Algorithms and their Applications CS2004 (2020-2021)

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15.1 Ant Colony Optimisation and Particle Swarm Optimisation

Class Tests So Far…

- Class Test CRI: 305 attempts
- Class Test CRII: 257 attempts
- Class Test CRIII: 184 attempts
- Class Test CRIV: 114 attempts
- **All four class tests must be passed to pass Task #1.**
- **Task #1 weighs 30% of the coursework**
- **But, if you do not pass Task #1 you will be capped at D- grade (coursework).**
- **Class tests needs to be completed by 16/02/2021**

This Lecture

- In this lecture we are going to cover:
  - Swarm Intelligence
  - Ant Colony Optimisation
  - Particle Swarm Optimisation

Swarm Intelligence

- A new field of study
  - around 30 years old (OK…maybe not that new…)
- The **interaction** of many simple parts creating **complex** behaviour
  - For example, ants, bees, fish, birds, etc…
  - The net effect is greater than the sum of the individuals
- Emergent behaviour as a side effect of the system

Social Insects

- Several million years of success
  - Efficient
  - Flexible
  - Robust
- Can solve many problems:
  - Find food, feed the brood, defend the nest
  - Build a nest …




Flocking

- “Boids” model created by Craig Reynolds in 1987
- Boids =“bird-oid” objects (also schooling fish)
- Video links:
  - http://www.red3d.com/cwr/boids/
  - http://www.youtube.com/watch?v=Psq0FSOF_xU&feature=related
- Only three simple rules [see Blackboard for materials]...

Swarm Intelligence

- First used by Beni, Hackwood and Wang in 1989 for work on cellular robotic systems
  - Later: for anything swarm inspired
- Study of collective behaviour of decentralised, self-organised systems
  - **No central control**
- Only simple rules for each individual
  - Simple but extremely powerful
  - The problems are usually difficult to define
  - Solutions result from the behaviour and interactions between individual agents
  - Solutions are emergent in the systems

Swarm Intelligence Algorithms

- Most Popular Algorithms
  - Ant Colony Optimisation (ACO)
  - Particle Swarm Optimisation (PSO)
- More esoteric (not covered)
  - Bacteria Colony Optimisation
  - Artificial Bee Colony Algorithm
  - Plant Propagation Algorithms
    - Strawberry Plant…

Ant Colony Optimisation

- First proposed by Marco Dorigo in 1992
- A **Heuristic** optimisation method inspired by **biological systems**
- A multiple agent based approach for solving difficult combinatorial optimisation problems
  - Mainly **Graph** based problems
  - Traveling Salesperson, vehicle routing, sequential ordering, graph colouring, routing in communications networks, etc…

Ant Behavior

- Ants (blind) navigate from nest to food sources
- The shortest path is discovered via pheromone trails
  - Each ant moves at random (biased – see below)
  - **Pheromone** is deposited onto the path
  - Ants detect the lead ants path and are inclined to follow
  - More pheromone on the path means an increased probability of the path being followed
  - Pheromone upgrade: **evaporation**

