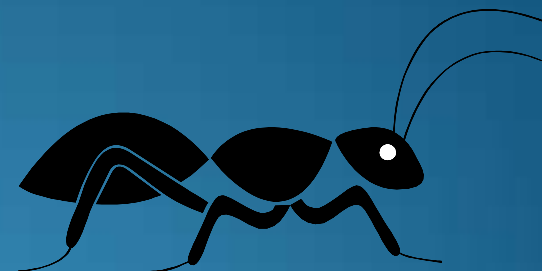
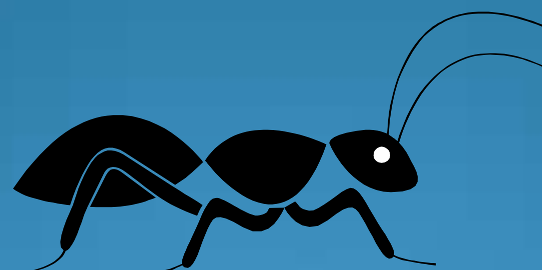
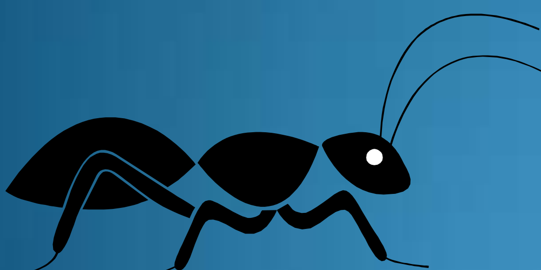
TERM PAPER ON -

ANT COLONY OPTIMIZATION







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Introduction

- In COMPUTER SCIENCE and OPERATION RESEARCH, the **ant colony optimization algorithm**(ACO) is a probabilistic technique for solving computational problems which can be reduced to finding good paths through graphs.

- This algorithm is a member of the ant colony algorithms family, in swarm intelligence methods, and it constitutes some metaheuristic optimizations.

- There are various algorithms, that are member of the **ant colony optimizations** algorithms, aiming to search for an optimal path in a graph, based on the behavior of ants seeking a path between their colony and a source of food.

- The original idea has since diversified to solve a wider class of numerical problems, and as a result, several problems have emerged, drawing on various aspects of the behavior of ants.

Introduction Cont..

- In the next generation of wireless communication systems, there will be need of networks that can establish themselves without any requirement of preexisting infrastructure.

- Mobile Ad-Hoc Networks (MANETS) - Mobile implies that the interconnecting nodes are not fixed to be remain at one place, rather they can move from one place to the other. Ad-Hoc implies that the network does not depend on any pre-existing infrastructure such as routers.

- One of the most important performance parameter in ad- hoc networks is minimizing the total transmission energy in the path and extending the battery life of the nodes.

Introduction Cont…

- There exists a protocol Minimum Transmission Power Routing (MTPR) which tries to minimize the total transmission power .

THE WHOLE CONCEPT OF ANT COLONY OPTIMIZATION IS TO MINIMIZE THE PATH AND POWER CONSUMPTION.

Overview

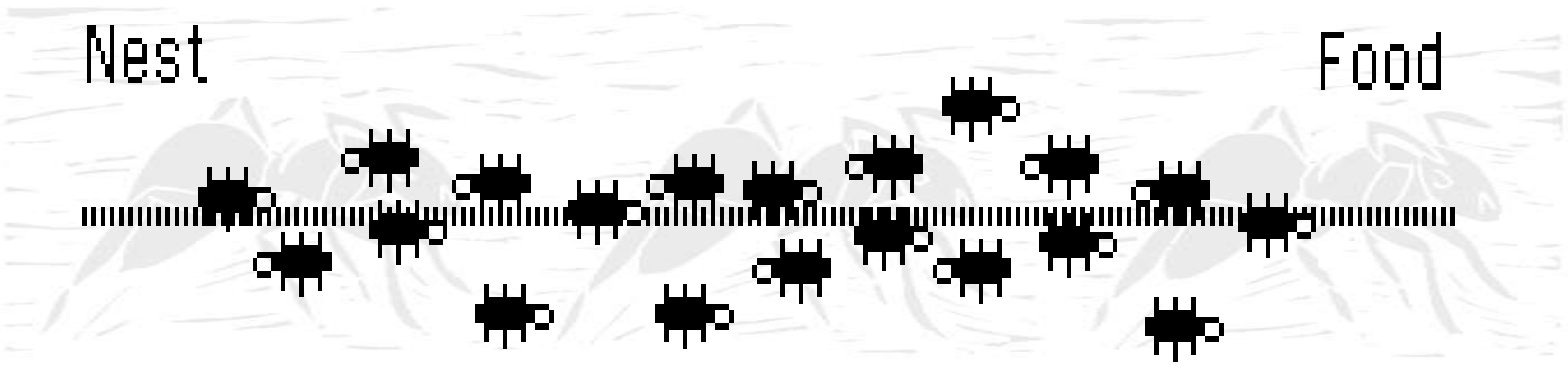
"Ant Colony Optimization (ACO) studies artificial systems that take inspiration from the *behavior of real ant colonies* and which are used to solve discrete optimization problems."

-Source: ACO website, http://iridia.ulb.ac.be/~mdorigo/ACO/about.html

PRACTICALLY……

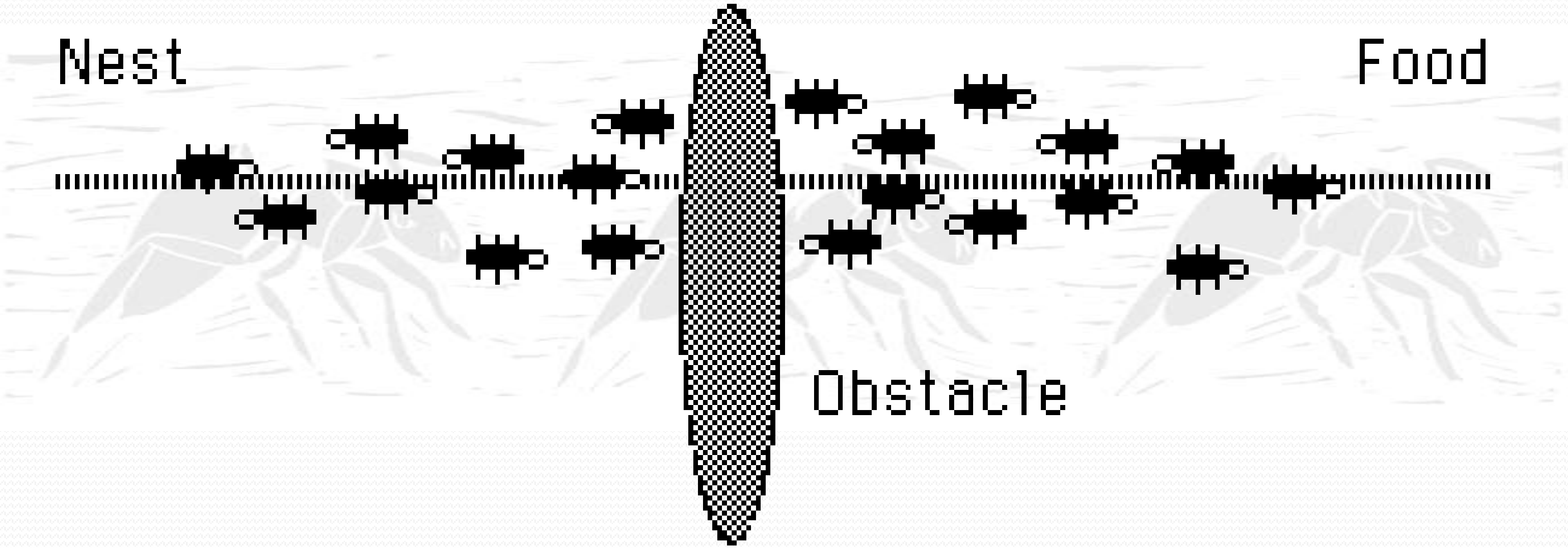
- Ants go through the food while laying down pheromone trails
- Shortest path is discovered via pheromone trails
  - each ant moves at random (first)
  - pheromone is deposited on path
  - Shorter path, more pheromone rails (positive feedback sys)
  - ants follow the intense pheromone trails

