Ant Colony Optimization. A metaheuristic approach to hard network optimization problems.

Metaheuristics

Metaheuristics are semi-stochastic approaches to solving a variety of hard optimization problems. They are iterative algorithms that improve candidate solutions.

- Simulated annealing (SA)
- Tabu search (TS)
- Genetic algorithms (GA)
- Ant Colony Optimization (ACO)

Ant Colony Optimization

- Real ants
- Stigmergy
- Autocatalyzation
- Ant System
- Ant Colony System

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

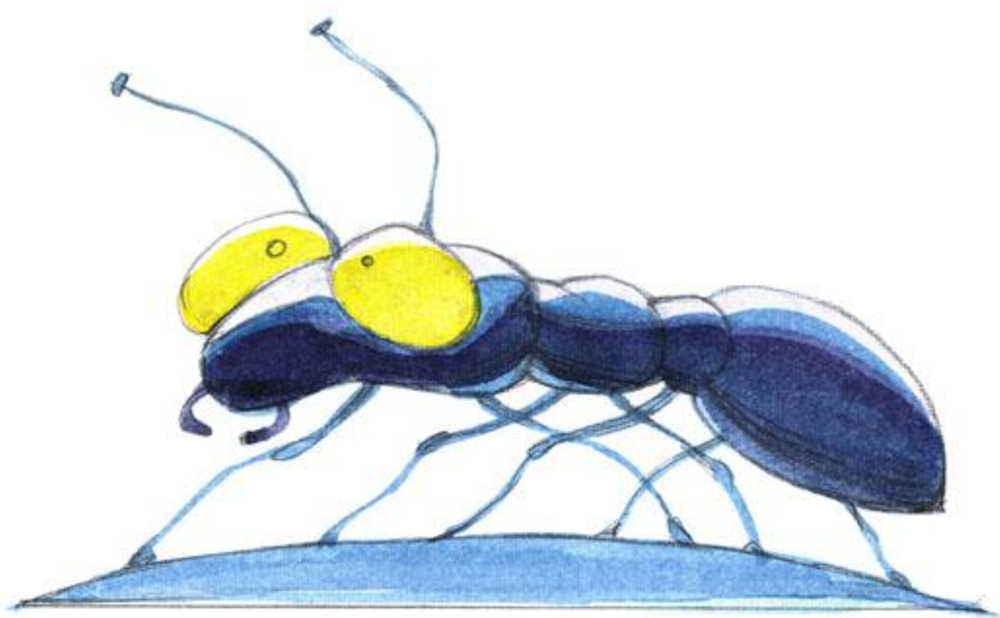
Almost blind.

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.

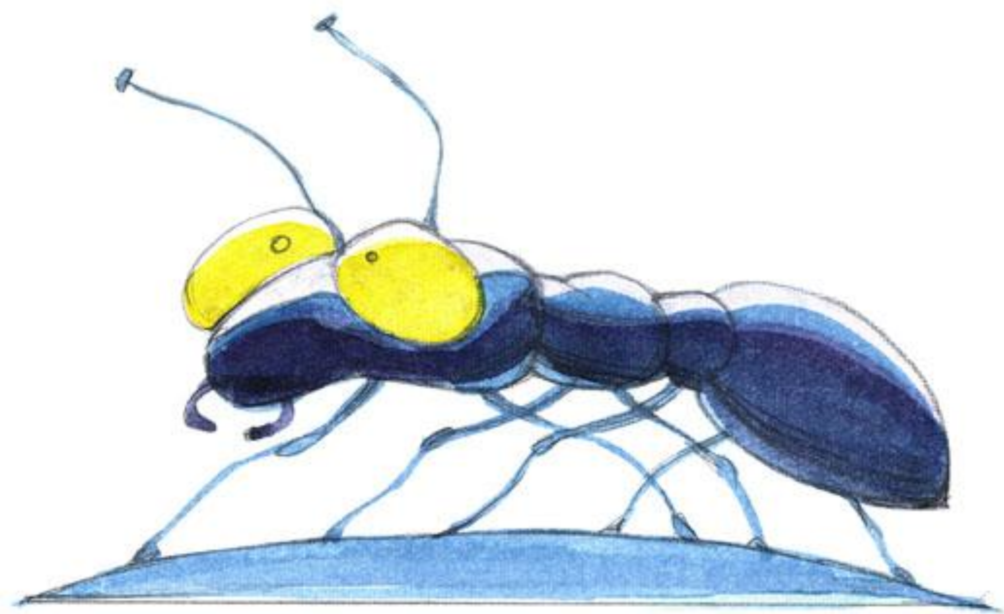
Use stigmergic communication via pheromone trails.



