/L_k & \text{if } (i,j) \in T_k \\ 0 & \text{otherwise} \end{cases}$$

where:

- Q : a heuristic parameter
- T_k : the path traversed by ant k
- L_k : the length of T_k calculated as the sum of all lengths of edges in T_k

Simple ACO: Shortest Paths

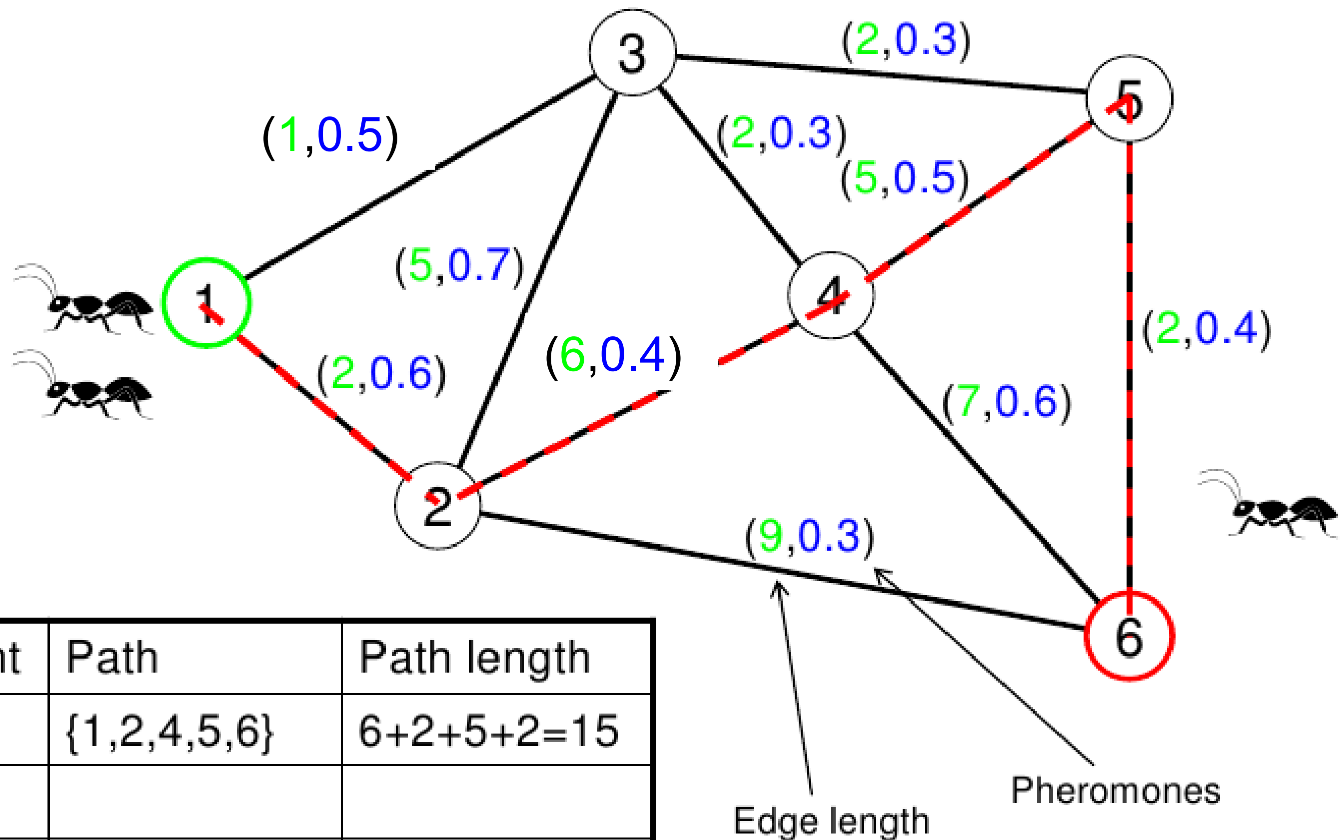
- Pheromone update on an edge i → j

$$\tau_{ij} = (1-\rho)\tau_{ij} + \sum_{k=0}^{m} \Delta\tau_{ij}^{k}$$

with

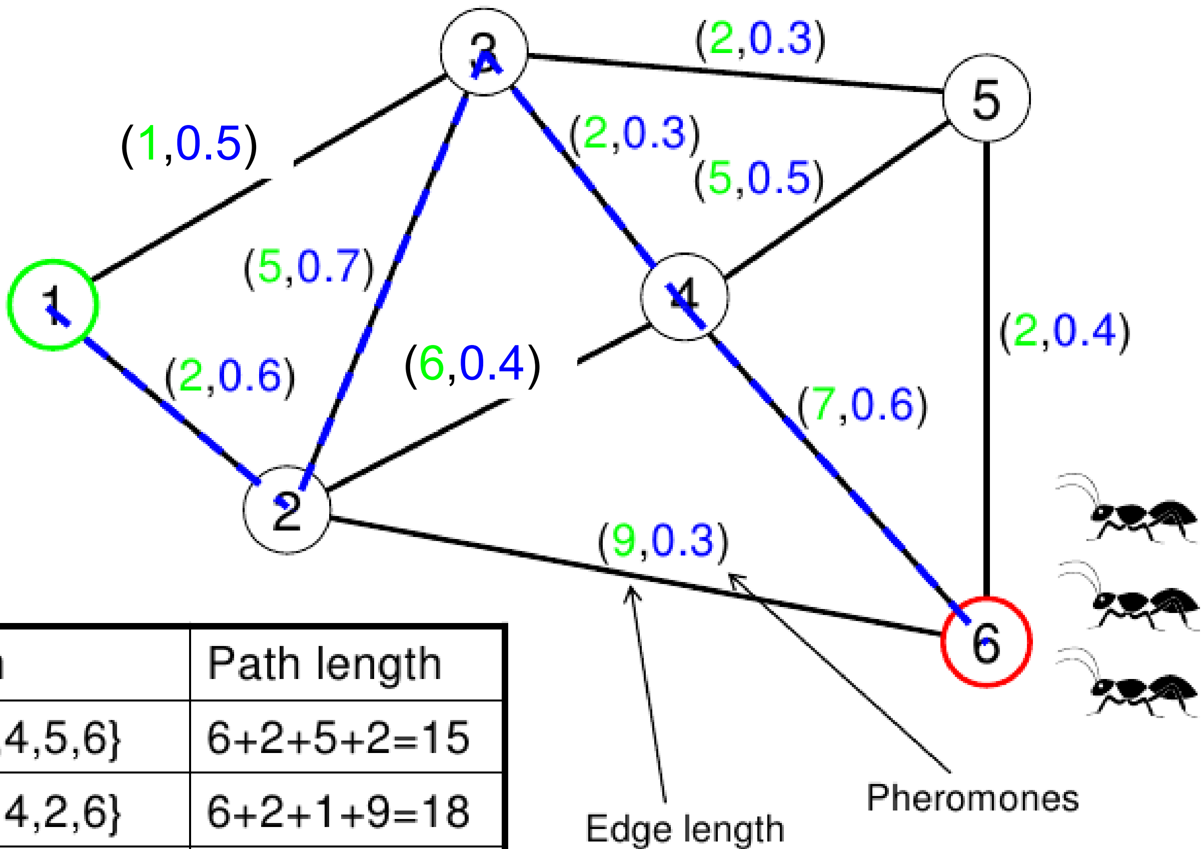
- ρ : the evaporation rate of the old pheromone