A Practical Scenario



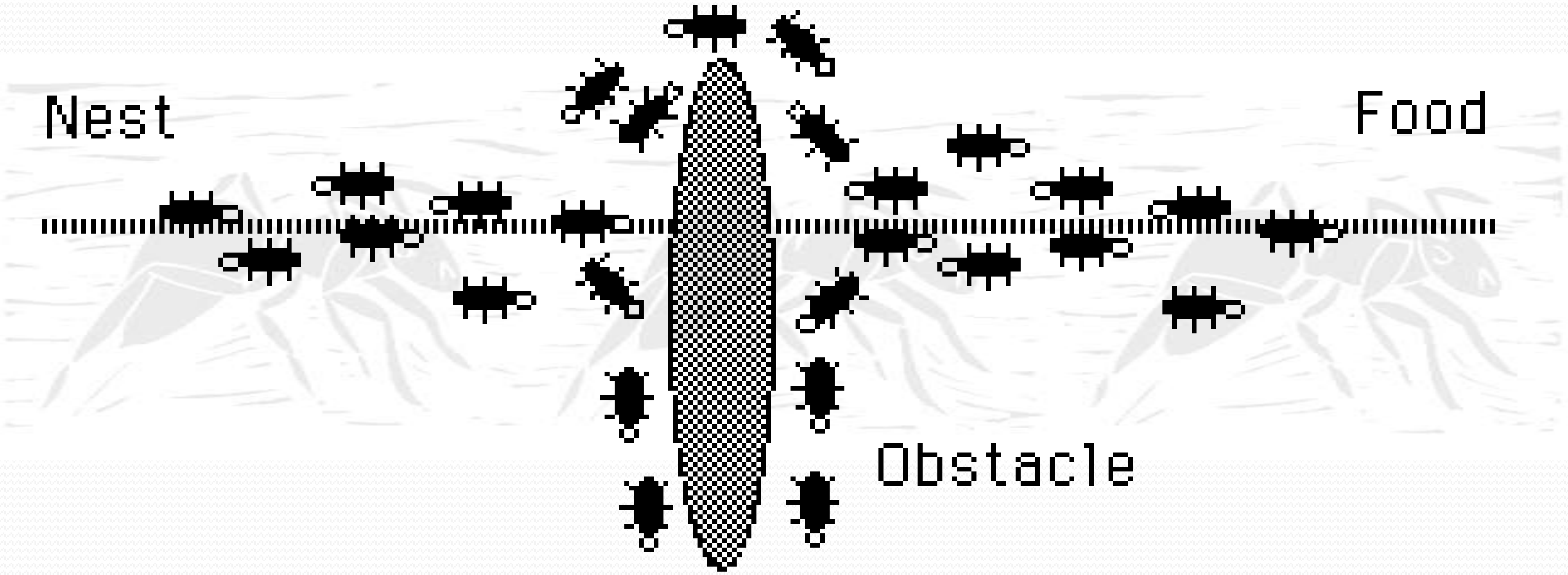
All is well in the world of the ant.

Naturally Observed Ant Behavior



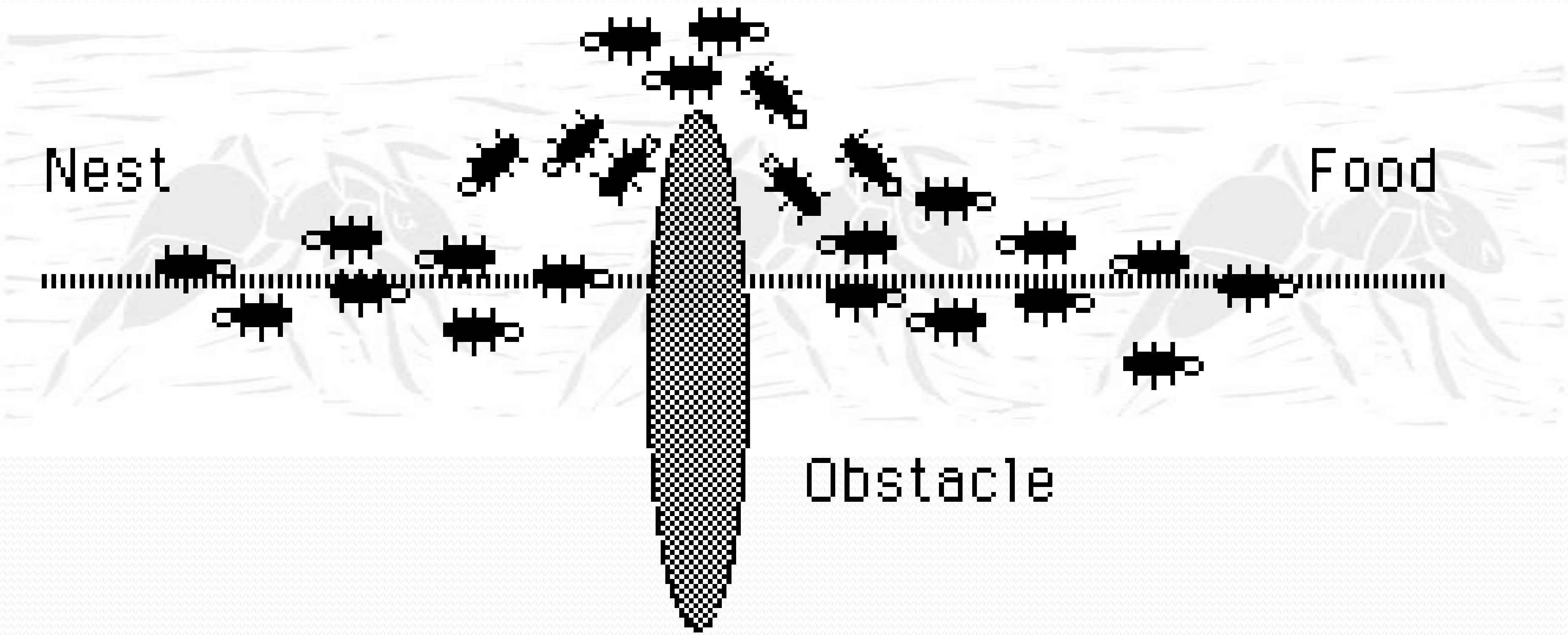
Oh no! An obstacle has blocked our path!

Naturally Observed Ant Behavior



Where do we go? Everybody, flip a coin.

Naturally Observed Ant Behavior



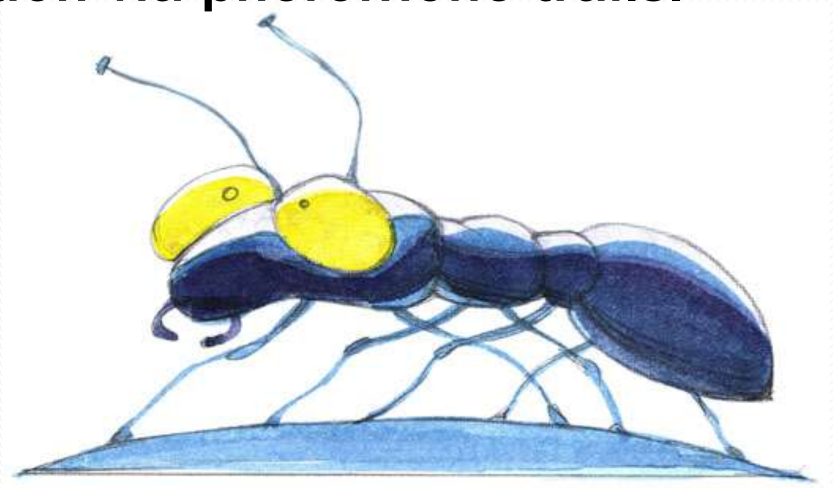
Shorter path reinforced.

ACTUAL SCENARIO

- Actual Scenario
- Swarm Intelligence
- Stigmergy
- Autocatalyzation
- Ant System

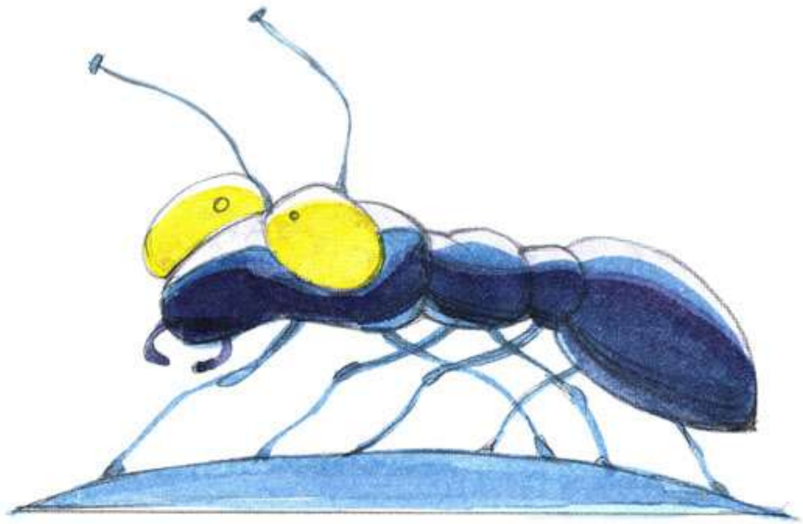
ACTUAL SCENARIO !!!

