Swarm Intelligence: A brief introduction

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1. Swarm intelligence
2. Ant foraging behaviour
3. Ant colony optimisation
4. Swarm robotics

Swarm Intelligence

Collective intelligence emerging in groups of (simple) agents.

Swarm Intelligence

Roots in models of social insects behavior:

- Foraging behavior
- Division of labor and task allocation
- Cemetery organization
- Nest building
- Collaborative transport

Swarm Intelligence

Properties of collective intelligence systems:

- Distributed computation
- Direct and **indirect** interactions
- Agents equipped with simple computational capabilities
- Robustness
- Adaptiveness

Self-organization

Dynamical mechanisms whereby structures appear at the global level from interactions among lower-level components.

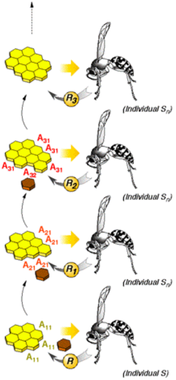
- Creation of spatio-temporal structures
- Possible coexistence of several stable states (multistability)
- Existence of bifurcations when some parameters are varied

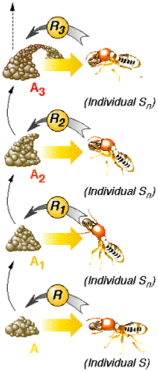
Self-organization

- Multiple interactions among agents
  - Simple agents (e.g., rule based)
  - Sistems composed of many agents
- Positive feedback
  - Amplification of random fluctuations and structure formation
  - Reinforcement of most common behavior patterns
- Negative feedback
  - Saturation
  - Competition
  - Resource exhaustion

Stigmergy

One agent modifies the environment and the other agent reacts to the changed environment.





Ant algorithms

- Algorithms inspired by the behavior of real ants

Examples:

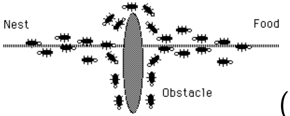
- Foraging
- Corpse clustering
- Division of labor

The model

- While walking ants deposit a substance called *pheromone* on the ground
- They choose with higher probability paths that are marked by stronger pheromone concentrations
- Cooperative interaction which leads to the emergence of short(est) paths

Ant foraging behavior

(1)



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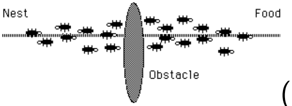

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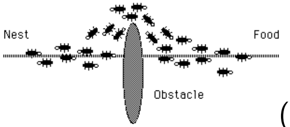

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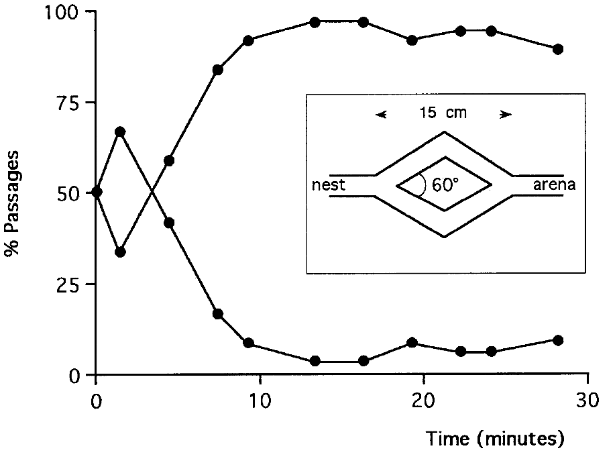
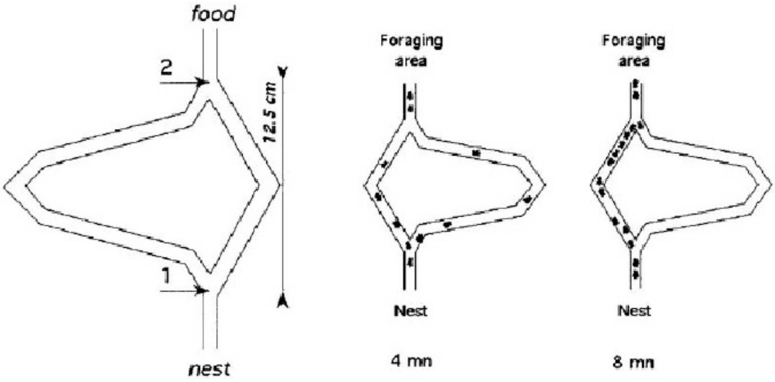
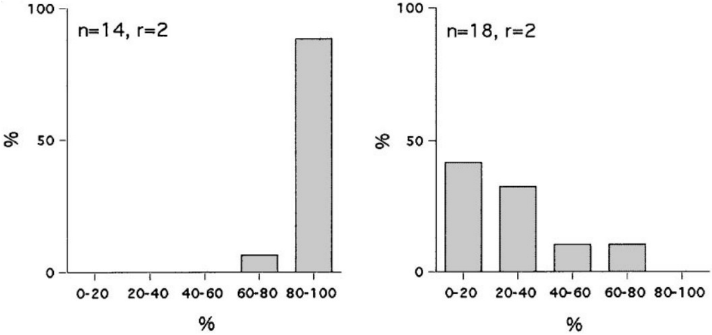
The double bridge