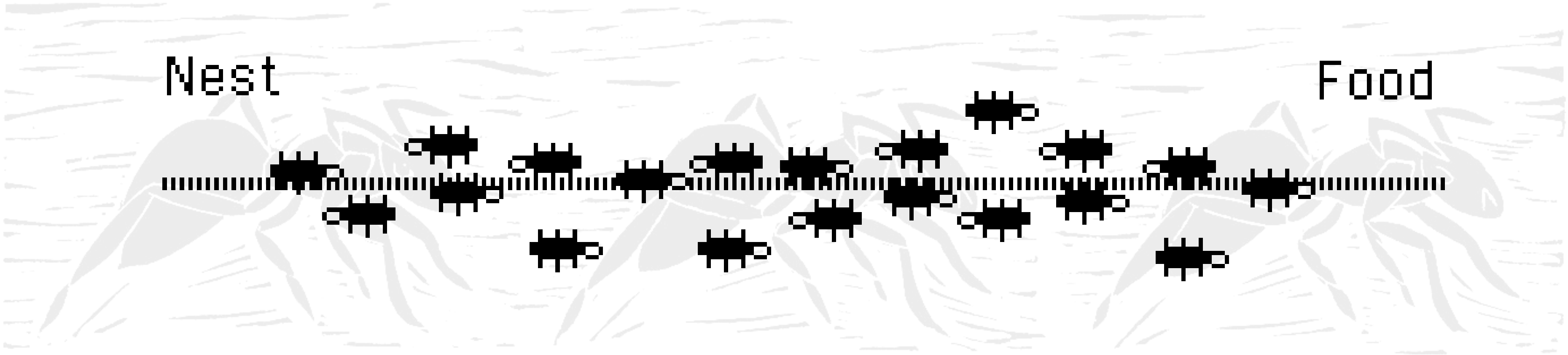
Follow existing pheromone trails with high probability.

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.

