Ant Colony Optimization

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Outline

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- Introduction to Ant Colony Optimization (ACO)
- Ant Behaviour
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- Pheromones
- Basic Algorithm
- Example
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- References

Swarm Intelligence

- Artificial intelligence technique based on the study of collective behavior in decentralized, self-organized systems
- Introduced by Beni & Wang in 1989
- **Collective system** capable of performing complex tasks in a dynamic environment
- Model suited to **distributed problem solving**
- Works without:
  - External guidance
  - Central coordination
- Typically made up of a population of **simple** agents

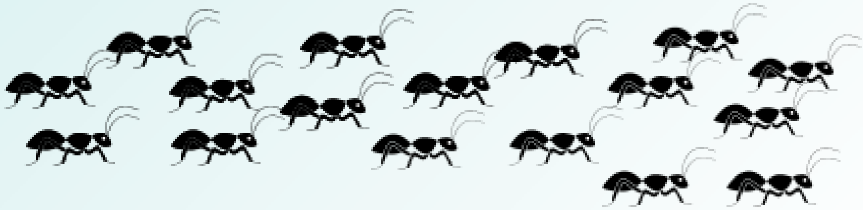
Swarm Intelligence

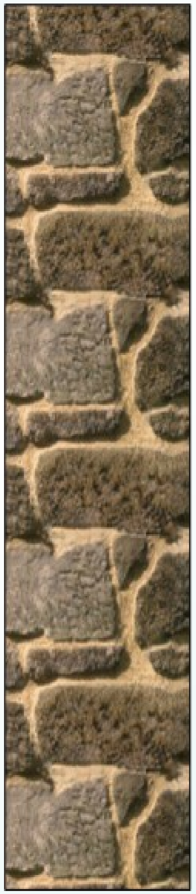
Ant Colony Optimization

- Proposed by **Marco Dorigo** in 1991
- Inspired in the behavior of real ants
- **Multi-agent approach** for solving complex combinatorial optimization problems
- Applications:
    - Traveling Salesman Problem
    - Scheduling
    - Network Model Problem
    - Vehicle routing