Simple ACO: Shortest Paths



Ant	Path	Path length
1	{1,2,4,5,6}	6+2+5+2=15
2		
3		

Simple ACO: Shortest Paths



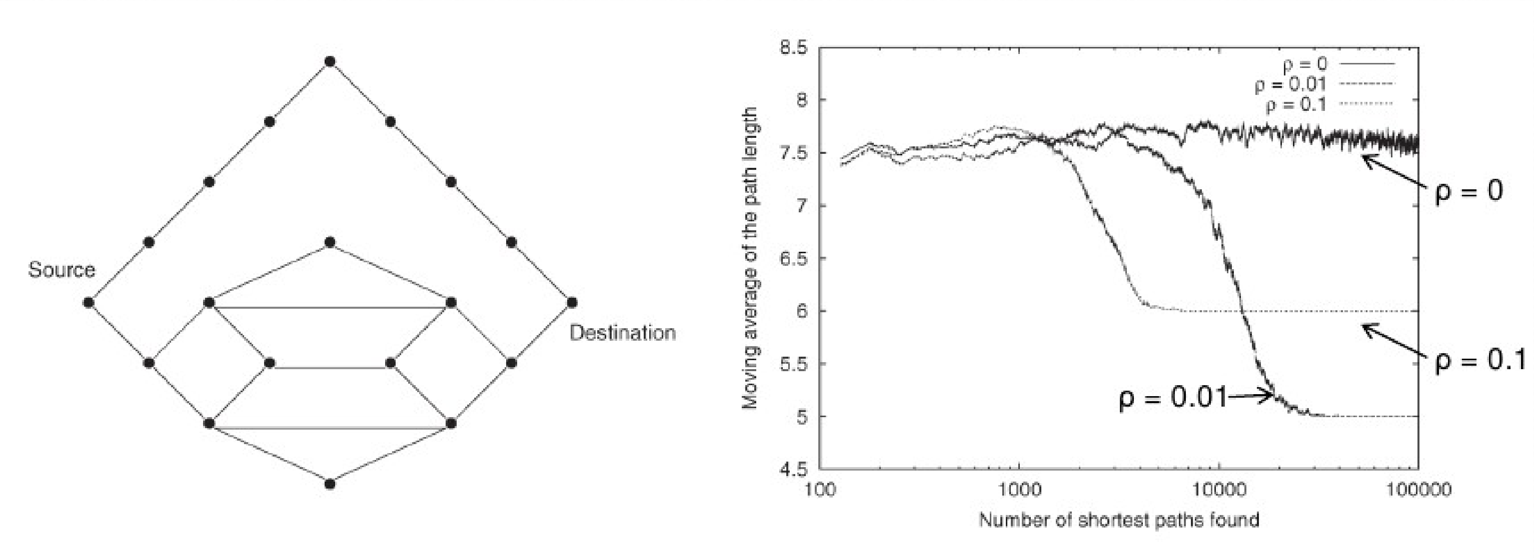
Ant	Path	Path length
1	{1,2,4,5,6}	6+2+5+2=15
2	{1,3,4,2,6}	6+2+1+9=18
3	{1,2,3,4,6}	2+5+2+7=16

Simple ACO: Shortest Paths

$Q = 1, \rho = 0.1$

	τ_{old}	$\Delta\tau_{ij}^1$	$\Delta\tau_{ij}^2$	$\Delta\tau_{ij}^3$	$\Delta\tau_{ij}$	τ_{new}
(1,2)	0.6	1/15	0	1/16	1/15 + 1/16 ≈ 0.129	0.6 * 0.9 + 0.129 = 0.669
(1,3)	0.5	0	1/18	0	1/18 ≈ 0.055	0.5 * 0.9 + 0.055 = 0.505
(2,3)	0.7	0	0	1/16	1/16 ≈ 0.063	0.7 * 0.9 + 0.063 = 0.693
(2,4)	0.4	1/15	1/18	0	1/15 + 1/18 ≈ 0.122	0.4 * 0.9 + 0.122 = 0.482
(2,6)	0.3	0	1/18	0	1/18 ≈ 0.055	0.3 * 0.9 + 0.055 = 0.325
(3,4)	0.3	0	1/18	1/16	1/18 + 1/16 ≈ 0.118	0.3 * 0.9 + 0.118 = 0.388
(3,5)	0.3	0	0	0	0	0.3 * 0.9 + 0 = 0.27
(4,5)	0.5	1/15	0	0	1/15 ≈ 0.067	0.5 * 0.9 + 0.067 = 0.517
(4,6)	0.6	0	0	1/16	1/16 ≈ 0.063	0.6 * 0.9 + 0.063 = 0.603
(5,6)	0.4	1/15	0	0	1/15 ≈ 0.067	0.4 * 0.9 + 0.067 = 0.427

Simple ACO: Shortest Paths



- Low ρ → low evaporation → slow convergence, “old” paths continue to be traversed instead of searching new ones
- High ρ → high evaporation → very fast convergence, but due to limited memory no drive to explore variations of a good path