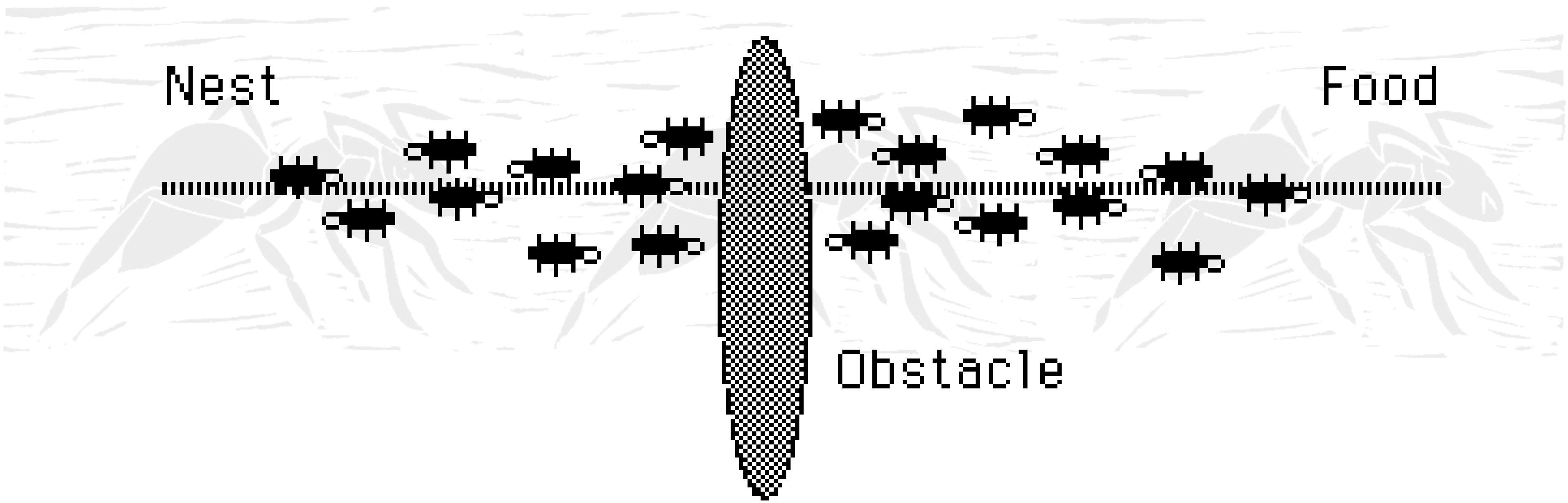


Naturally Observed Ant Behavior



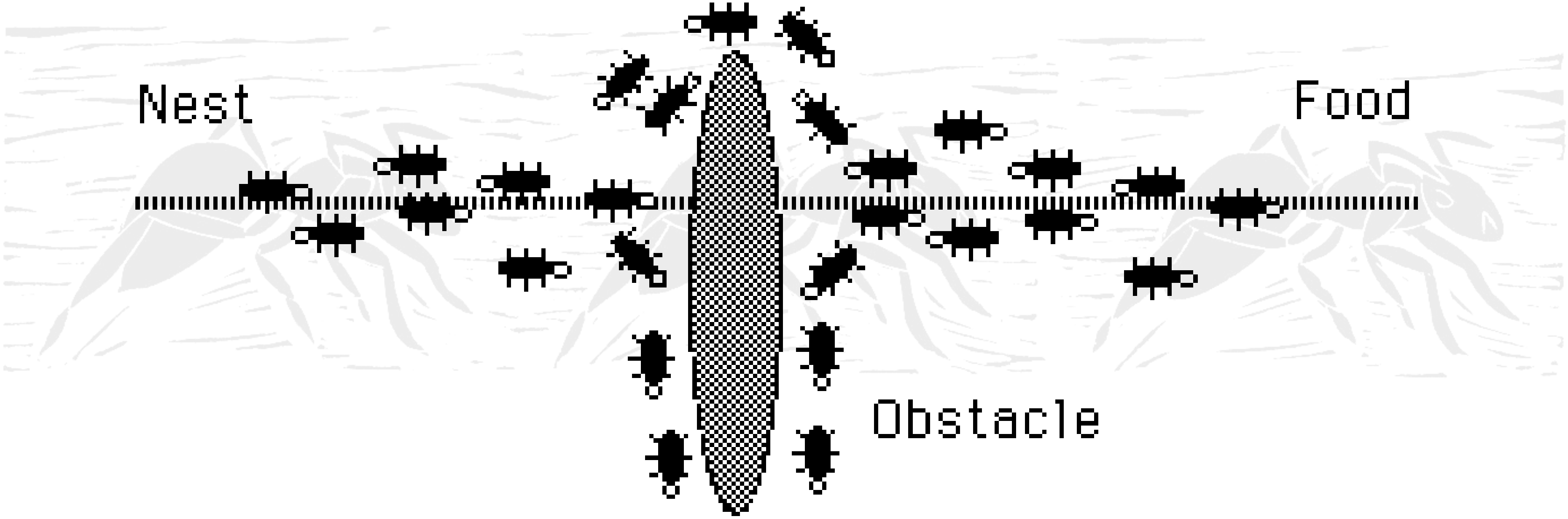
All is well in the world of the ant.

