Lecture 9

- ❖ **Ant Colony Optimization (ACO) Algorithm**
- ❖ **Solving TSP using ACO**

CENG 632- Computational Intelligence, 2024-2025, Spring

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Ant Colony Optimization

- Ant Colony Optimization (ACO) is a probabilistic and evolutionary technique that is used to solve combinatorial optimization problems.

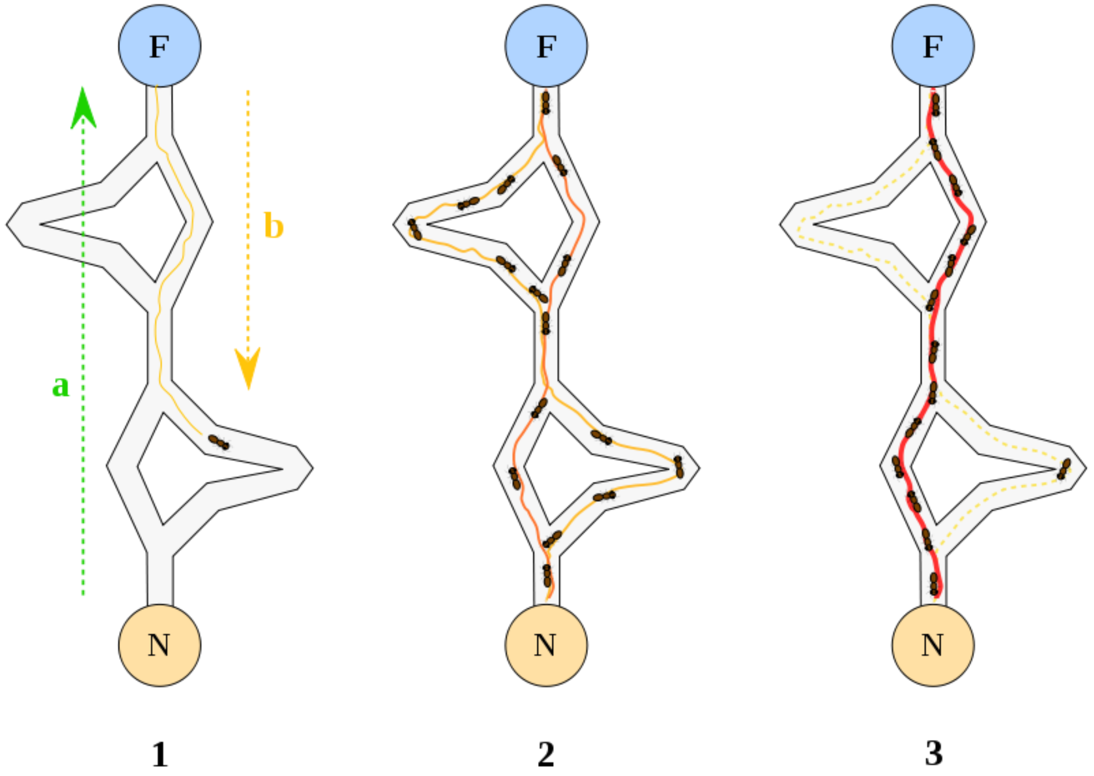
- Proposed by Marco Dorigo in 1992 in his PhD thesis

- Search for an optimal path in a graph, based on the behavior of ants.

- Initially proposed and tested for Travelling Salesman Problem.

How do Natural Ants Find Shortest Path to their Food?

- Initially move randomly.
- After finding food, return to their colony while laying down pheromone trail (stigmergy).
- If another ant finds such a path its movement is not completely random anymore, more likely to follow that path.
- Pheromone trail evopoorates over time.



ACO Metaheuristic

Set parameters, initialize pheromone trails

while termination condition not met **do**

ConstructAntSolutions

ApplyLocalSearch (optional)

UpdatePheromones

endwhile

ConstructAntSolutions Phase

- A set of $\boldsymbol{m}$ artificial ants construct solutions from elements of a finite set of available solution components **C**

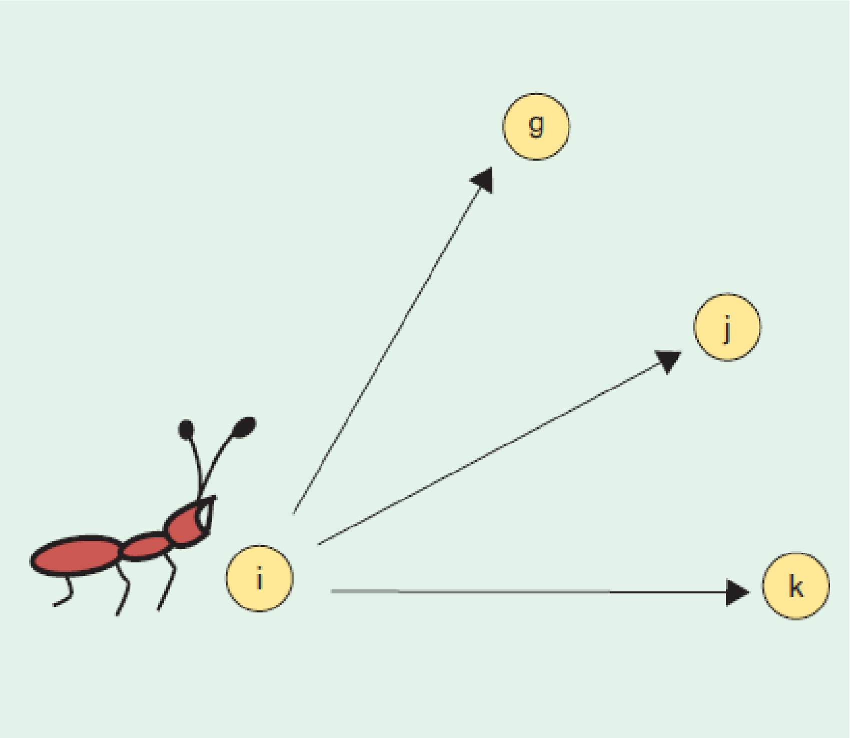
- Solution construction starts from an empty partial solution $\boldsymbol{S^P} = \emptyset$