- Almost blind.
- Incapable of achieving complex tasks alone.
- Rely on the phenomena of swarm intelligence for survival.
- Capable of establishing shortest-route paths from their colony to feeding sources and back.
- Use stigmergic communication via pheromone trails.



Actual Scenario!!! (cont..)

- Follow existing pheromone trails with high probability.
- What emerges is a form of *autocatalytic* behavior: the more ants follow a trail, the more attractive that trail becomes for being followed.
- The process is thus characterized by a positive feedback loop, where the probability of a discrete path choice increases with the number of times the same path was chosen before.



“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

- Constituting a natural model particularly suited to distributed problem solving

"Stigmergic"

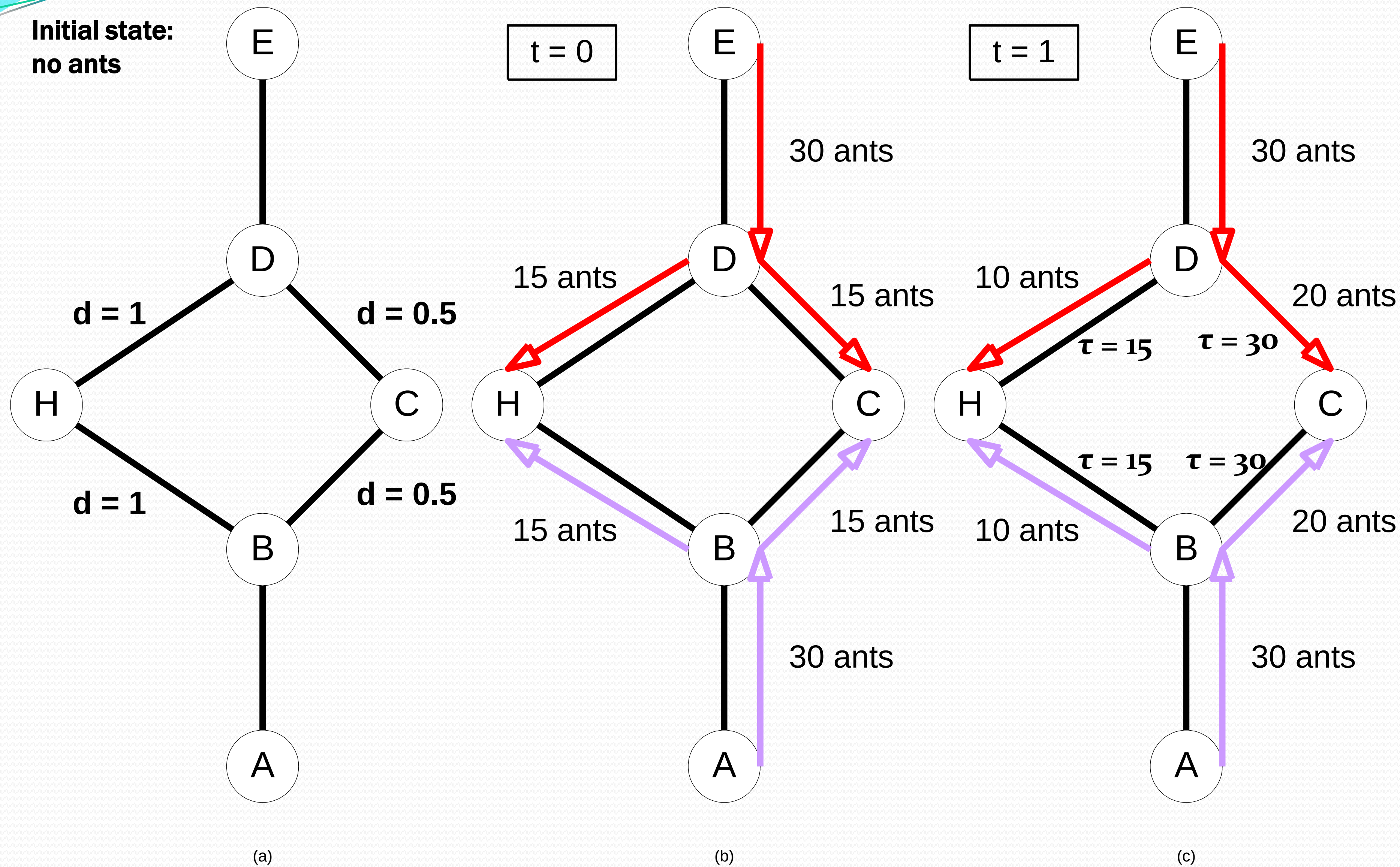
- Two individuals interact indirectly when one of them modifies the environment and the other responds to the new environment at a later time. This is stigmergy.

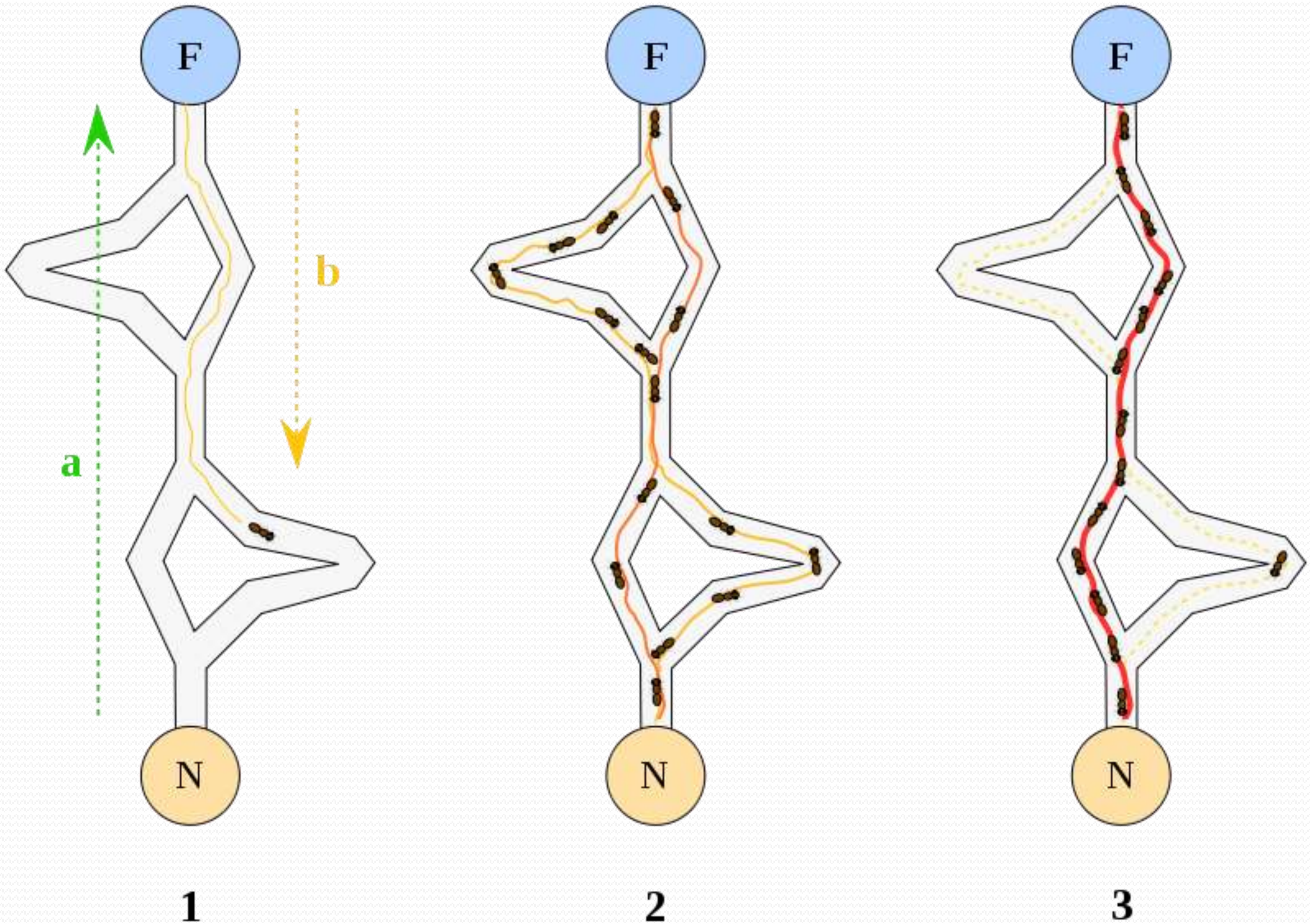
Real ants use stigmergy. How again?

PHEROMONES!!!

“Autocatalyzation”

Autocatalysis is a **positive feedback loop** that drives the ants to explore promising aspects of the search space over less promising areas.