Dealing With Obstacles

The more ants follow a trail, the more attractive to follow that trail becomes

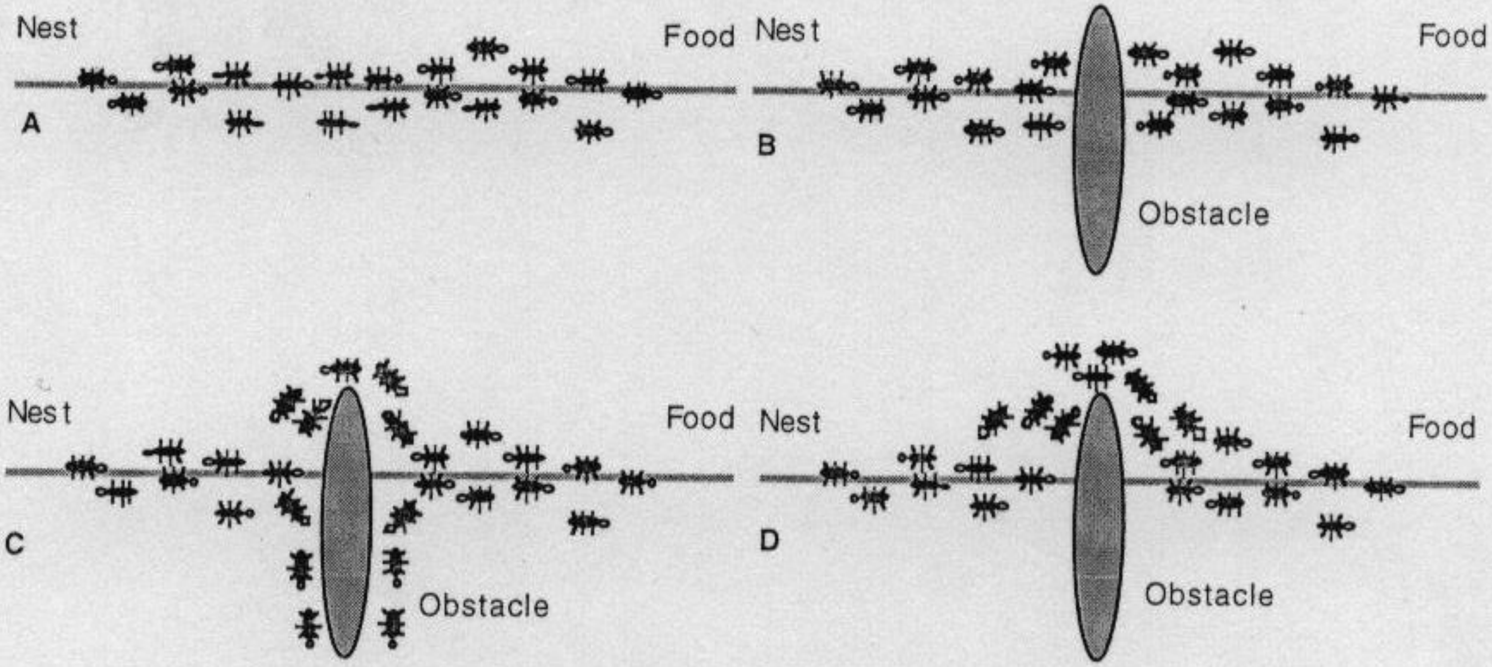


Fig.1. (A) Real ants follow a path between nest and food source. (B) An obstacle appears on the path: Ants choose whether to turn left or right with equal probability. (C) Pheromone is deposited more quickly on the shorter path. (D) All ants have chosen the shorter path.

Stigmergy

- Indirect coordination/communication between agents or actions
  - Individual behaviour modifies the environment, which in turn modifies the behaviour of other individuals
  - Stimulates the performance of subsequent actions leading to the spontaneous emergence of coherent, apparently systematic activity
  - Reduces (or eliminates) communications between agents
  - Supports efficient collaboration between simple agents
  - Produces complex, seemingly intelligent structures, without need for any planning, control, or even direct communication between the agents

Route Selection

- At the beginning of the search process, a constant amount of **pheromone** is assigned to all arcs
- When located at a node i an ant k uses the **pheromone** trail to compute the probability of choosing j as the next node:

$$p_{ij}^{k} \propto \frac{\text{Pheromone from node } i \text{ to } j}{\text{Sum of Pheromone for all valid paths}}$$

- The probability is zero for nodes that are unreachable from node i
- Similar to **Roulette Wheel Selection** in a Genetic Algorithm…

Pheromone Update

- The pheromone value of an arc (i,j) is updated when traversed by ant k as follows:

$$\tau'_{ij} = \tau_{ij} + \Delta\tau^k_{ij}$$

$$\Delta\tau^k_{ij} \propto \frac{1}{\text{The Tour Length of Ant } k \text{ so far}}$$

- The probability of an arc being taken by subsequent ants is proportional to how "**good**" it was deemed by ants that have already traversed it