Naturally Observed Ant Behavior



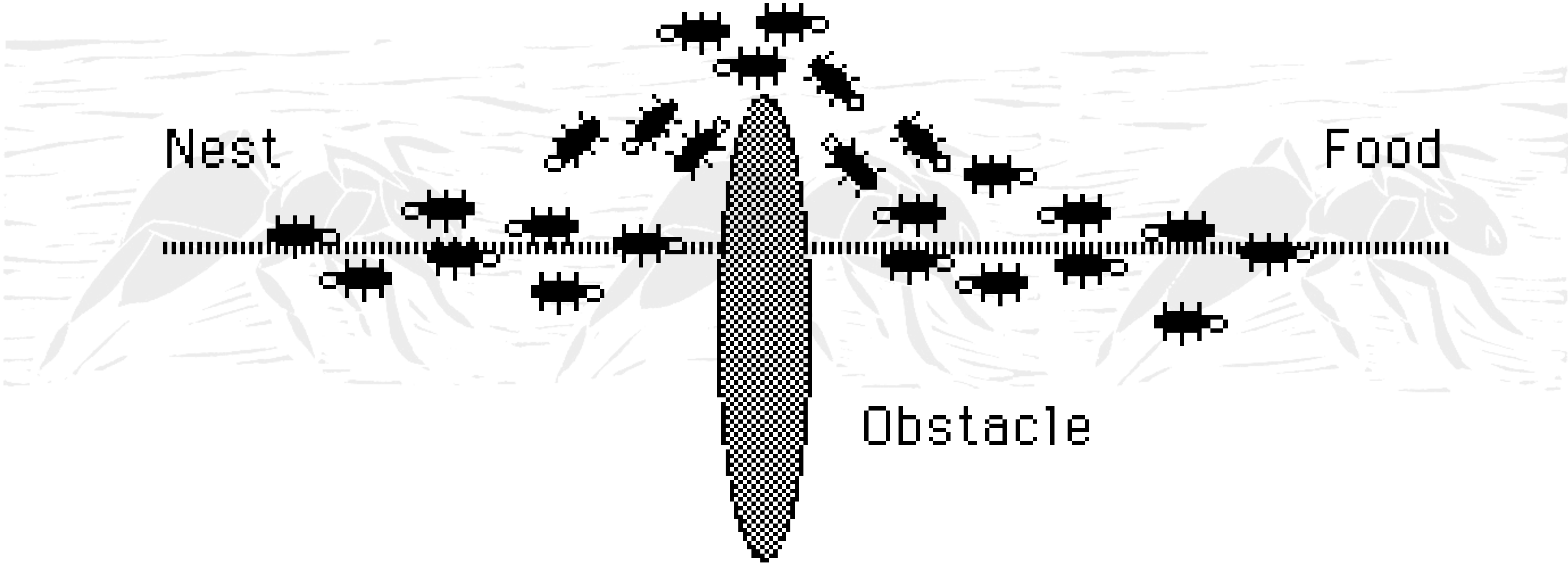
Oh no! **An obstacle has blocked our path!**

Naturally Observed Ant Behavior



Where do we go? Everybody, flip a coin.

Naturally Observed Ant Behavior



Shorter path reinforced.

"Stigmergic?"

- Stigmergy, a term coined by French biologist Pierre-Paul Grasse, is interaction through the environment.
- 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.