Initial state:
no ants
E
D
H
C
B
A
d = 1
d = 0.5
d = 1
d = 0.5
(a)
t = 0
E
D
H
C
B
A
30 ants
15 ants
15 ants
15 ants
15 ants
30 ants
(b)
t = 1
E
D
H
C
B
A
30 ants
10 ants
20 ants
τ = 15
τ = 30
τ = 15
τ = 30
10 ants
20 ants
30 ants
(c)

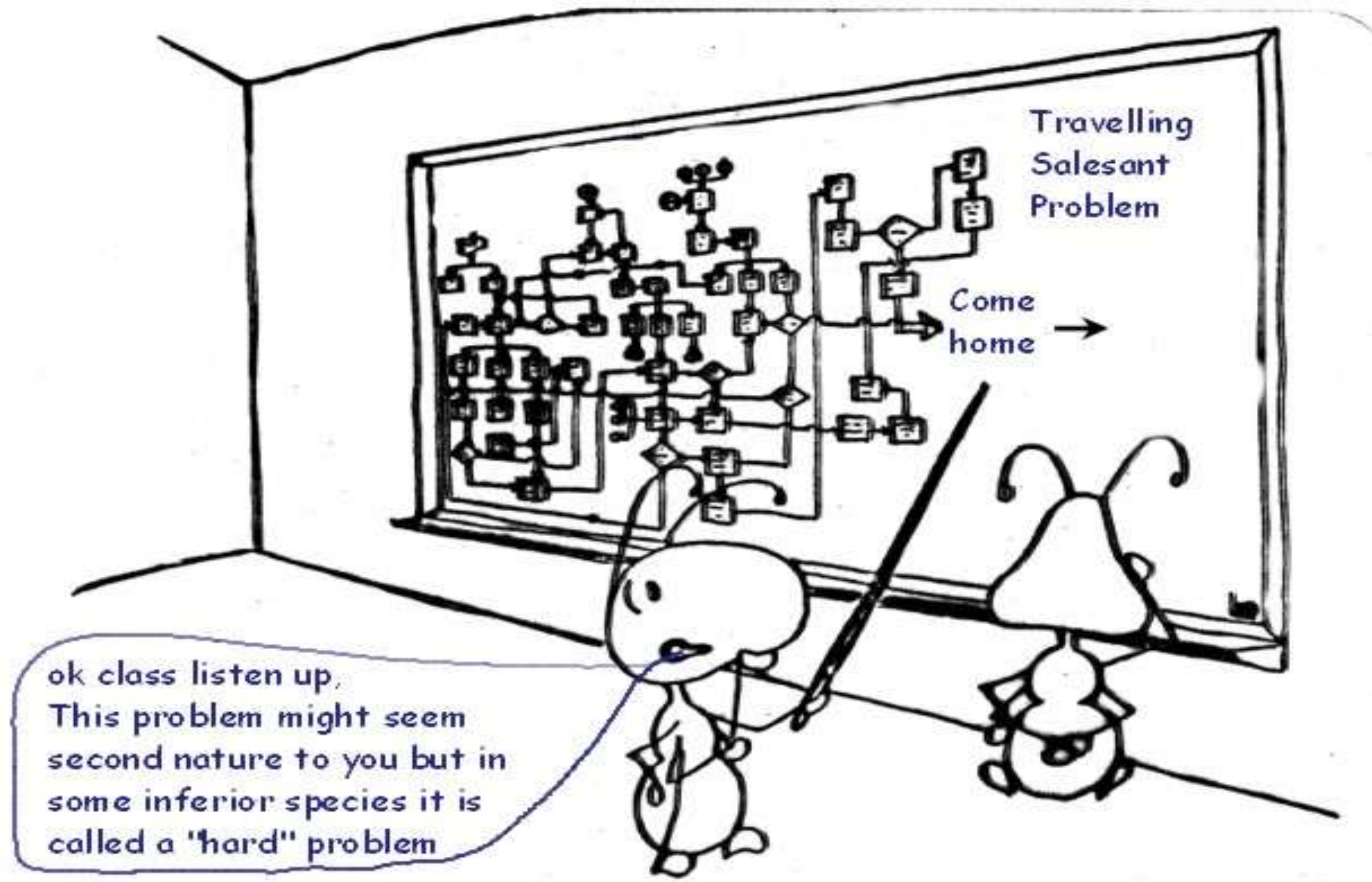


F
N
a
b
F
N
F
N
1
2
3

Autocatalyzation

This is why ACO algorithms are called autocatalytic positive feedback algorithms!

Ant Colony Optimization



ACO for Traveling Salesman Problem

The first **ACO** algorithm was called the **Ant system** and it was aimed to solve the travelling salesman problem, in which the goal is to find the shortest round-trip to link a series of cities. At each stage, the ant chooses to move from one city to another according to some rules:

- It must visit each city exactly once;
- A distant city has less chance of being chosen (the visibility);
- The more intense the pheromone trail laid out on an edge between two cities, the greater the probability that that edge will be chosen;
- Having completed its journey, the ant deposits more pheromones on all edges it traversed, if the journey is short;
- After each iteration, trails of pheromones evaporate.

Ant System

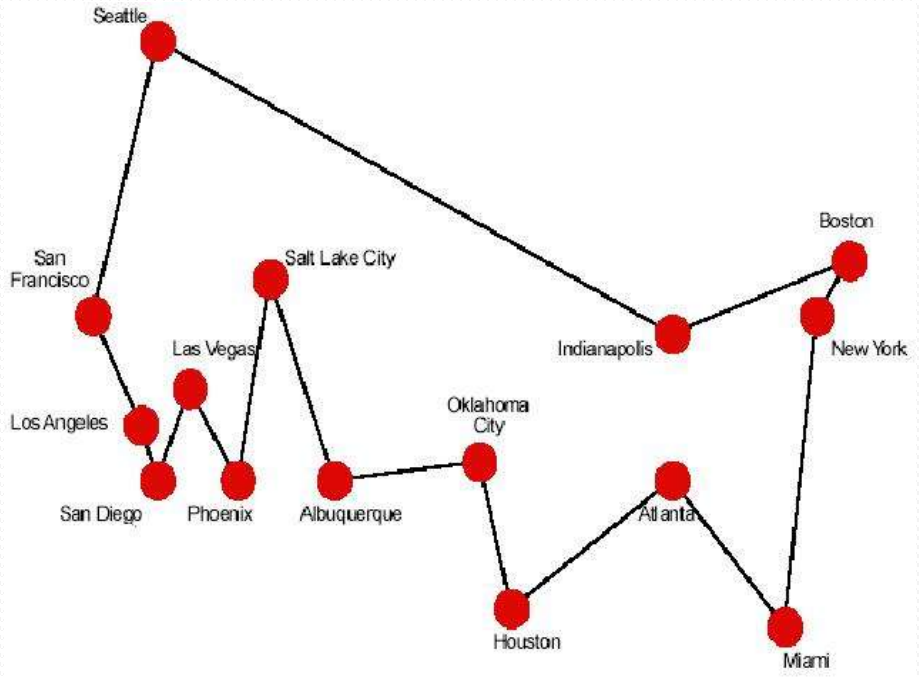
- First introduced by Marco Dorigo in 1992
- Progenitor to “Ant Colony System,” later discussed
- Result of research on computational intelligence approaches to combinatorial optimization
- Originally applied to Traveling Salesman Problem
- Applied later to various hard optimization problems

Traveling Salesman Problem

TSP PROBLEM : Given N cities, and a distance function d between cities, find a tour that:

1. Goes through every city once and only once
2. Minimizes the total distance.

- Problem is NP-hard
- Classical combinatorial optimization problem to test.



HOW TO IMPLEMENT IN A PROGRAM

- Ants: Simple computer agents
- Move ant: Pick next component in the const. solution
- Pheromone: $\Delta\tau_{i,j}^{k}$
- Memory: M_K or $Tabu_K$
- Next move: Use probability to move ant

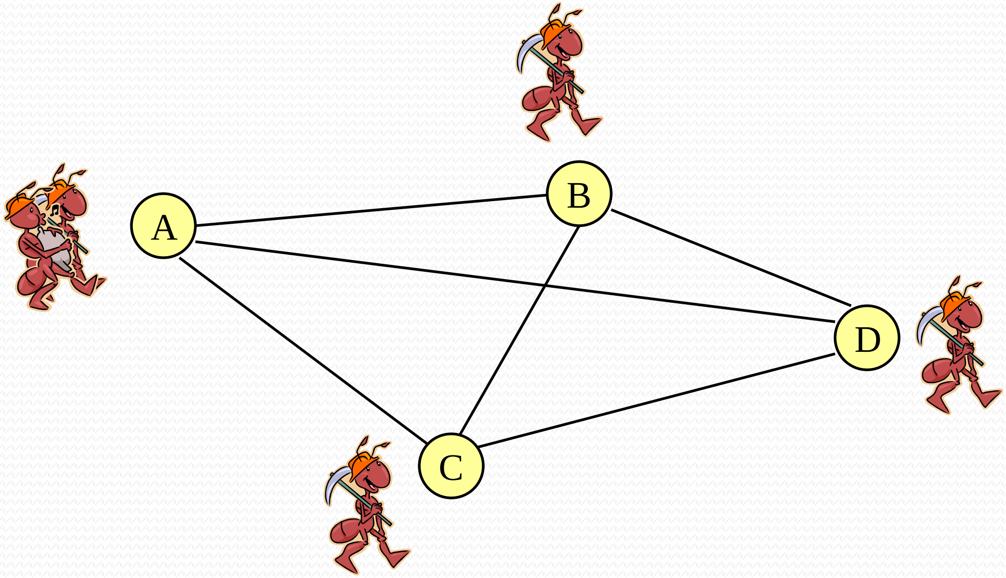
Ant Systems (AS)