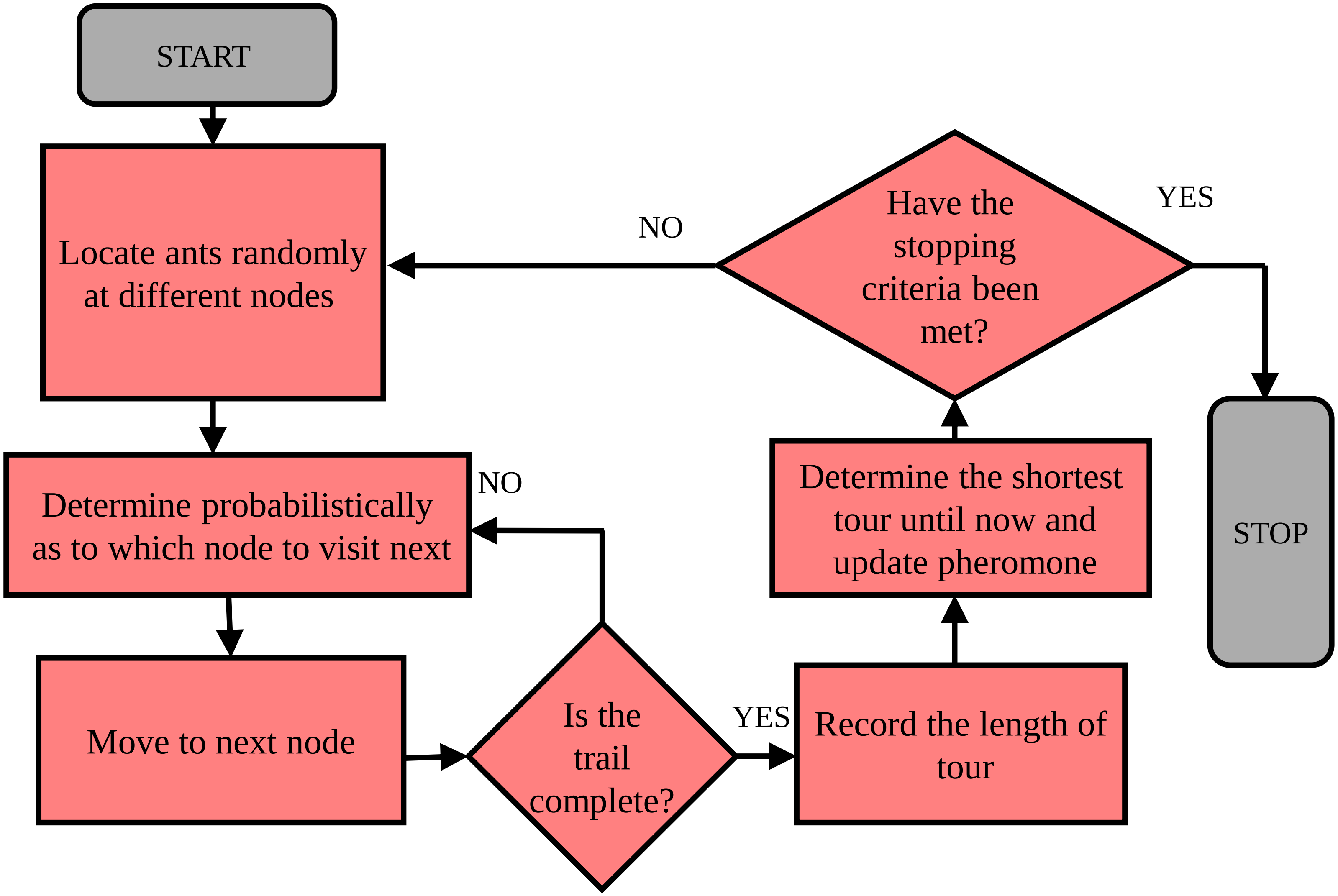
Pheromone Evaporation

- The pheromones "**evaporate**" by applying the following equation to all the arcs:

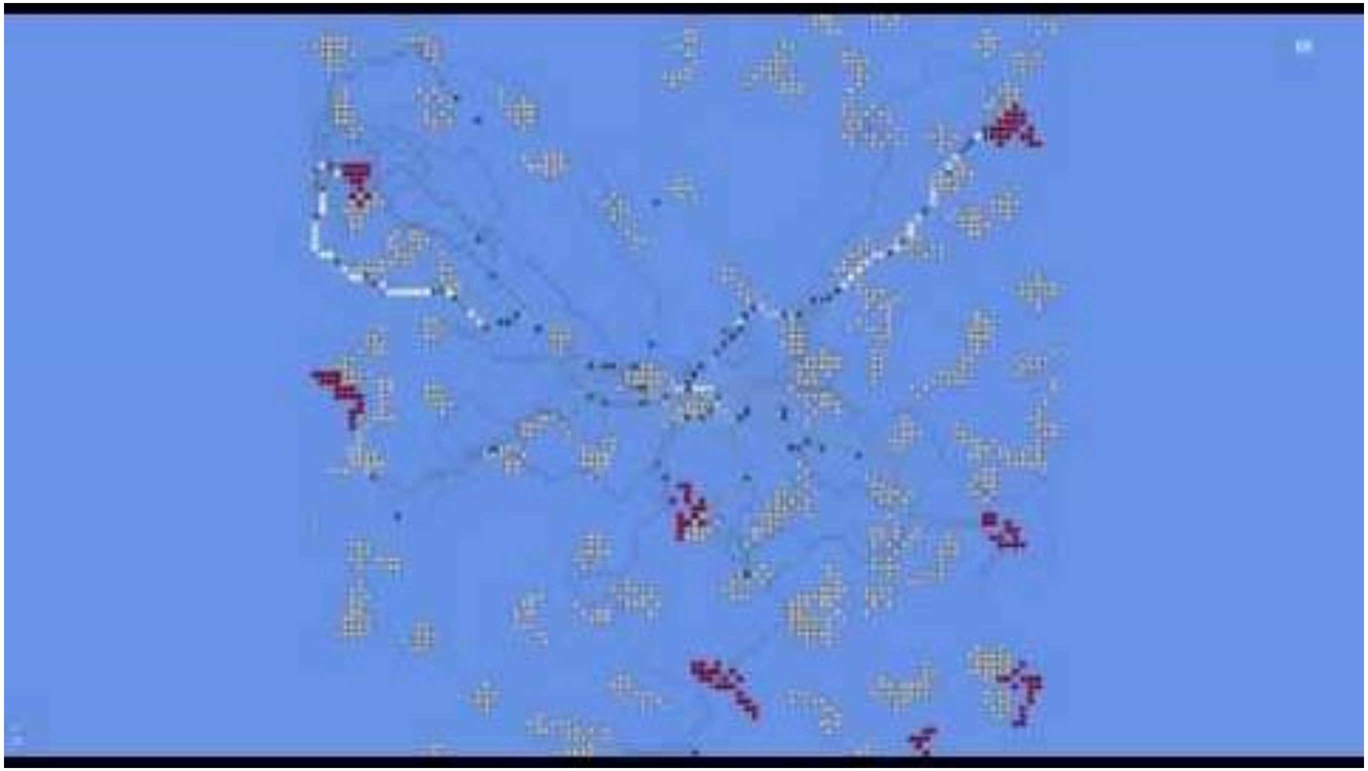
$$\tau'_{ij} = (1 - p)\tau_{ij}$$

- Here $p \in (0,1)$ is a parameter
- Similar to the cooling rate heuristic for the temperature in Simulated annealing
- An iteration is a complete cycle involving the ant's **movement**, **pheromone depositing** and **pheromone evaporation**

