SWINBURNE UNIVERSITY OF TECHNOLOGY

COS30018 – Intelligent Systems. Week 8: Collective Intelligence/Swarm Intelligence

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Nature-inspired computing

- Nature has always served as a source of inspiration for engineers and scientists
- The best problem solver known in nature is:
  - the (human) brain that created "the wheel, New York, wars and so on" (after Douglas Adams' Hitch-Hikers Guide)
  - the evolution mechanism that created the human brain (after Darwin's Origin of Species)
- Answer 1 → neurocomputing
  - Artificial Neural Networks (Week 6)
- Answer 2 → evolutionary computing
  - Genetic Algorithms and Evolutionary Computing (Week 7)
  - Swarm Intelligence (Today)

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Outline

- Swarm Intelligence
- Introduction to Particle Swarm Optimization (PSO)
  - Origins
  - Concept
  - PSO Algorithm
- Introduction to Ant Colony Optimization (ACO)
  - Origin & Concept
  - ACO Algorithm

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School of fish or flock of birds
COORDINATION??

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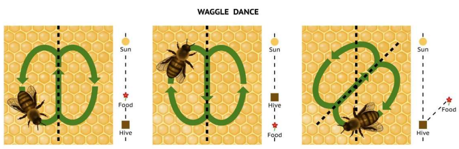

Waggle dance is one of the main types of **communication** methods used by bees

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Long trail of ants
Coordinated behaviour
(Communication-based??)

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Swarm intelligence

- Collective system capable of accomplishing difficult tasks in dynamic and varied environments:
  - NO external guidance or control
  - NO central coordination
- Achieving a **collective performance** which could not normally be achieved by an individual acting alone

Source: http://www.scs.carleton.ca/~arpwhite/courses/95590Y/notes/SI Lecture 3.pdf

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Swarm intelligence

- Constituting a natural model particularly suited to **distributed problem solving**
  - Particle Swarm Optimisation (**PSO**) — a way to solve optimisation problems, based on the swarming behaviour via direct communication.
  - Ant Colony Optimisation (**ACO**) – a different way to solve optimisation problems based on the way that ants indirectly communicate directions to each other.

Source: http://www.scs.carleton.ca/~arpwhite/courses/95590Y/notes/SI Lecture 3.pdf

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Introduction to the PSO: Origins

- Inspired from the nature social behavior and dynamic movements with communications of insects, birds and fish

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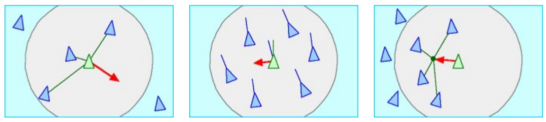
Introduction to the PSO: Origins

- In 1986, Craig Reynolds described this process in 3 simple behaviors:



Separation
avoid crowding local flock mates

Alignment
move towards the average heading of local flock mates

Cohesion
move toward the average position of local flock mates

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Introduction to the PSO: Origins

- Application to optimization: Particle Swarm Optimization
- Proposed by James Kennedy & Russell Eberhart (1995)
- Combines **self-experiences** with **social experiences**

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Introduction to the PSO: Concept

- Many **particles** (called **agents** in PSO) constituting a swarm "fly" around in the search space looking for the best solution
- Each particle in search space adjusts its "flying" based on:
  - its position,
  - its own flying experience, AND
  - the flying experience of other particles

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Introduction to the PSO: Concept

- Collection of flying particles (swarm) - Changing solutions
- Search area - Possible solutions
- Movement towards a promising area to get the global optimum
- Each particle keeps track:
  - its best solution, personal best, *pbest*
  - the best value of any particle, global/**neighborhood** best, *gbest*

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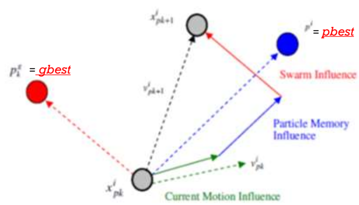
Introduction to the PSO: Concept

- Each particle modifies its position according to:
  - its current **position**: x^i_{pk}
  - its current **velocity**: v^i_{pk}
  - the vector between its current position and *pbest*
  - the vector between its current position and *gbest*