Ant Systems for TSP

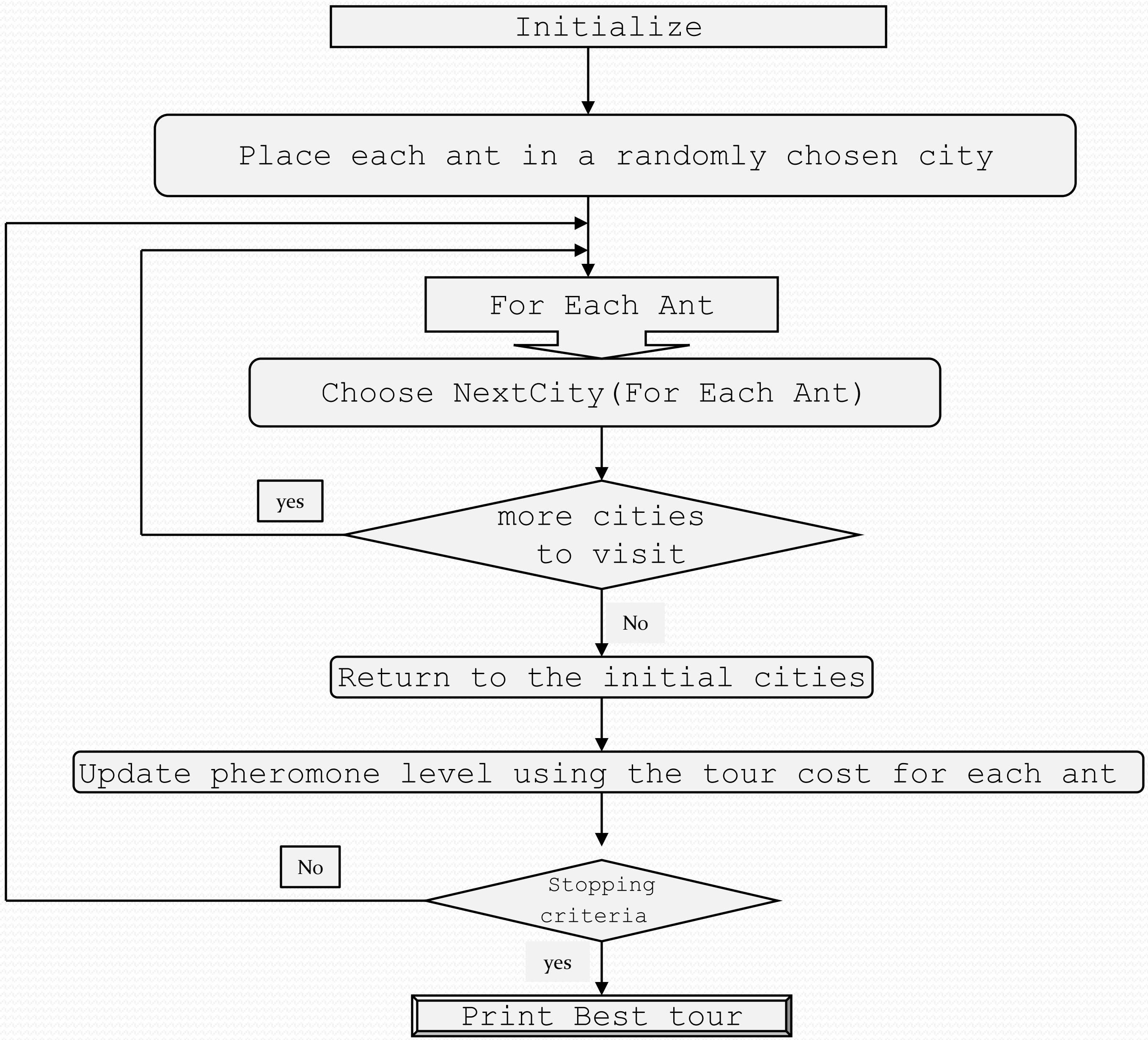
Graph (N,E): where N = cities/nodes, E = edges

d_{ij} = *the tour cost from city i to city j (edge weight)*

Ant move from one city i to the next j with some transition probability.

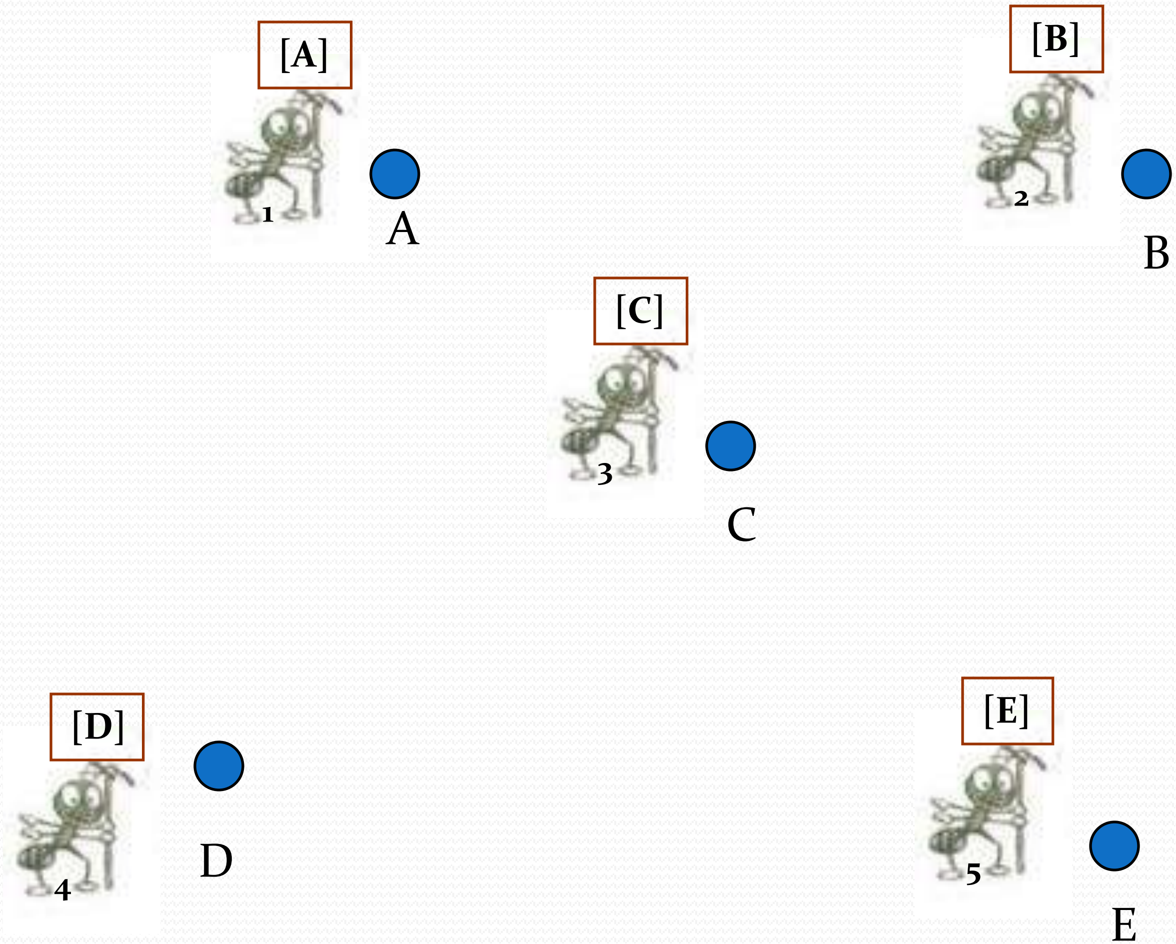


Algorithm for TSP(AS)