ACO Flowchart



ACO Simulator (searching for food)



https://www.youtube.com/watch?v=hXUCCRiNBOc

ACO Advantages and Disadvantages

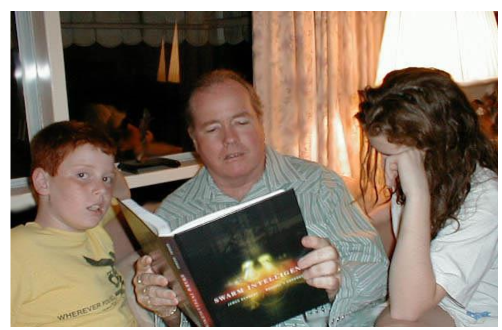
- Advantages
  - Can be used in dynamic applications
  - Rapid discovery of good solutions
  - Performs better against other global optimisation techniques
  - Easily parallelised
- Disadvantages
  - Theoretical analysis is difficult
  - Time to convergence uncertain
  - Performed poorly for large scale problems e.g. >75 cities TSP

ACO Applications

- Graph based and combinatorial optimisation type problems, e.g.:
  - TSP (Travelling Salesperson Problem)
  - Vehicle Routing
  - Graph Colouring
  - Timetable Scheduling
  - Manufacturing Scheduling
  - Network Routing
  - Etc...

Particle Swarm Optimisation (PSO)

- ❑ It was developed in 1995 by James Kennedy (social psychologist) and Russell Eberhart (electrical engineer)
- ❑ **Population based stochastic optimisation technique**
- ❑ It uses a number of agents (particles) that constitute a swarm moving around in the search space looking for the best solution
- ❑ Each particle is treated as a point in an n-dimensional space which adjusts its "**flying**" according to its own flying experience as well as the flying experience of other particles



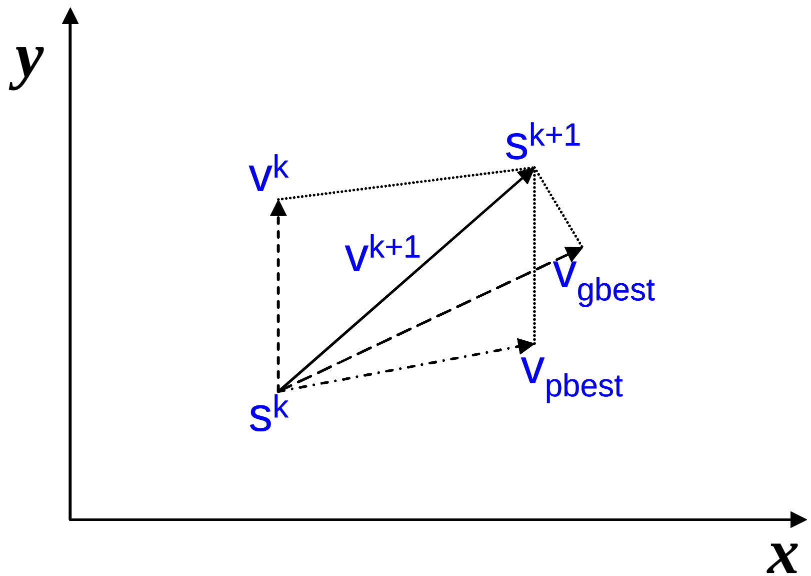
PSO Concepts – Part 1

- Each particle keeps track of its coordinates in the solution space and associated fitness, along with the best solution and fitness it has achieved so far
  - This value is called the personal best, p_{best}
- The PSO algorithm also tracks the best value obtained so far by any particle in swarm
  - This value is called the global best, g_{best}
- The basic concept of PSO lies in accelerating each particle toward its p_{best} and the g_{best} locations, with a random weighted acceleration at each time step
  - Inspired by “Boids”

PSO Concepts – Part 2

- Each particle tries to modify its position using the following information:
  - The current position
  - The current velocity
  - The distance between the current position and p_{best}
  - The distance between the current position and g_{best}

PSO Concepts – Part 3



s^k: current position in the search space

s^{k+1}: modified position

v^k: current velocity

v^{k+1}: modified velocity

v_{pbest}: velocity based on p_{best}

v_{gbest}: velocity based on g_{best}

PSO Update Formulae

Particle i velocity at iteration k+1

Particle i best position

$$r_p, r_g \sim UR(0,1)$$

$$v_i^{k+1} = \omega v_i^k + \alpha r_p \left(p_{best,i} - s_i^k\right) + \beta r_g \left(g_{best} - s_i^k\right)$$