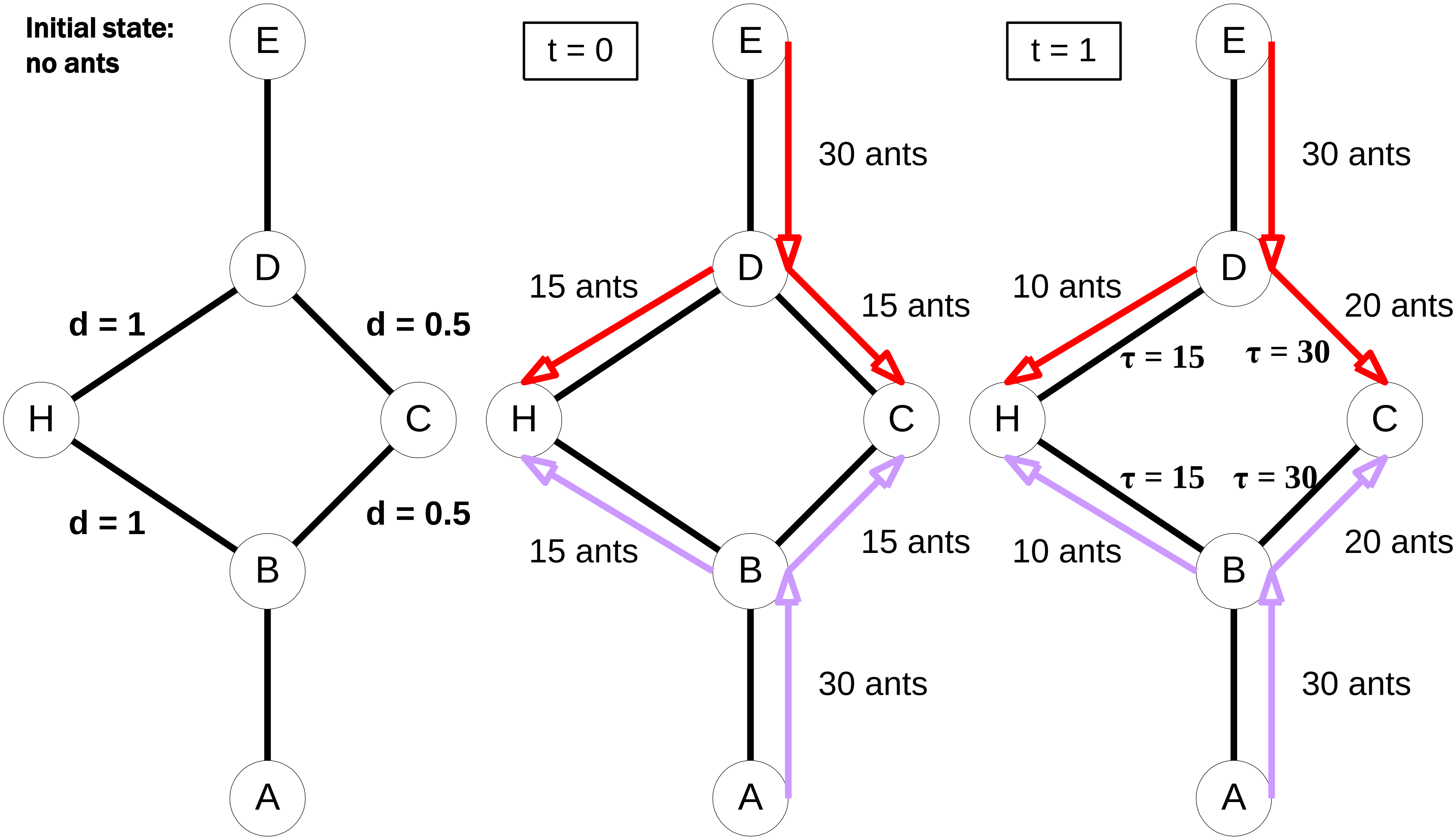
Stigmergy

Real ants use stigmergy. How again?

PHEROMONES!!!

Autocatalyzation

What is *autocatalytic behavior*?