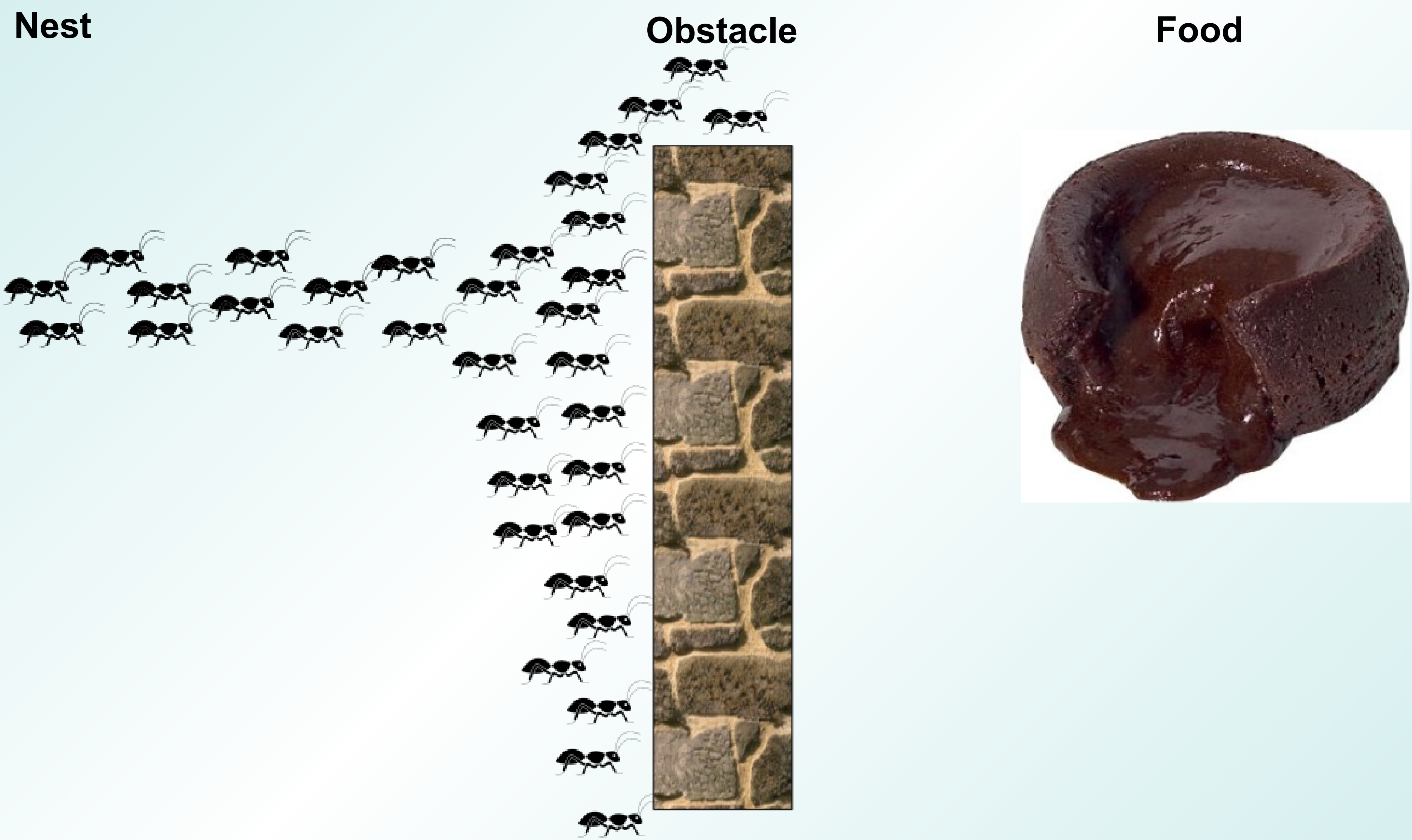
Ant Behavior

Nest **Obstacle** **Food**

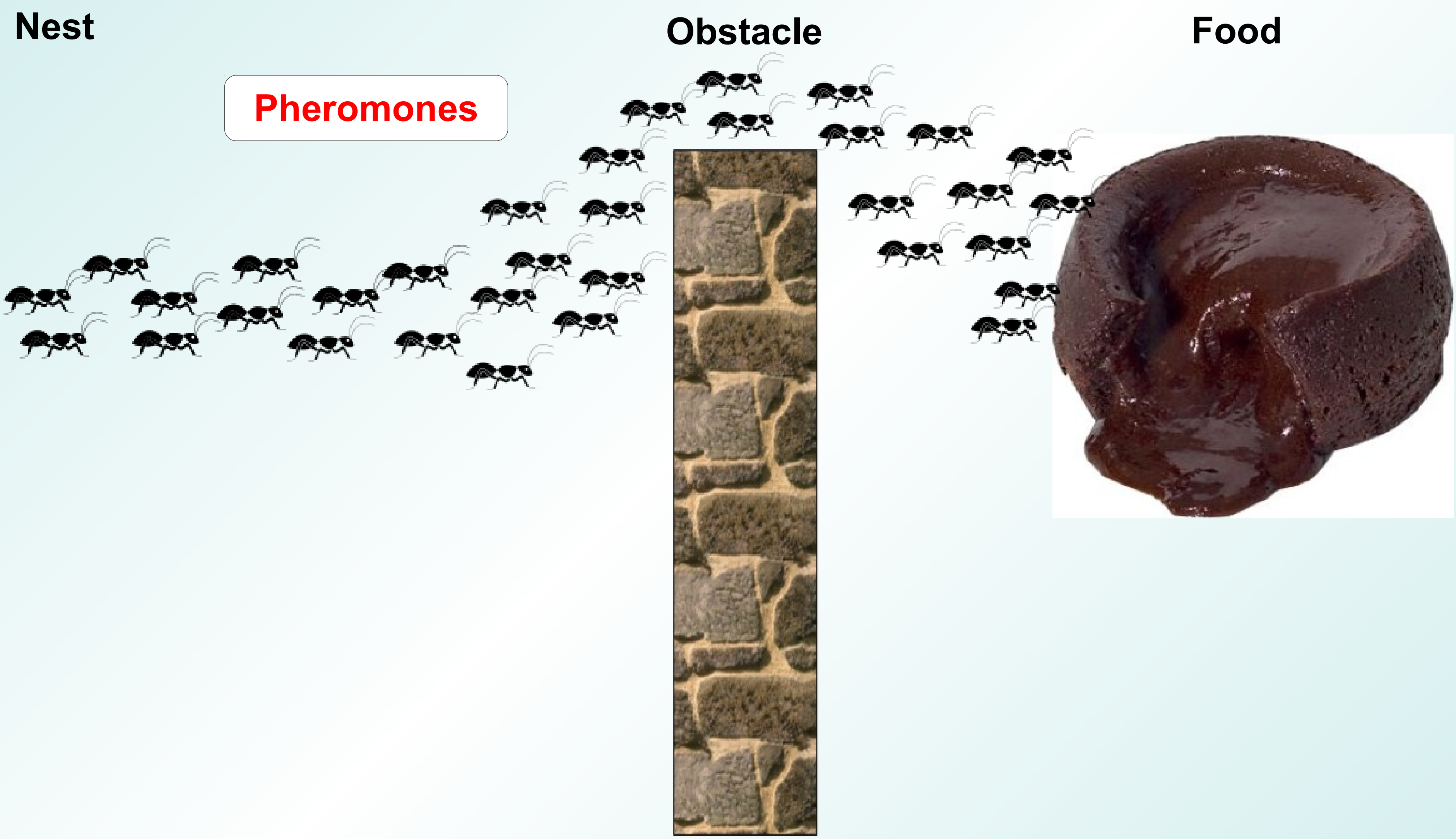




Ant Behavior

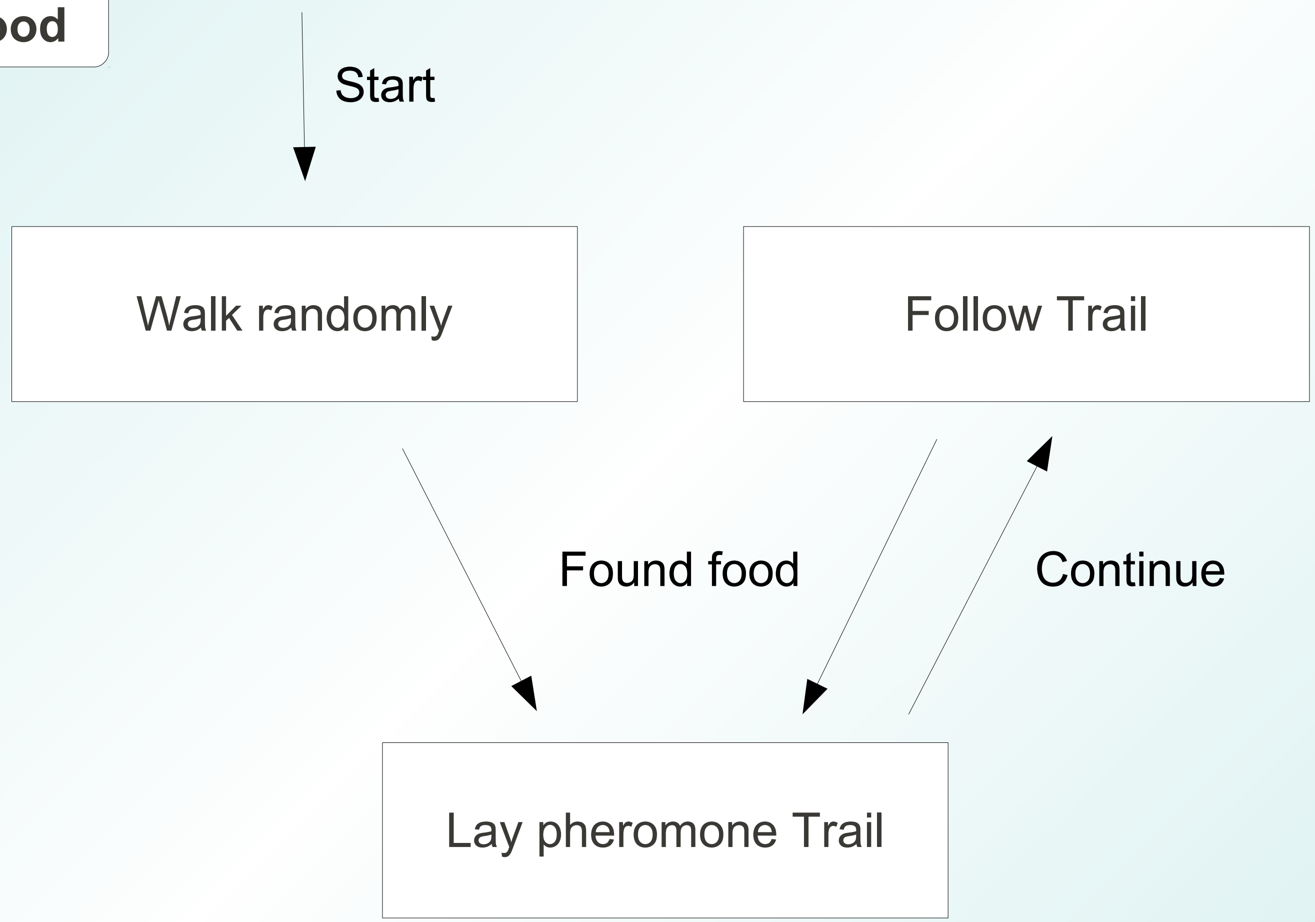


Ant Behavior



Ant Behavior

Quest for food



Ant Behavior

- Ant behavior is **stochastic**
- The behavior is induced by **indirect communication** (pheromone paths) - **Stigmergy**
- Ants explore the search space