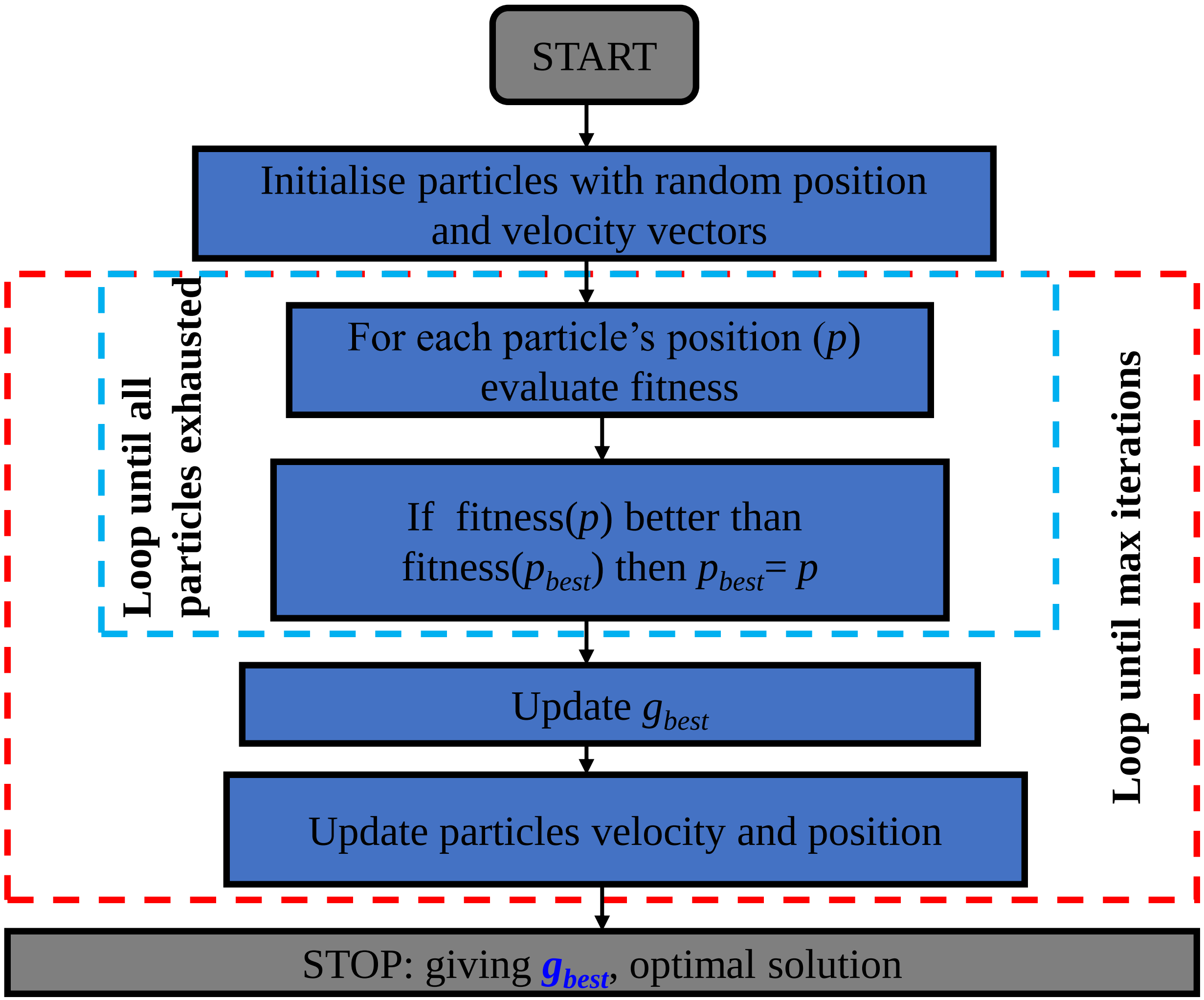
$$s_i^{k+1} = s_i^k + v_i^{k+1}$$

Particle i position at iteration k