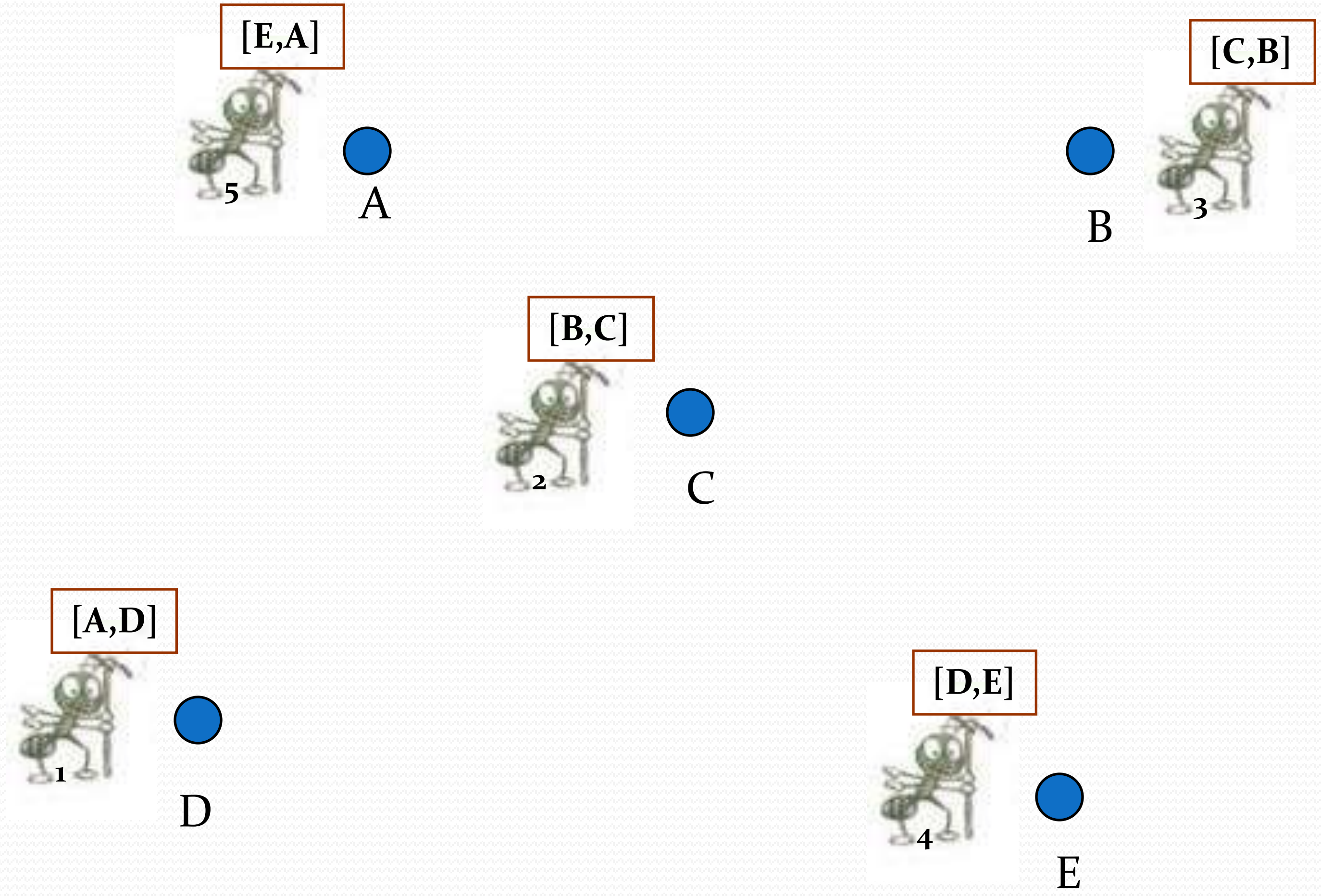


Let see with this small example:

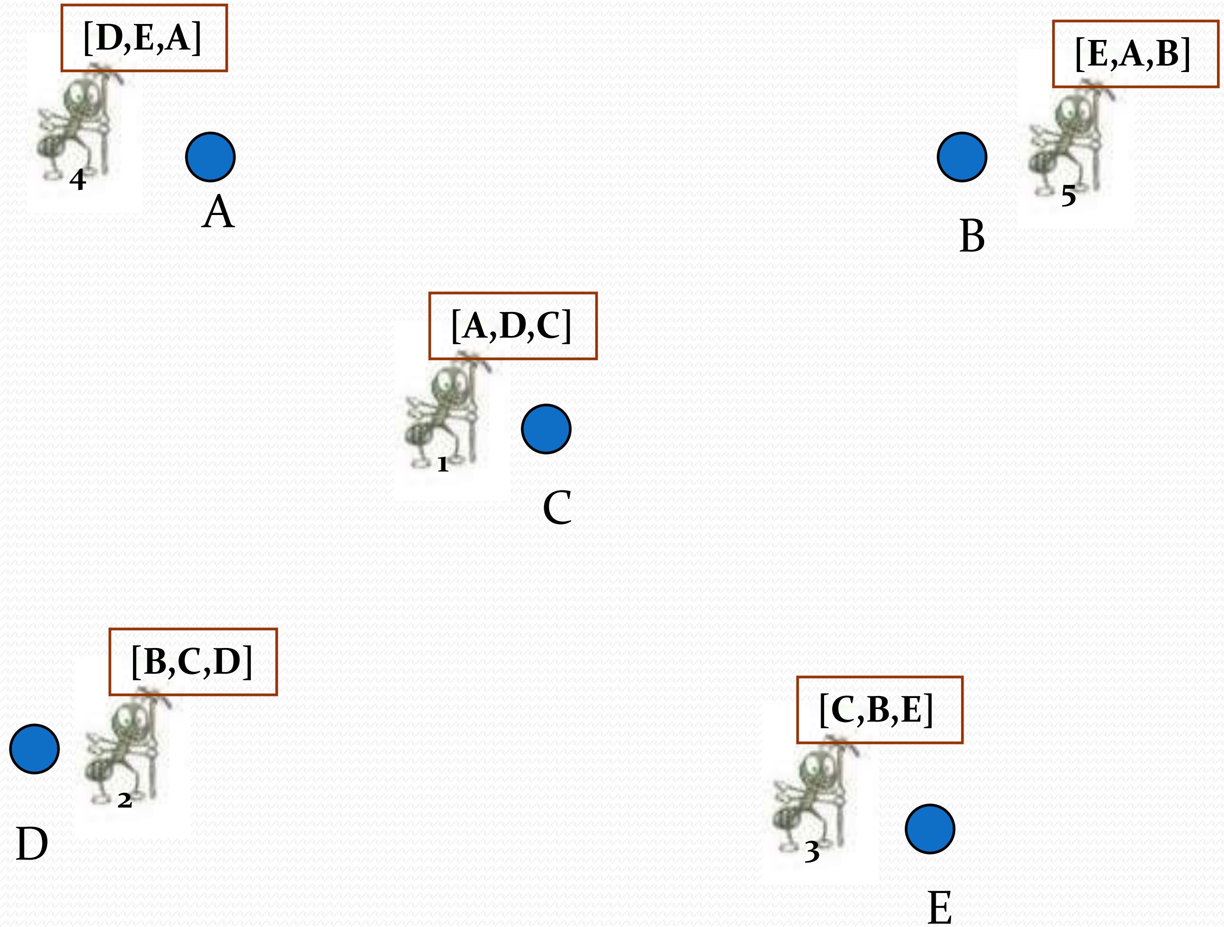
Iteration 1



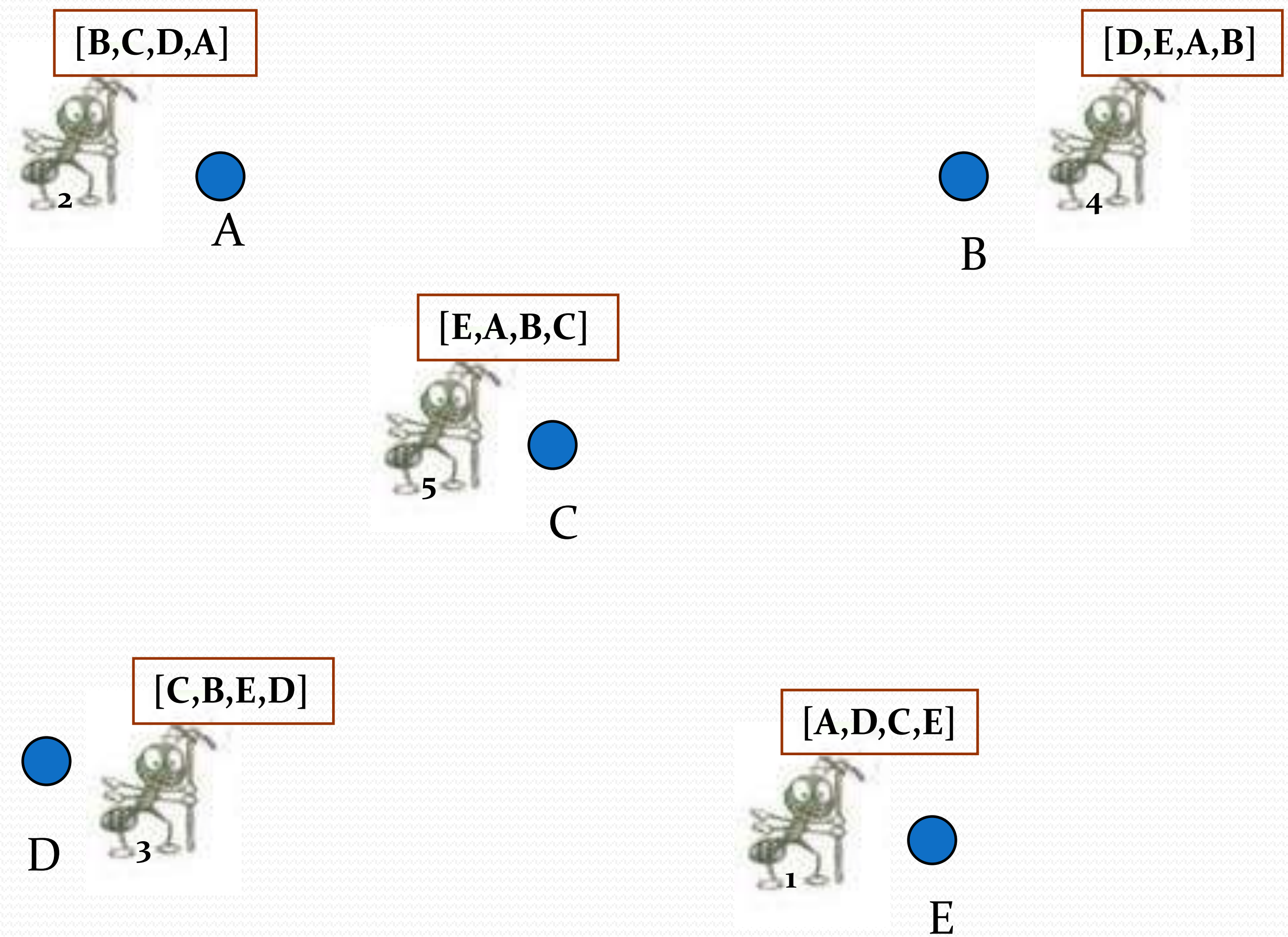
Iteration 2



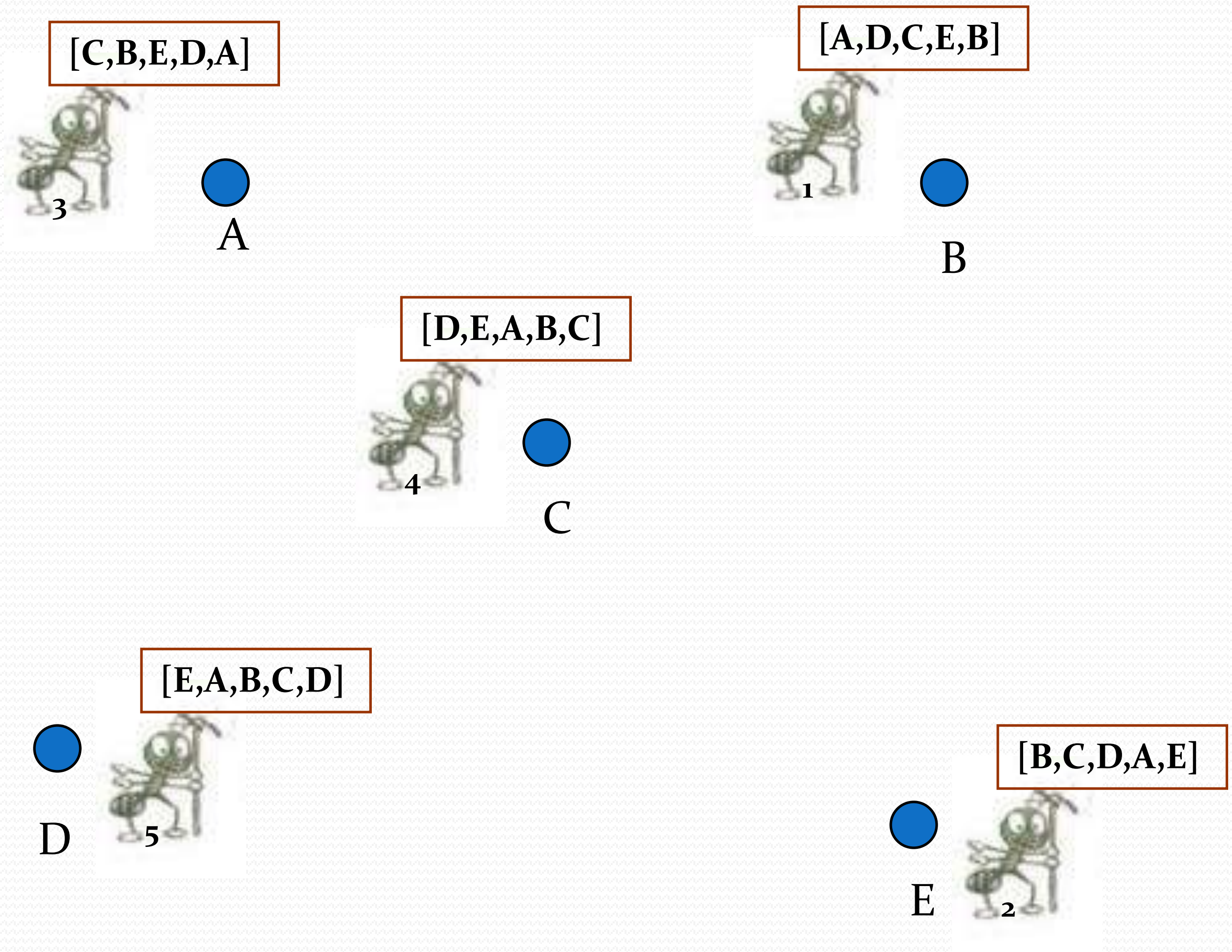
Iteration 3



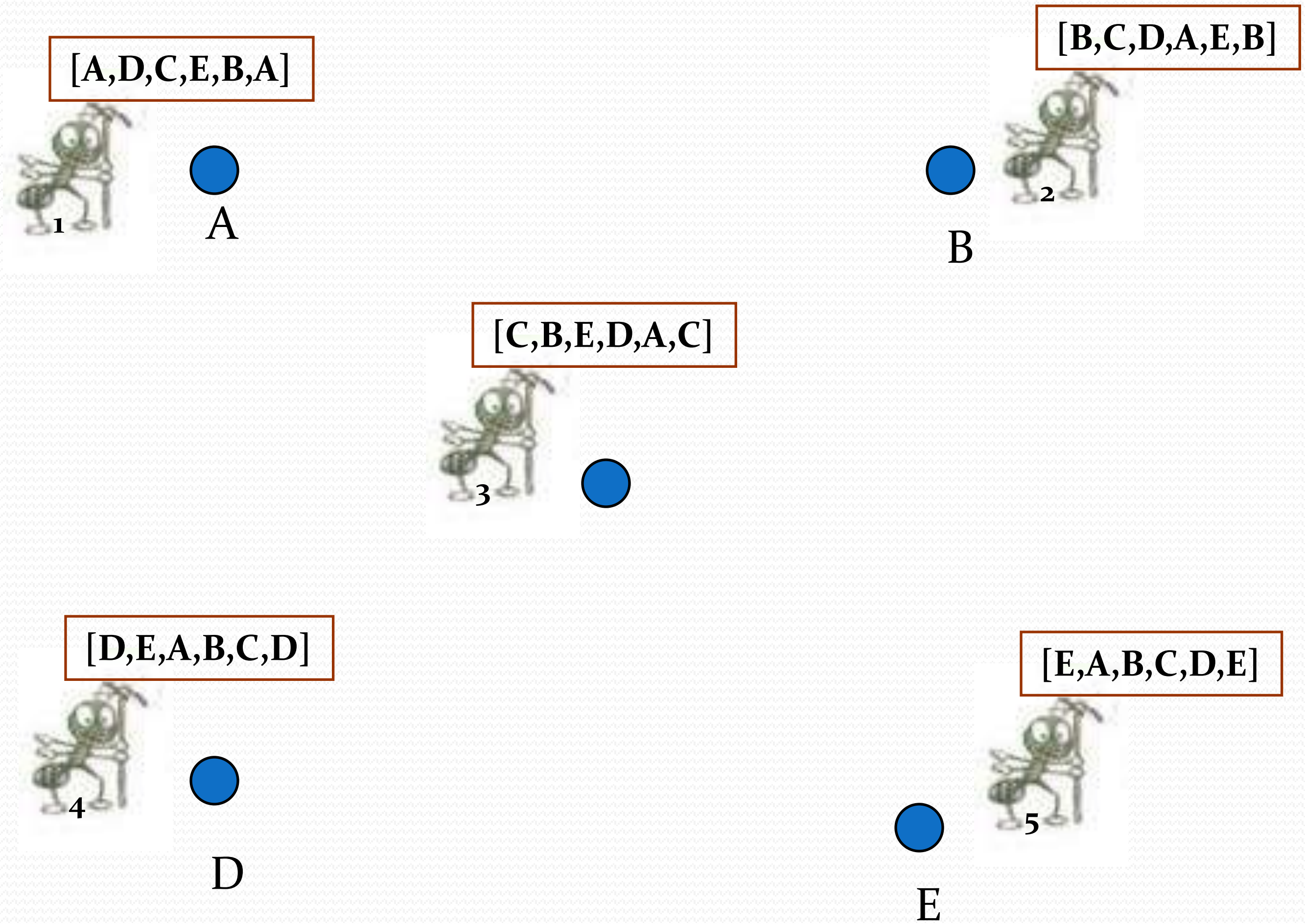
Iteration 4



Iteration 5



Iteration 6



CALCULATION

1. Path and Pheromone Evaluation
2. End of First Run
3. Save Best Tour (Sequence and length)
4. All ants die
5. New ants are born