- Limited ability to sense local environment
- Act **concurrently** and **independently**
- High quality solutions emerge via **global cooperation**

Stigmergy

- Term coined by French biologist Pierre-Paul Grasse, means interaction through the environment
- Indirect communication via **interaction with environment**
- Agents **respond to changes** in the environment
- Allows simpler agents
- Decreases direct communication

Pheromones

- Ants lay pheromone trails while traveling
- Pheromones **accumulate** with multiple ants using a path
- This behavior leads to the appearance of **shortest paths**

Pheromones = **long-term memory** of an ant colony

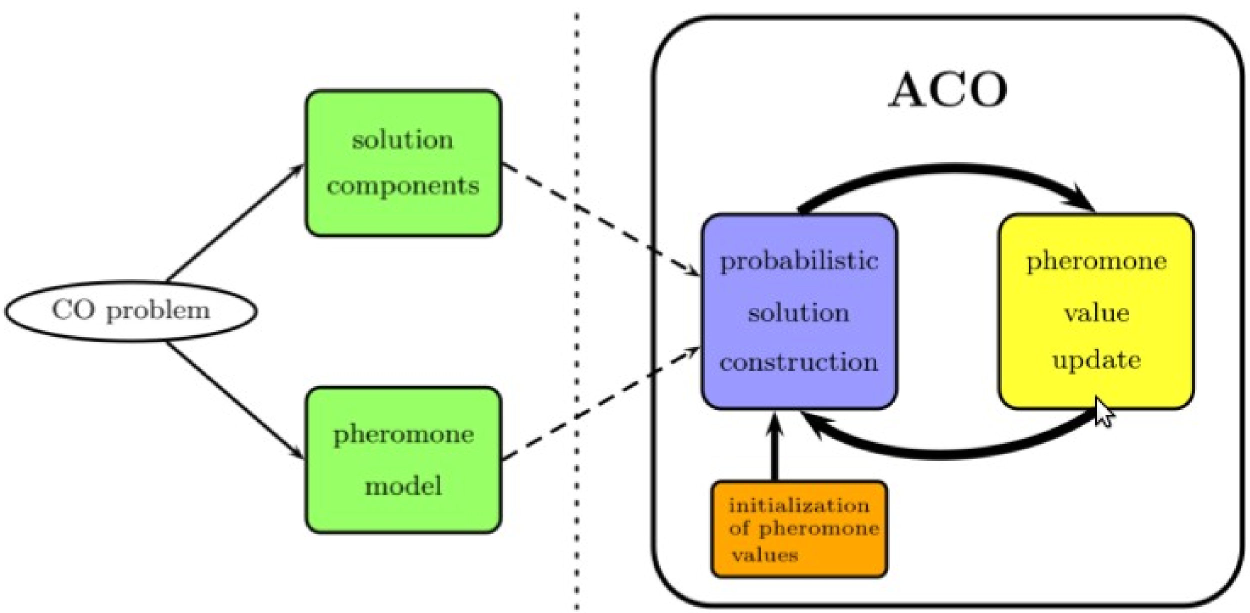
- Pheromones **evaporate**
  - **Avoids being trapped** in local optima