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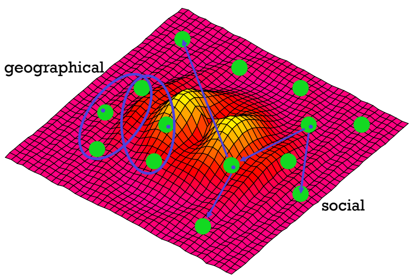
Introduction to the PSO: Algorithm - Neighborhood



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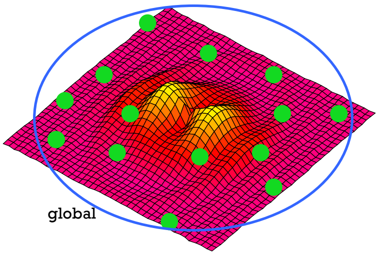
Introduction to the PSO: Algorithm - Neighborhood



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Introduction to the PSO: Algorithm - Parameters

- Algorithm parameters:
  - ***A*** : Population of agents (**agent = particle**)
  - $\boldsymbol{p_i}$: Position of agent $\boldsymbol{a_i}$ in the solution space ($\boldsymbol{a_i}$.Pos)
  - ***f*** : Objective function
  - $\boldsymbol{v_i}$: Velocity of agent's $\boldsymbol{a_i}$ ($\boldsymbol{a_i}$.Vel)
  - $\boldsymbol{V(a_i)}$: Neighborhood of agent a_i ($\boldsymbol{a_i}$.NB)

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Introduction to the PSO: Algorithm

```
[x*] = PSO()
[aj.Pos] = Particle_Initialization();
For i=1 to it_max
  For each particle a in A do
    a.fp = f(a.Pos);
    If a.fp is better than f(a.pBest)
        a.pBest = a.Pos;
    end
  end
  For each particle a in A:   a.gBest = best p in a.NB;
  For each particle a in A do
     a.Vel = a.Vel + c1*rand*(a.pBest – a.Pos)
                   + c2*rand*(a.gBest – a.Pos);
     a.Pos = a.Pos + a.Vel;
  end
end
```

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Introduction to the PSO: Algorithm

- Particle update rule
  a.Pos = a.Pos + a.Vel
  - with
    a.*Vel* = a.*Vel + c1*rand**(a.*pBest* – *a.Pos*)
    + *c2*rand**(a.*gBest* – *a.Pos*)
  - where
    - *a.Pos* : particle's position
    - a.*Vel* : path direction
    - *c1* : weight of local information
    - *c2* : weight of global information
    - a.*pBest* : best position of the particle
    - a.*gBest* : best position of the (neighbouring) swarm
    - *rand* : random variable

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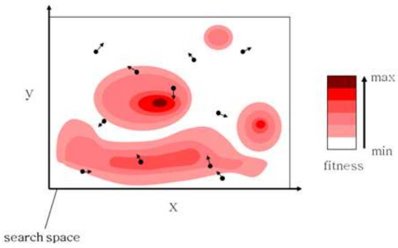
Introduction to the PSO: Algorithm - Example



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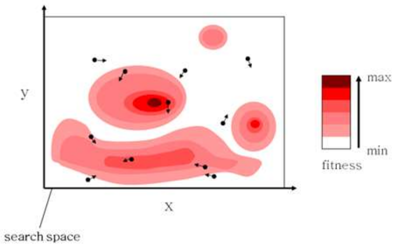
Introduction to the PSO: Algorithm - Example



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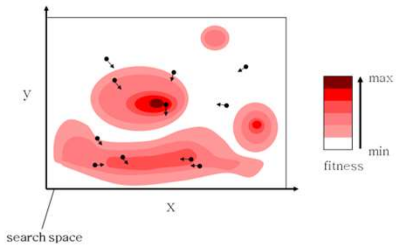
Introduction to the PSO: Algorithm - Example