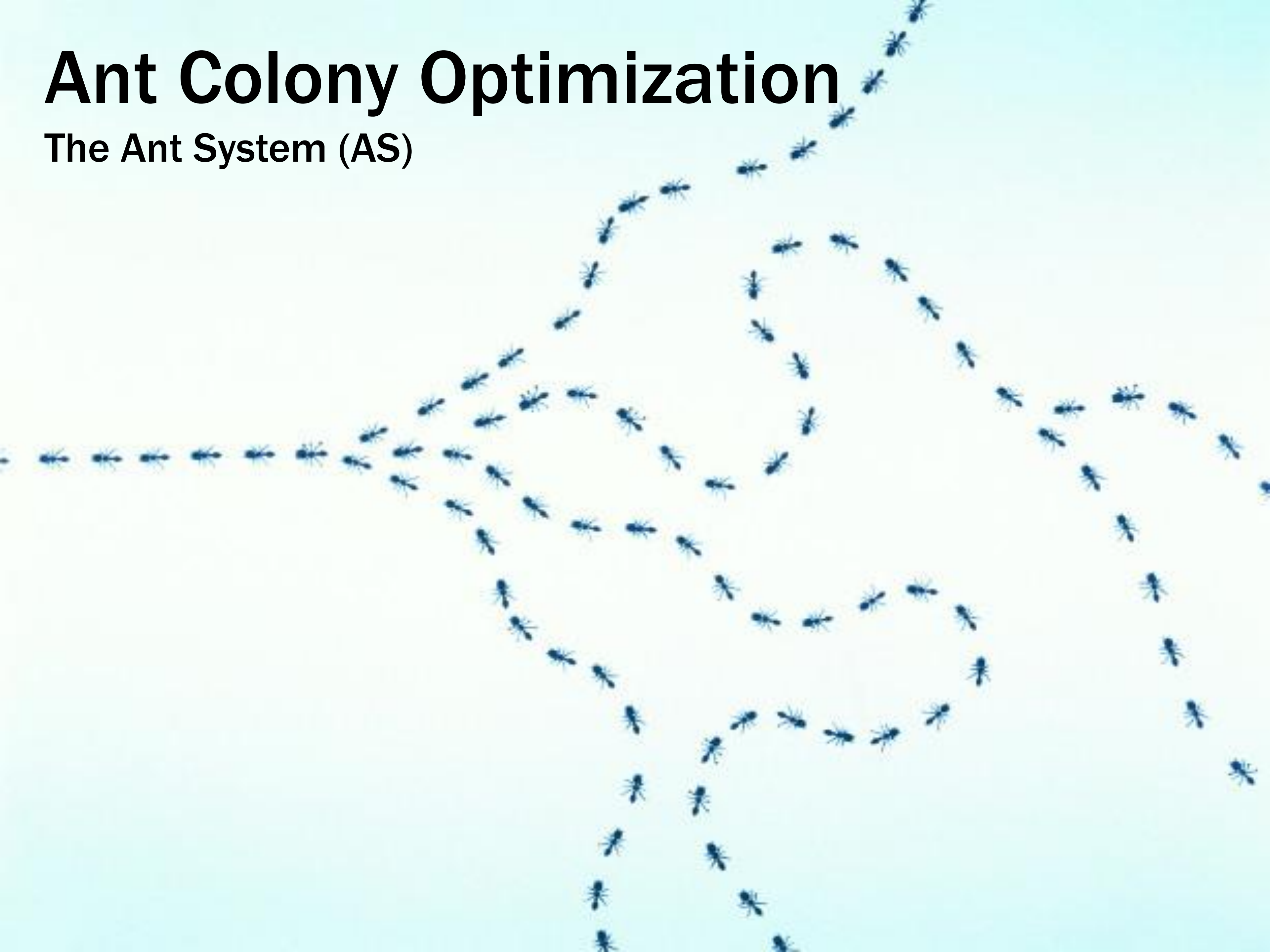


Initial state:
no ants
E
D
H
C
B
A
d = 1
d = 0.5
d = 1
d = 0.5
t = 0
E
30 ants
15 ants
D
15 ants
H
C
15 ants
15 ants
B
30 ants
A
t = 1
E
30 ants
10 ants
D
20 ants
τ = 15
τ = 30
H
C
τ = 15
τ = 30
10 ants
B
20 ants
30 ants
A

(a) (b) (c)

Ant Colony Optimization

The Ant System (AS)



Ant System

- First introduced by Marco Dorigo in 1992
- Result of research on computational intelligence approaches to combinatorial optimization
- Originally applied to Traveling Salesman Problem
- Applied later to various hard optimization problems
- Variations later developed (you are only responsible for the basic Ant System: item 1 in Section II.C of Dorigo et al. 2006)

Ants as Agents

Each ant is a simple agent with the following characteristics:

- It chooses the town to go to with a probability that is a function of the town distance and of the amount of trail present on the connecting edge;
- To force the ant to make legal tours, transitions to already visited towns are disallowed until a tour is complete (this is controlled by a tabu list);
- When it completes a tour, it lays a substance called *trail* on each edge (i, j) visited.

We use d_{ij} to denote the distance between any two cities in the problem.

We let $\tau_{ij}(t)$ denote the intensity of trail on edge (i,j) at time t. Trail intensity is updated following the completion of each algorithm cycle, at which time every ant will have completed a tour. Each ant subsequently deposits trail of quantity Q/L_k on every edge (i,j) visited in its individual tour. Notice how this method would favor shorter tour segments. The sum of all newly deposited trail is denoted by $\Delta \tau_{ij}$. Following trail deposition by all ants, the trail value is updated using $\tau_{ij}(t + 1) = p \times \tau_{ij}(t) + \Delta \tau_{ij}$, where p is the rate of trail decay per time interval and $\Delta \tau_{ij} = \sum_{k=1}^{m} \Delta \tau_{ij}^{k}$

Two factors drive the probabilistic model:

1) ***Visibility***, denoted η_{ij}, equals the quantity $1/d_{ij}$

2) ***Trail***, denoted $\tau_{ij}(t)$

These two factors play an essential role in the central probabilistic transition function of the Ant System.

In return, the weight of either factor in the transition function is controlled by the variables α and β, respectively. Significant study has been undertaken by researchers to derive optimal α:β combinations.

Probabilistic Transition Function

$$p_{ij}^{k}(t)=\begin{cases}\dfrac{[\tau_{ij}(t)]^{\alpha}\cdot[\eta_{ij}]^{\beta}}{\sum\limits_{k\in allowed_k}[\tau_{ij}(t)]^{\alpha}\cdot[\eta_{ij}]^{\beta}} & \text{if } k\in allowed_k \\ 0 & otherwise\end{cases}$$

The subscripts in denominator should be ik, not ij

A high value for α means that trail is very important and therefore ants tend to choose edges chosen by other ants in the past.

Ant System (AS) Algorithm

1. Initialization
2. Randomly place ants
3. Build tours
4. Deposit, update trail
5. Loop or exit

- Suggested parameters:
  - p evaporation rate (trail decay): 0.1
  - Number of ants: 25
  - Q = 1
  - 200 iterations
  - Alpha, Beta == 0.5
- But feel free to experiment