- At each construction step, the partial solution S^P is extended by adding a feasible solution component $\boldsymbol{c_i^j} \in$ N$(S^P) \subseteq$ C without violating any of the constraints in $\boldsymbol{\Omega}$

ConstructAntSolutions Phase:
Solution Component Selection

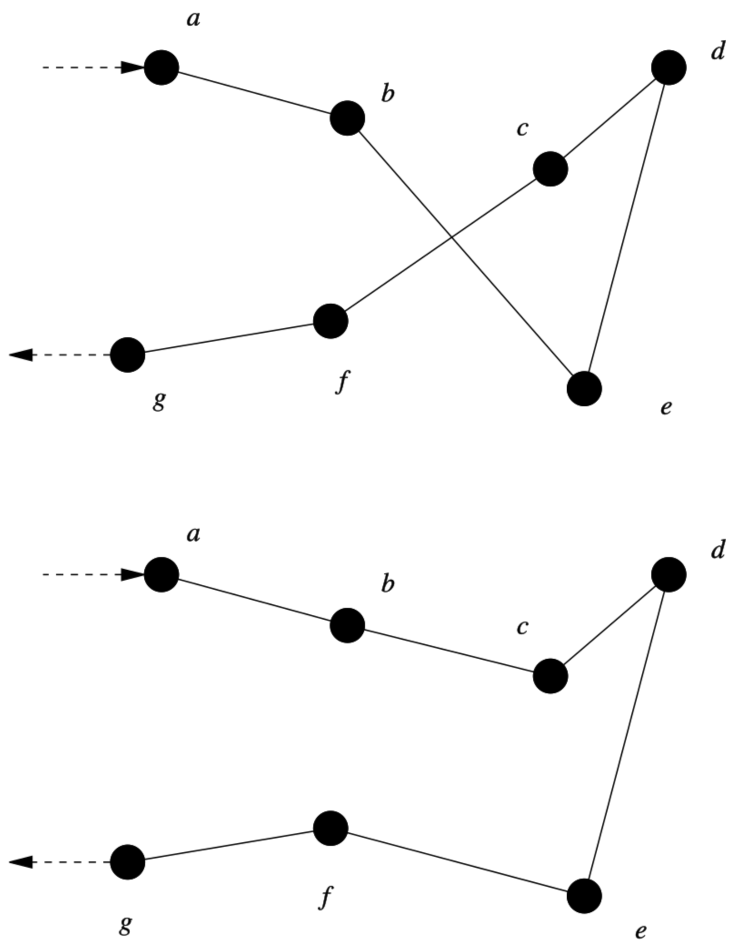
- Probability of selecting solution component, or edge (i,j):
- $p(c_i^j | S_p) = \frac{T_{ij}^{a} . \eta_{ij}^{\beta}}{\sum_{c_i^z \in N(S_p)} T_{iz}^{a} . \eta_{iz}^{\beta}}, \forall c_i^j \in N(S_p)$
- **τ** is the pheromone (trail) level
- **η** is the heuristic information:

  a.k.a, visibility, attractiveness:
  - e.g., $\eta_{ij} = \frac{1}{d_{ij}}$, where d_{ij} is the distance between i and j



ApplyLocalSearch Phase (optional)

- After solution construction and before pheromone update, solutions obtained by the ants are improved through a local search (2-opt, 3-opt, Lin-Kernighan ...).



https://en.wikipedia.org/wiki/2-opt

UpdatePheromones Phase

- When all the ants completed their solutions, the trails are updated by:

- $T_{ij} = (1 \ - \rho)T_{ij} + \sum_{k}^{m} \Delta\,\tau_{ij}^{k}$
- $\Delta\,\tau_{ij}^{k} \ = \begin{cases} \frac{Q}{L_k} \ if ant\ k\ uses\ edge\ (i,j)\ in\ its\ tour, \\ \qquad 0\ otherwise \end{cases}$
- L_k is the cost of the k^th ant's tour (e.g., tour length)
- Q is a constant

Main ACO Variants

- Ant System (AS)
- MAX – MIN Ant System (MMAS)
- Ant Colony System (ACS)
- Elitist Ant System (ASe)
- Rank-based Ant System (RBAS)

TSP Example

- Code example: https://github.com/Akavall/AntColonyOptimization/blob/master/ant_colony.py

- Simulation example: https://thiagodnf.github.io/aco-simulator/