ρ small ⇒ low evaporation ⇒ **slow adaptation**

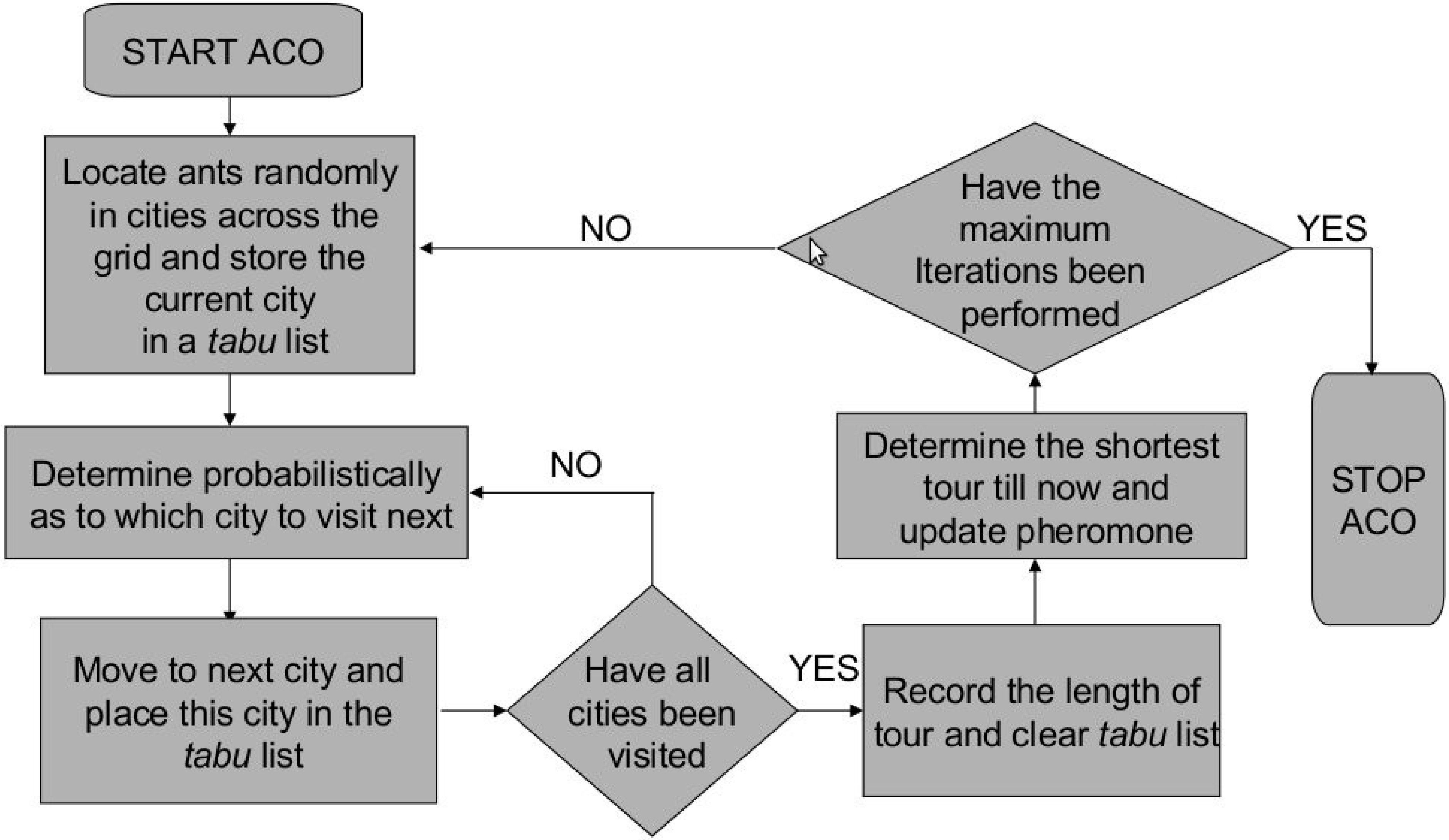
ρ large ⇒ high evaporation ⇒ **fast adaptation**