COMMON EXTENSIONS TO ACO ALGORITHMS

Here are some of most popular variations of ACO algorithms-

- **Elitist Ant System (EAS)**
- **MMAS**
- **As$_{\mathbf{rank}}$**
- **ACS**
- **COAC**
- **ACO WITH FUZZY**

Extensions(cont..)

- **Elitist ant system(EAS)**

  The global best solution deposits pheromone on every iteration along with all the other ants.

- **Max-Min ant system (MMAS)**

  Added Maximum and Minimum pheromone amounts [τmax,τmin] Only global best or iteration best tour deposited pheromone. All edges are initialized to τmax and reinitialized to τmax when nearing stagnation.

- **Rank-based ant system (ASrank)**

  All solutions are ranked according to their length. The amount of pheromone deposited is then weighted for each solution, such that solutions with shorter paths deposit more pheromone than the solutions with longer paths.

Extensions(cont..)

- **Ant Colony System (ACS)**

  It has been presented before.

- **Continuous orthogonal ant colony (COAC)**

  The pheromone deposit mechanism of COAC is to enable ants to search for solutions collaboratively and effectively. By using an orthogonal design method, ants in the feasible domain can explore their chosen regions rapidly and efficiently, with enhanced global search capability and accuracy.

  The orthogonal design method and the adaptive radius adjustment method can also be extended to other optimization algorithms for delivering wider advantages in solving practical problems.

- **Ant Colony Optimization with Fuzzy Logic(ACO WITH FUZZY)**

  This method introduces fuzzy intelligence into ants to accelerate searching ability.

ACO Applications

- **Scheduling Problem**
  - Job-shop scheduling problem (JSP)
  - Open-shop scheduling problem (OSP)
  - Resource-constrained project scheduling problem (RCPSP)
  - Group-shop scheduling problem (GSP)
- **Vehicle routing problem**
  - Multi-depot vehicle routing problem (MDVRP)
  - Period vehicle routing problem (PVRP)
  - Split delivery vehicle routing problem (SDVRP)
  - Stochastic vehicle routing problem (SVRP)
  - Vehicle routing problem with time windows (VRPTW)

Applications (cont..)

- **Assignment problem**
  - Quadratic assignment problem(QAP)
  - Generalized assignment problem (GAP)
  - Frequency assignment problem (FAP)
  - Redundancy allocation problem
- **Set problem**
  - Set covering problem(SCP)
  - Set partition problem (SPP)
  - Multiple knapsack problem (MKP)
  - Maximum independent set problem (MIS)

Applications(cont..)

Others

- Connection-oriented network routing
- Connectionless network routing
- Data mining
- Discounted cash flows in project scheduling
- Distributed Information Retrieval
- Grid Workflow Scheduling Problem
- Image processing
- Intelligent testing system
- System identification
- Protein Folding
- Power Electronic Circuit Design

ACO Algorithms : An Overview

Problem name	Authors	Algorithm name	Year
Traveling salesman	Dorigo, Maniezzo & Colorni	**AS**	1991
	Gamberdella & Dorigo	**Ant-Q**	1995
	Dorigo & Gamberdella	**ACS &ACS 3 opt**	1996
	Stutzle & Hoos	**MMAS**	1997
	Bullnheimer, Hartl & Strauss	**AS_{rank}**	1997
	Cordon, et al.	**BWAS**	2000
Quadratic assignment	Maniezzo, Colorni & Dorigo	**AS-QAP**	1994
	Gamberdella, Taillard & Dorigo	**HAS-QAP**	1997
	Stutzle & Hoos	**MMAS-QAP**	1998
	Maniezzo	**ANTS-QAP**	1999
	Maniezzo & Colorni	**AS-QAP**	1994
Scheduling problems	Colorni, Dorigo & Maniezzo	**AS-JSP**	1997
	Stutzle	**AS-SMTTP**	1999
	Barker et al	**ACS-SMTTP**	1999
	den Besten, Stutzle & Dorigo	**ACS-SMTWTP**	2000
	Merkle, Middenderf & Schmeck	**ACO-RCPS**	1997
Vehicle routing	Bullnheimer, Hartl & Strauss	**AS-VRP**	1999
	Gamberdella, Taillard & Agazzi	**HAS-VRP**	1999

ACO Algorithms : An Overview cont…

Problem name	Authors	Algorithm name	Year
Connection-oriented	Schoonderwood et al.	**ABC**	1996
Network routing	White, Pagurek & Oppacher	**ASGA**	1998
	Di Caro & Dorigo	**AntNet-FS**	1998
	Bonabeau et al.	**ABC-smart ants**	1998
Connection-less	Di Caro & Dorigo	**AntNet & AntNet-FA**	1997
Network routing	Subramanian, Druschel & Chen	**Regular ants**	1997
	Heusse et al.	**CAF**	1998
	van der Put & Rethkrantz	**ABC-backward**	1998
Sequential ordering	Gamberdella& Dorigo	**HAS-SOP**	1997
Graph coloring	Costa & Hertz	**ANTCOL**	1997
Shortest common super sequence	Michel & Middendorf	**AS_SCS**	1998
Frequency assignment	Maniezzo & Carbonaro	**ANTS-FAP**	1998
Generalized assignment	Ramalhinho Lourenco & Serra	**MMAS-GAP**	1998
Multiple knapsack	Leguizamon & Michalewicz	**AS-MKP**	1999
Optical networks routing	Navarro Varela & Sinclair	**ACO-VWP**	1999
Redundancy allocation	Liang & Smith	**ACO-RAP**	1999
Constraint satisfaction	Solnon	**Ant-P-solver**	2000

Related methods

- **Genetic algorithms (GA)** maintain a pool of solutions rather than just one. The process of finding superior solutions mimics that of evolution, with solutions being combined or mutated to alter the pool of solutions, with solutions of inferior quality being discarded.

- **Simulated annealing (SA)** is a related global optimization technique which traverses the search space by generating neighboring solutions of the current solution. A superior neighbor is always accepted. An inferior neighbor is accepted probabilistically based on the difference in quality and a temperature parameter. The temperature parameter is modified as the algorithm progresses to alter the nature of the search.

- **Reactive search optimization** focuses on combining machine learning with optimization, by adding an internal feedback loop to self-tune the free parameters of an algorithm to the characteristics of the problem, of the instance, and of the local situation around the current solution.

RELATED METHODS(cont..)

- **Tabu search (TS)** is similar to simulated annealing in that both traverse the solution space by testing mutations of an individual solution. While simulated annealing generates only one mutated solution, tabu search generates many mutated solutions and moves to the solution with the lowest fitness of those generated. To prevent cycling and encourage greater movement through the solution space, a tabu list is maintained of partial or complete solutions. It is forbidden to move to a solution that contains elements of the tabu list, which is updated as the solution traverses the solution space.

- **Stochastic diffusion search (SDS),** an agent-based probabilistic global search and optimization technique best suited to problems where the objective function can be decomposed into multiple independent partial-functions.

- **etc**

Advantages

- Positive Feedback accounts for rapid discovery of good solutions
- Distributed computation avoids premature convergence
- The greedy heuristic helps find acceptable solution in the early solution in the early stages of the search process.
- The collective interaction of a population of agents.

Disadvantages

- Slower convergence than other Heuristics
- Performed poorly for TSP problems larger than 75 cities.
- No centralized processor to guide the AS towards good solutions

Conclusion

- ACO is a recently proposed metaheuristic approach for solving hard combinatorial optimization problems(NP HARD Problems).
- Artificial ants implement a randomized construction heuristic which makes probabilistic decisions.
- The a cumulated search experience is taken into account by the adaptation of the pheromone trail.
- ACO Shows great performance with the "ill-structured" problems like network routing.
- In ACO Local search is extremely important to obtain good results.

Thank You!!!