technische universität
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# Computational Intelligence

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## Contents

- Ant algorithms (combinatorial optimization)
- Particle swarm algorithms (optimization in $\mathbb{R}^n$)

metaphor

swarms of bird or fish

seeking for food

↓

concepts:

- evaluation of own current situation
- comparison with other conspecific
- imitation of behavior of successful conspecifics

⇒ audio-visual communication

ants or termites

seeking for food

↓

concepts:

- communication / coordination by means of „stigmergy“
- reinforcement learning → positive feedback

⇒ olfactoric communication

**ant algorithms** (ACO: Ant Colony Optimization)

paradigm for design of metaheuristics for combinatorial optimization

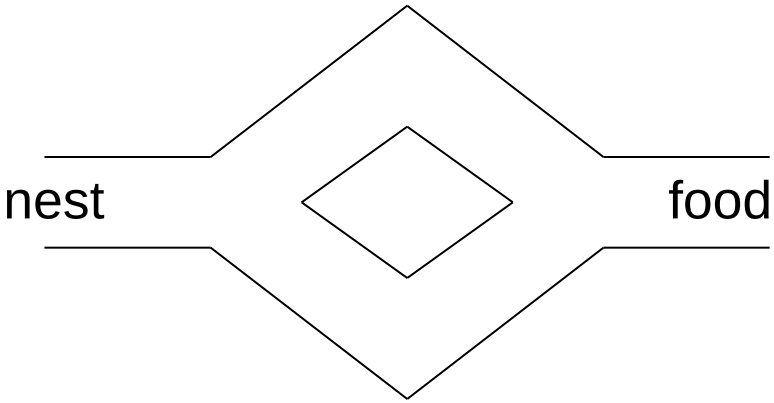
stigmergy = indirect communication through modification of environment

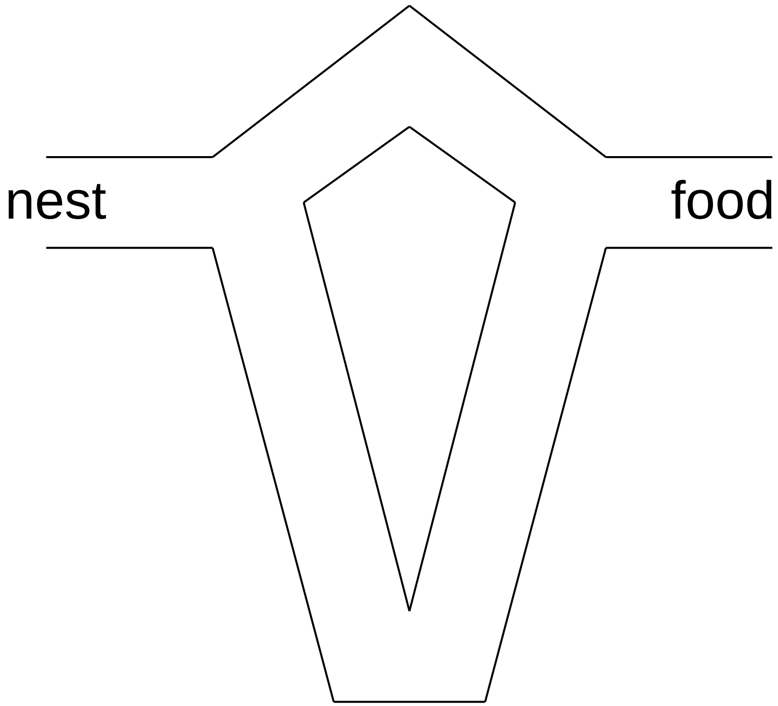
$\sim$ 1991 Colorni / Dorigo / Maniezzo: Ant System (also: 1. ECAL, Paris 1991)
Dorigo (1992): collective behavor of social insects (PhD)

**some facts:**

- about 2% of all insects are social
- about 50% of all social insects are ants
- total weight of all ants = total weight of all humans
- ants populate earth since 100 millions years
- humans populate earth since 50.000 years

**double bridge experiment** (Deneubourg et al. 1990, Goss et al. 1989)




**initially:**
both bridges used equally often

**finally:**
all ants run over single bridge only!

**finally:**
all ants use the shorter bridge!

**How does it work?**

- ants place pheromons on their way
- routing depends on concentration of pheromons

**more detailed:**

ants that use shorter bridge return faster

→ pheromone concentration higher on shorter bridge

→ ants choose shorter bridge more frequently than longer bridge

→ pheromon concentration on shorter bridge even higher

→ even more ants choose shorter bridge

→ a.s.f.

positive feedback loop

## Ant System (AS) 1991

combinatorial problem:

- components $C = \{ c_1, c_2, ..., c_n \}$
- feasible set $F \subseteq 2^C$
- objective function $f: 2^C \to \mathbb{R}$

**ants =** set of concurrent (or parallel) asynchronous agents
move through state of problems

$\downarrow$

partial solutions of problems

$\to$ caused by movement of ants the final solution is compiled incrementally

**movement:** stochastic local decision

(2 parameters)

‘trails‘ — ‘attractiveness‘

paths — excitement, stimulus

while constructing the solution (if possible), otherwise at the end:

1. evaluation of solutions
2. modification of ‘trail value‘ of components on the path

feedback

**ant k in state i**

- determine all possible continuations of current state i
- choice of continuation according to probability distribution $p_{ij}$

$p_{ij}$ = q( attractivity, amount of pheromone )

heuristic is based on *a priori* desirability of the move

*a posteriori* desirability of the move „how rewarding was the move in the past?“

- update of pheromone amount on the paths: as soon as all ants have compiled their solutions

  good solution ↑ increase amount of pheromone, otherwise decrease ↓

## **Combinatorial Problems** (Example TSP)

<u>TSP:</u>

- ant starts in arbitrary city i
- pheromone on edges (i, j): $\tau_{ij}$
- probability to move from i to j: $$p_{ij}^{(t)} = \frac{\tau_{ij}^{\alpha}\,\eta_{ij}^{\beta}}{\sum\limits_{k \in \mathcal{N}_i(t)} \tau_{ik}^{\alpha}\,\eta_{ik}^{\beta}} \quad \text{for } j \in \mathcal{N}_i(t)$$
- $\eta_{ij} = 1/d_{ij}$ ; $d_{ij}$ = distance between city i and j
- $\alpha = 1$ and $\beta \in [2, 5]$ (empirical), $\rho \in (0,1)$ “evaporation rate“
- $\mathcal{N}_i(t)$ = neighborhood of i at time step t (without cities already visited)
- update of pheromone after $\mu$ journeys of ants: $$\tau_{ij} := \rho\,\tau_{ij} + \sum_{k=1}^{\mu} \Delta\tau_{ij}(k)$$
- $\Delta\tau_{ij}(k)$ = 1 / (tour length of ant k), if (i,j) belongs to tour

**two additional mechanisms:**

1. *trail evaporation*
2. *demon actions* (for centralized actions; not executable in general)

Ant System (AS) is prototype

tested on TSP-Benchmark → not competitive

→ but: works in principle!

subsequent: 2 targets

1. increase efficiency (→ competitiveness with *state-of-the-art* method)
2. better explanation of behavior

1995 ANT-Q (Gambardella & Dorigo), simplified: 1996 ACS *ant colony system*

## Particle Swarm Optimization (PSO)

↓

abstraction from fish / bird / bee swarm

paradigm for design of metaheuristics for <u>continuous</u> optimization

developed by Russel Eberhard & James Kennedy (~1995)

**concepts:**

- particle (x, v) consists of position $x \in \mathbb{R}^n$ and "velocity" (i.e. direction) $v \in \mathbb{R}^n$
- PSO maintains multiple potential solutions at one time
- during each iteration, each solution/position is evaluated by an objective function
- particles "fly" or "swarm" through the search space
  to find position of an extremal value returned by the objective function

## PSO update of particle ($x_i$, $v_i$) at iteration t

<u>1st step:</u>

$$v_i(t+1) = \omega\, v_i(t) + \gamma_1\, R_1\, (x_b^*(t) - x_i(t)) + \gamma_2\, R_2\, (x^*(t) - x_i(t))$$

const. const. const.

random variable random variable

best solution among all solutions of iteration t ≥ 0

$$x_b^*(t) = \underset{i=1,\dots,\mu}{\operatorname{argmin}}\{f(x_i(t))\}$$

best solution among all solutions up to iteration t ≥ 0

$$x^*(t) = \underset{\tau=0,\dots,t}{\operatorname{argmin}}\{f(x_b^*(\tau))\}$$

## PSO update of particle ($x_i$, $v_i$) at iteration t

<u>1st step:</u>

$$\underbrace{v_i(t+1)}_{\text{new direction}} = \omega \underbrace{v_i(t)}_{\text{old direction}} + \gamma_1 R_1 \underbrace{(x_b^*(t) - x_i(t))}_{\text{direction from } x_i(t) \text{ to } x_b^*(t)} + \gamma_2 R_2 \underbrace{(x^*(t) - x_i(t))}_{\text{direction from } x_i(t) \text{ to } x^*(t)}$$

$\omega$ : inertia factor, often $\in [0.8, 1.2]$

$\gamma_1$ : cognitive factor, often $\in [1.7, 2.0]$

$\gamma_2$ : social factor, often $\in [1.7, 2.0]$

$R_1$ : positive r.v., often $r_1 \sim U[0, 1]$

$R_2$ : positive r.v., often $r_2 \sim U[0, 1]$

## PSO update of particle ($x_i$, $v_i$) at iteration t

2nd step:

$$\underbrace{x_i(t+1)}_{\text{new position}} = \underbrace{x_i(t)}_{\text{old position}} + \underbrace{v_i(t+1)}_{\text{new direction}}$$

Note the similarity to the concept of mutative step size control in EAs:
first change the step size (direction),
then use changed step size (direction)
for changing position.

**More swarm algorithms:**

- Artificial Bee Colony
- Krill Herd Algorithm
- Firefly Algorithm
- Glowworm Swarm
- ...

**But be watchful:**

Is there a new algorithmic idea inspired from the biological system?

Take a look at the code / formulas: Discover similarities & differences!

Often: “Old wine in new skins.“