ACO Algorithm

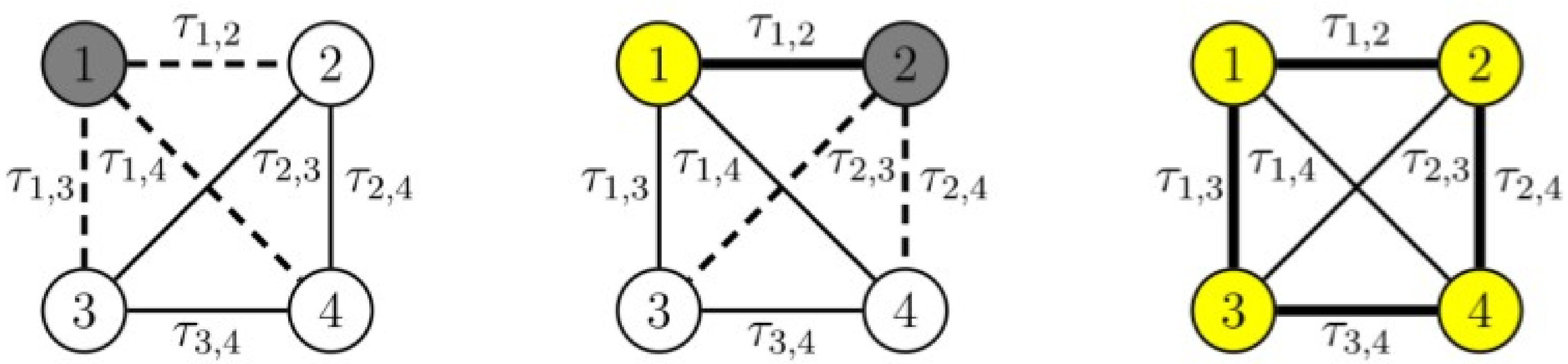
- **Construct solutions**
  - Explore the search space
  - Choose next step **probabilistically** according to the **pheromone model**
- Apply local search to constructed solutions (Optional)
- **Update pheromones** (add new + evaporate)



Example: TSP


START ACO
Locate ants randomly in cities across the grid and store the current city in a tabu list
Determine probabilistically as to which city to visit next
Move to next city and place this city in the tabu list
Have all cities been visited
NO
YES
Record the length of tour and clear tabu list
Determine the shortest tour till now and update pheromone
Have the maximum Iterations been performed
NO
YES
STOP ACO

Example: TSP



$$\mathbf{p}(e_{1,j}) = \frac{\tau_{1,j}}{\tau_{1,2} + \tau_{1,3} + \tau_{1,4}}$$

$$\mathbf{p}(e_{2,j}) = \frac{\tau_{2,j}}{\tau_{2,3} + \tau_{2,4}}$$

(a) First step of the solution construction.

(b) Second step of the solution construction.

(c) The complete solution after the final construction step.

