

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

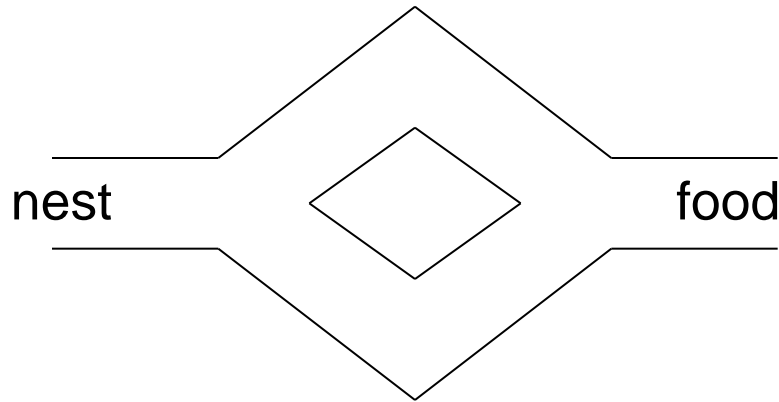
~ 1991 Coloni / Dorigo / Maniezzo: Ant System (also: 1. ECAL, Paris 1991)

Dorigo (1992): collective behavior 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)

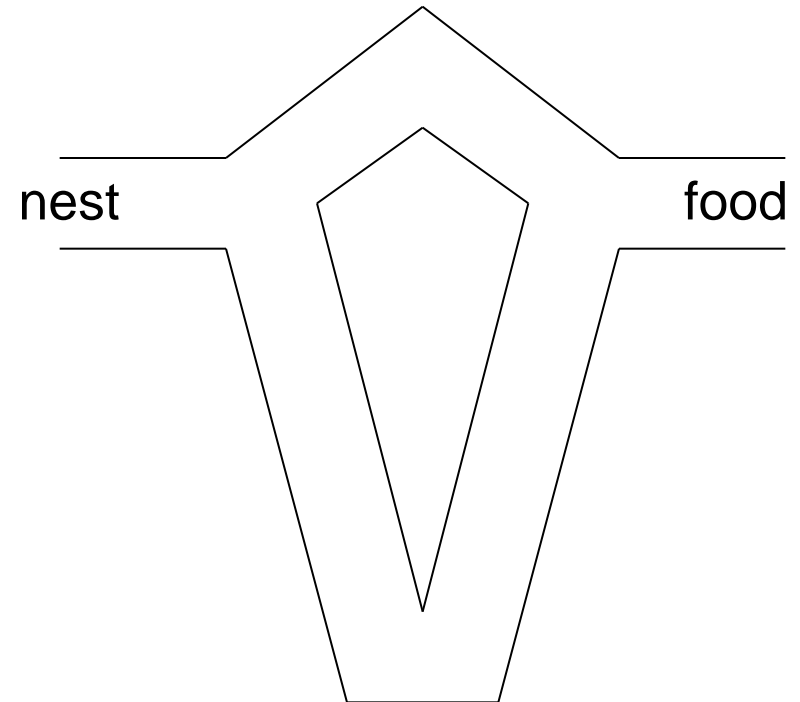


initially:

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

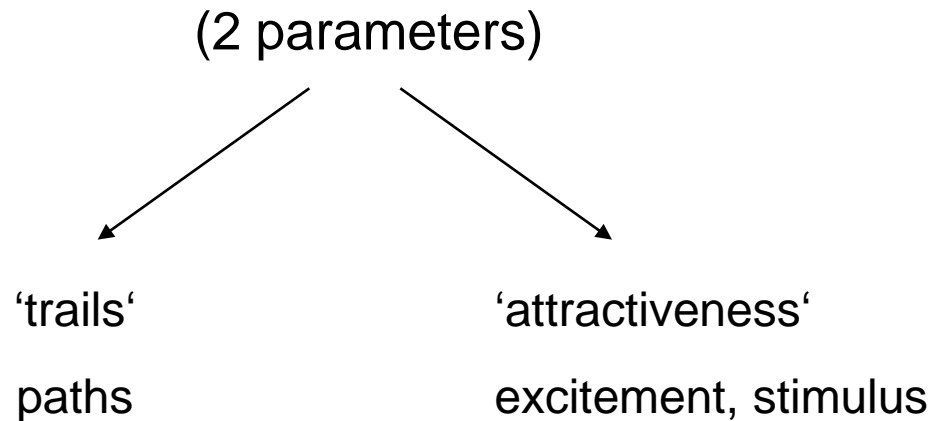
ants = set of concurrent (or parallel) asynchronous agents
move through state of problems



partial solutions of problems

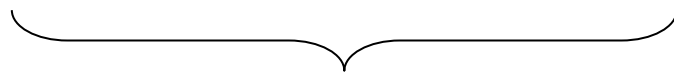
→ caused by movement of ants the final solution is compiled incrementally

movement: stochastic local decision



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}

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



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 \uparrow increase amount of pheromone, otherwise decrease \downarrow

Combinatorial Problems (Example TSP)

TSP:

- ant starts in arbitrary city i
- pheromone on edges (i, j) : τ_{ij}
- probability to move from i to j :
$$p_{ij}^{(t)} = \frac{\tau_{ij}^\alpha \eta_{ij}^\beta}{\sum_{k \in \mathcal{N}_i(t)} \tau_{ik}^\alpha \eta_{ik}^\beta} \quad \text{for } j \in \mathcal{N}_i(t)$$
- $\eta_{ij} = 1/d_{ij}$; 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 μ journeys of ants:
$$\tau_{ij} := \rho \tau_{ij} + \sum_{k=1}^{\mu} \Delta \tau_{ij}(k)$$
- $\Delta \tau_{ij}(k) = 1 / (\text{tour length of ant } k)$, 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 continuous 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

1st step:

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

↓
const.

↓
const.

↓
random
variable

best solution
among all solutions
of iteration $t \geq 0$

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

↓
const.

↓
random
variable

best solution
among all solutions
up to iteration $t \geq 0$

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

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

1st step:

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



new
direction



old
direction



direction from
 $x_i(t)$ to $x_b^*(t)$



direction from
 $x_i(t)$ to $x^*(t)$

- ω : inertia factor, often $\in [0.8, 1.2]$
- γ_1 : cognitive factor, often $\in [1.7, 2.0]$
- γ_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!

Oftentimes: “Old wine in new skins.”