The double bridge



The double bridge



Ant Colony Optimization

- Population-based metaheuristic inspired by the foraging behavior of ants
- Ants can find the shortest path between the nest and a food source
- Heuristic strategy for optimization problems

Ant Colony Optimization

Parametrized probabilistic model – the *pheromone model* – that is used to model the chemical pheromone trails.

Ants incrementally construct solutions by adding components to a partial solution under consideration

Ants perform stochastic walks on the *construction graph*: a completely connected graph $\mathcal{G} = (\mathcal{C}, \mathcal{L})$.

ACO construction graph

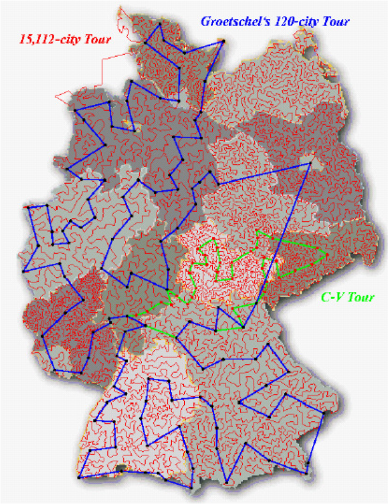
$\mathcal{G} = (\mathcal{C}, \mathcal{L})$

- vertices are the solution components $\mathcal{C}$
- $\mathcal{L}$ are the connections
- *states* are paths in $\mathcal{G}$

Solutions are *states*, i.e., encoded as paths on $\mathcal{G}$

Constraints are also provided in order to construct feasible solutions

Example: TSP



Example

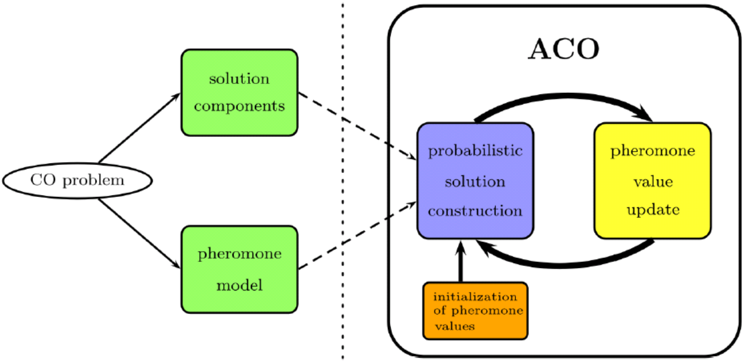
One possible TSP model for ACO:

- nodes of $\mathcal{G}$ (the components) are the cities to be visited;
- states are partial or complete paths in the graph;
- a solution is an Hamiltonian tour in the graph;
- constraints are used to avoid cycles (an ant can not visit a city more than once).