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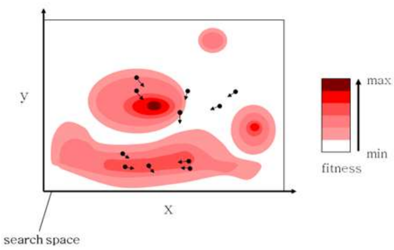
Introduction to the PSO: Algorithm - Example



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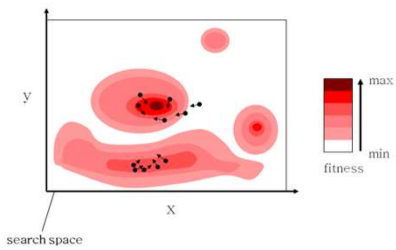
Introduction to the PSO: Algorithm - Example



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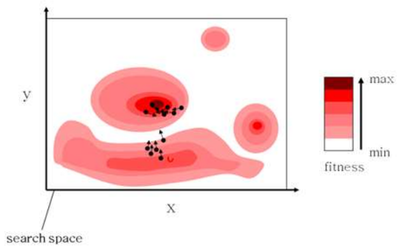
Introduction to the PSO: Algorithm - Example



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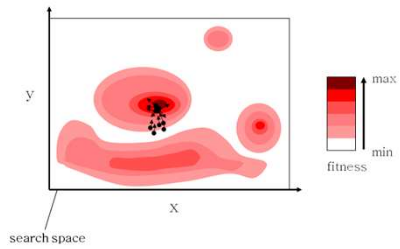
Introduction to the PSO: Algorithm - Example



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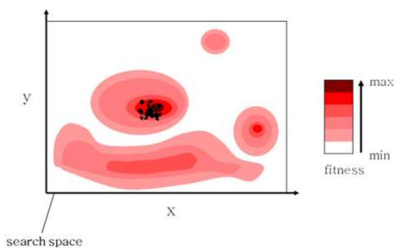
Introduction to the PSO: Algorithm - Example



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PSO: Applications

- **Suitable for problems whose solutions can be mapped to an R^n space.**
  - Energy management: what is a user's optimal consumption profile given the multiple objectives: Minimizing cost, maximizing comfortability, minimizing environmental damages, etc.
  - Aircraft surface design: safety vs cost vs practicality
  - Vehicle routing problems
  - Structural engineering problems
  - … and even
    - weights of an ANN

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Presentation Outline

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Collective intelligence as emergent property of many individuals operating simple rules

For *Lasius Niger* ants, [Franks, 89] observed:

- regulation of nest temperature within 1 degree celsius range;
- **forming bridges;**
- raiding specific areas for food;
- building and protecting nest;
- **sorting brood and food items;**
- **cooperating in carrying large items;**
- emigration of a colony;
- **finding shortest route from nest to food source;**
- preferentially exploiting the richest food source available.

The ACO algorithm is inspired by this:

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A key concept: Stigmergy

Stigmergy is:

indirect communication via interaction with the environment [Gassé, 59]

- A problem gets solved bit by bit ..
- Individuals communicate with each other in the above way, affecting what each other does on the task.
- Individuals leave *markers* or *messages* – these don't solve the problem in themselves, but they affect other individuals in a way that helps them solve the problem …
  - e.g. as we will see, this is how ants find shortest paths.

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Stigmergy in Ants

Ants are behaviorally unsophisticated, but collectively they can perform complex tasks.

Ants have *highly developed sophisticated sign-based* ***stigmergy***

- They communicate using pheromones;
- They **lay trails of pheromone** that can be followed by other ants.

- If an ant has a **choice of two pheromone trails** to follow, one to the NW, one to the NE, but the NW one is *stronger* – which one will it follow?

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ACO Concept: Pheromone Trails

- Individual ants lay pheromone trails while travelling from the nest, to the nest or possibly in both directions.
- The pheromone trail gradually evaporates over time.
- But pheromone trail strength accumulate with multiple ants using path.