Advantages and Disadvantages

- Advantages
  - Can be used in **dynamic** applications
  - **Positive Feedback** leads to rapid discovery of good solutions
  - **Distributed computation** avoids premature convergence
- Disadvantages
  - Convergence is **guaranteed**, but **time** to convergence **uncertain**
  - Coding is not straightforward

References

- Dorigo M., Blum C., *Ant colony optimization theory: A survey,* Theoretical Computer Science, Volume 344, Issues 2-3, November 2005
- Blum C., *Ant colony optimization: Introduction and recent trends*, Physics of Life Reviews, Volume 2, Issue 4, December 2005
- Dorigo M., Stutzle T., *Ant Colony Optimization*, Ant Colony Optimization, MIT Press 2004

AntPacking – An Ant Colony Optimization Approach for the One-Dimensional Bin Packing Problem

by B. Brugger, K. Doerner , R. Hartl and M. Reimann

Introduction

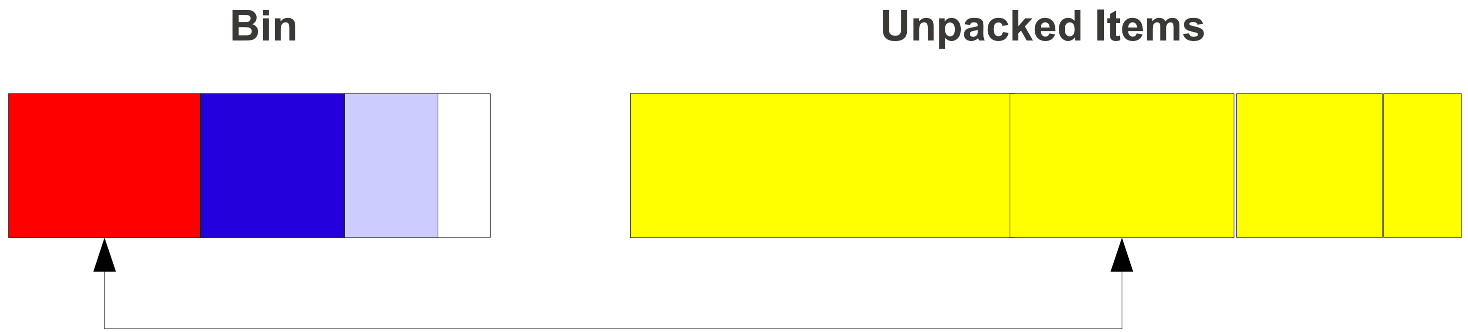
- Deals with the **one-dimensional** BPP
- Meta-heuristic solution approach based on Ant Colony Optimization
- A set of ants repeatedly build and improve solutions
- Ants update joint memory, **guiding** future searches
- Memory update is based on **solution quality**

Pheromone Decoding

- Items are grouped according to their **size**
- Relates the size of an item to be packed to the **filling degree** of the current bin
- They only consider how much **space is left** in the bin
- The importance of filling a bin is emphasized

Solution Construction and Local Search

- A ant fills bins until all items are packed
- The decision about which item to add is based on:
  - **FFD** rule
  - **Pheromone** information
- **Local search** is performed when a ant finishes filling a bin
  - Tries to replace **one bin item** with an **unpacked item** if this leads to **less free space**
  - Stops when the bin is full or no improving moves are available



Fitness Function and Pheromone Update

- The fitness function **guides** the search
- Fitness is calculated for each bin
- Only **full bins** receive pheromone
- **Each ant** is allowed to modify the memory (**pheromone update**)
- All the solution elements are subject to **evaporation**

Dataset and Preprocessing

- Benchmark instances properties:
  - bin capacity C = 150
  - item sizes bounded by [20, 100]
- Procedure was applied to **reduce the ants search effort**
- Eliminates mainly **large items**
- Problem size is **reduced** and consequently **easier to solve**

Computational Analysis

- Algorithm coded in **C** and executed on a Pentium 3, 750 MHz
- Number of ants fixed to **10**
- Time limit for termination of the algorithm set to **60 seconds**
- Computational test:
  - Benchmark comparison with **Hybrid Grouping Genetic Algorithm** (HGGA) and the **Hybrid ACO** (HACO)

Algorithm Comparison

Problem class	HACO		HGGA		AntPacking	
	# of optima	seconds	# of optima	seconds	# of optima	seconds
u120	20	1	20	0.31	20	0.04
u250	18	52	20	0.75	20	0.58
u500	20	50	20	1.5	20	1.11
u1000	20	147	20	3.78	20	3.88

Conclusion

- New pheromone decoding scheme and update strategy
- Results show **excellent performance**
- AntPacking approach performs **at least as good** as the HGGA which is considered to be the best algorithm for BPPs