Sources of information

- Connections, components (or both) can have associated pheromone trail and heuristic value.
- Pheromone trail takes the place of natural pheromone and encodes a long-term memory about the whole ants' search process
- Heuristic represents a priori information about the problem or dynamic heuristic information

The basic principle



Ant system

- First ACO example
- Ants construct a solution by building a path along the construction graph
- The *transition rule* is used to choose the next node to add
- Both heuristic and pheromone are used
- The pheromone values are updated on the basis of the quality of solutions built by the ants

Ant system

```
InitializePheromoneValues()
while termination conditions not met do
   for all ants a ∈ 𝒜 do
      s_a ← ConstructSolution(τ,η)
   end for
   ApplyOnlineDelayedPheromoneUpdate()
end while
```

Ant system

The probability of moving from city i to city j for ant k is:

$$p_{ij}^k = \begin{cases} \frac{\left[\tau_{ij}\right]^{\alpha}\left[\eta_{ij}\right]^{\beta}}{\sum_{k \in \mathrm{feasible}_k} [\tau_{ik}]^{\alpha} [\eta_{ik}]^{\beta}} & \text{if} \quad j \in \mathrm{feasible}_k \\ 0 & \text{otherwise} \end{cases}$$

α e β weight the relative influence of pheromone and heuristic

Ant System

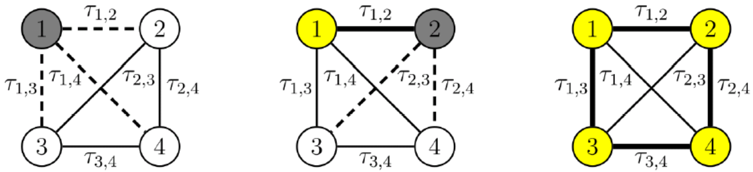
Pheromone update rule:

$$\tau_{ij} \leftarrow (1-\rho)\cdot\tau_{ij} + \sum_{k=1}^{m} \Delta\tau_{ij}^{k} \qquad (\rho : \text{evaporation coefficient})$$

$$\Delta\tau_{ij}^{k} = \begin{cases} \frac{1}{L_k} & \text{if ant } k \text{ used arc } (i,j) \\ 0 & \text{otherwise} \end{cases}$$

L_k: length of the tour built by ant k

A pictorial view



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

(by courtesy of C. Blum)

ACO: State of the art

- $\mathcal{MAX}$-$\mathcal{MIN}$ Ant System
- Hyper-cube Framework
- Multi-level ACO
- Beam ACO

Towards swarm robotics

Division of labor

- Several kinds of division of labor. E.g., reproductive, castes, tasks accomplished in the colony.
- The ratios of workers performing the different tasks can vary

A simple model of task allocation

- A stimulus is associated to a task
- Individuals start to be engaged in a task when the corresponding stimulus exceeds a given threshold
- The intensity of a stimuls can be a number of encounters, a chemical concentration, etc.

A simple model of task allocation

- Let us assume one task to be performed
- Let S_i be the state of individual i (inactive:0, active:1)
- Let s be the amount of stimulus corresponding to the task
- Let θ_i be the *response threshold* of individual i (the higher θ, the lower the tendency to perform the task)

A simple model of task allocation

An inactive individual starts performing the task with a probability p per unit time:

$$p(S_i = 0 \rightarrow S_i = 1) = \frac{s^n}{s^n + \theta_i^n}$$

where n is a parameter.

An active individual becomes inactive probability $p = p_0$ per unit time.