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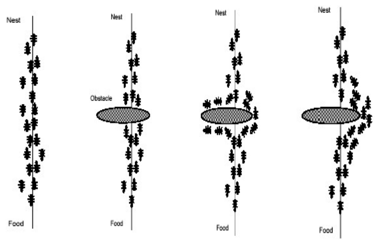
ACO Concept: Pheromone Trails



Ant Algorithms – (P.Koumoutsakos – based on notes L. Gamberdella (www.idsia.ch)

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Ant Colony Optimisation Algorithms: Basic Ideas

- Ants are *agents* that interact with its environment (and leave its information on the env.)
- Typical environment in ACO is a graph.

Ants:

Move along between nodes in a graph.

They choose where to go based on pheromone strength (and maybe other things)

An ant's path represents a specific candidate solution.

When an ant has finished a solution, pheromone is laid on its path, according to quality of solution.

This pheromone trail affects behaviour of other ants by `stigmergy' …

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Some nice online demo:

- http://www.theprojectspot.com/tutorial-post/ant-colony-optimization-for-hackers/10

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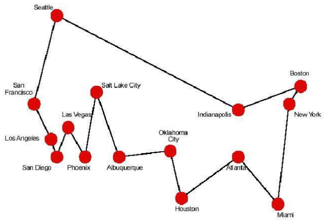
Travelling Salesman Problem (TSP)

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.



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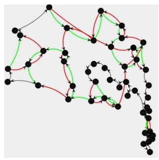
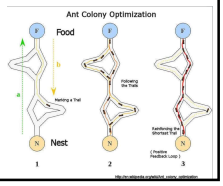
ACO: Algorithm



```
[x*] = ACO()
  [a_i State] = Ant_Colony_Initialization();
  while not terminated:
    For each ant a in A do:
      a.generateSolutions();
      a.transitionToNewState();
    end
    pheromoneUpdate();
  end
```



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ACO for the Traveling Salesman Problem – generateSolution()

$$p_{xy}^k = \frac{(\tau_{xy}^{\alpha})(\eta_{xy}^{\beta})}{\sum_{z \in \mathrm{allowed}_y} (\tau_{xz}^{\alpha})(\eta_{xz}^{\beta})}$$

Note: Ants don't have to start from the same city.
-> *Parallelized computation*.

p_{xy}^k: The probability that the k^{th} ant currently at city x would move to (*allowable*) city y

τ_{xy}: the amount of pheromone deposited for transition from x to y

η_{xy}: the heuristics for how desirable it is to go from x to y (*e.g.*, $\frac{1}{d_{xy}}$, where d_{xy} is distance between x and y)

α and β parameters to control the influence of τ_{xy} and η_{xy}, respectively.

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ACO for TSP – Pheromone update

$$\tau_{xy} \leftarrow (1-\rho)\tau_{xy} + \sum_{k}^{m} \Delta\tau_{xy}^k$$

$$\Delta\tau_{xy}^k = \begin{cases} Q/L_k & \text{if ant } k \text{ uses curve } xy \text{ in its tour} \\ 0 & \text{otherwise} \end{cases}$$

τ_{xy}: the amount of pheromone deposited for transition from x to y

ρ : the **pheromone evaporation** coefficient

m: the number of ants, and

$\Delta\tau_{xy}^k$: the amount of pheromone deposited on link xy by the k^{th} ant.

Q: a constant

L_k: cost for the route taken by the k^{th} ant (*e.g., total distance of that route)*

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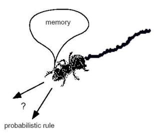
ACO State Transition Rule



Next city is chosen between the **not visited** cities according to a *probabilistic* rule

Exploitation: the best edge is chosen

Exploration: each of the edges in proportion to its value

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Summary

- Swarm intelligence:
  - Achieving a collective performance which could not normally be achieved by an individual acting alone: **PARALLELIZING THE SEARCH**
- PSO has a memory (for storing *pbest* and *gbest*)
- There is no selection in PSO
  - → all particles survive for the length of the run
  - → PSO is the only EA that does not remove candidate population members
- PSO is: Simple in concept, easy to implement, and computationally efficient
- ACO is an approach for solving hard **combinatorial optimization problems**.
- Artificial ants implement a randomized construction heuristic which makes probabilistic decisions.
- The accumulated search experience is taken into account by the adaptation of the pheromone trail.

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