Corpse clustering

- Ants collect dead bodies and aggregates them in clusters
- Basic mechanism: clusters of items grow by attracting workers to deposit more items (positive feedback)

The model:

- Let f be the fraction of perceived items in the neighbourhood of the ant.
- Ants move randomly
- Probability of pick-up: $p_p = \left(\frac{k_1}{k_1+f}\right)^2$
- Probability of delivery: $p_d = \left(\frac{f}{k_2+f}\right)^2$
- k_1 and k_2 are threshold constants

Ant algorithms applications

- Combinatorial optimization
- Mixed integer-continuous optimization
- Networks: AntNet
- Data clustering and exploratory data analysis
- Coordinated motion
- Self-assembling

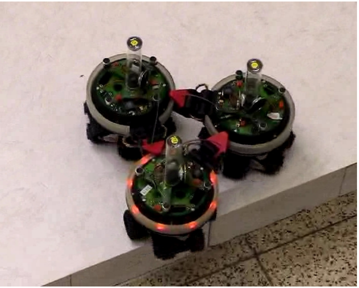
The swarm-bots project

GOAL: Study a novel approach to the design and implementation of self-organising and self-assembling artefacts

`www.swarm-bots.org`

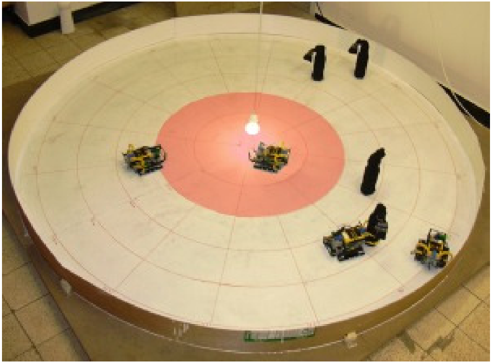
Swarm-bots: results

- Hole/obstacle avoidance



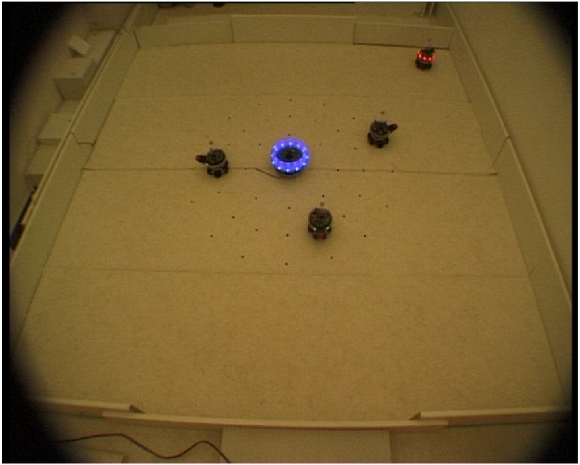
Swarm-bots: results

- Adaptive division of labour



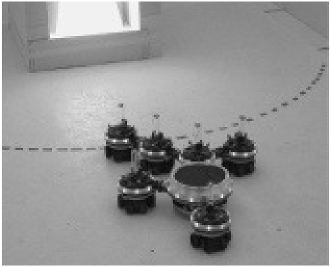
Swarm-bots: results

- Finding object/goal



Swarm-bots: results

- Cooperative transport

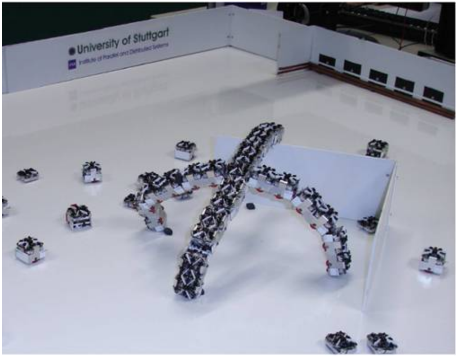


The SYMBRION project

GOAL: The main focus of these projects is to investigate and develop novel principles of adaptation and evolution for symbiotic multi-robot organisms based on bio-inspired approaches and modern computing paradigms

http://www.symbrion.eu/

The SYMBRION project



To know more

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