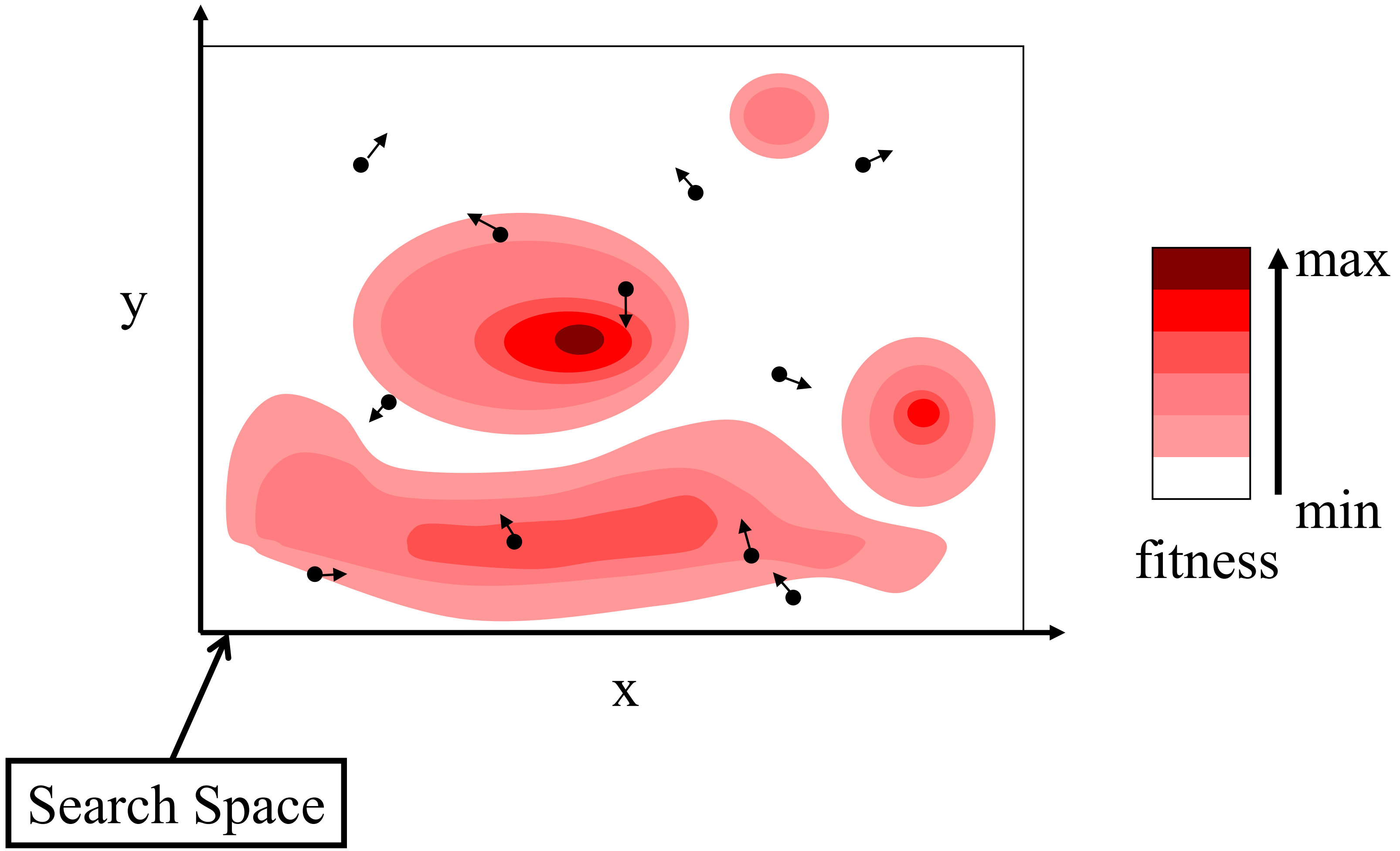
Position of global best

ω, α and β are parameters…

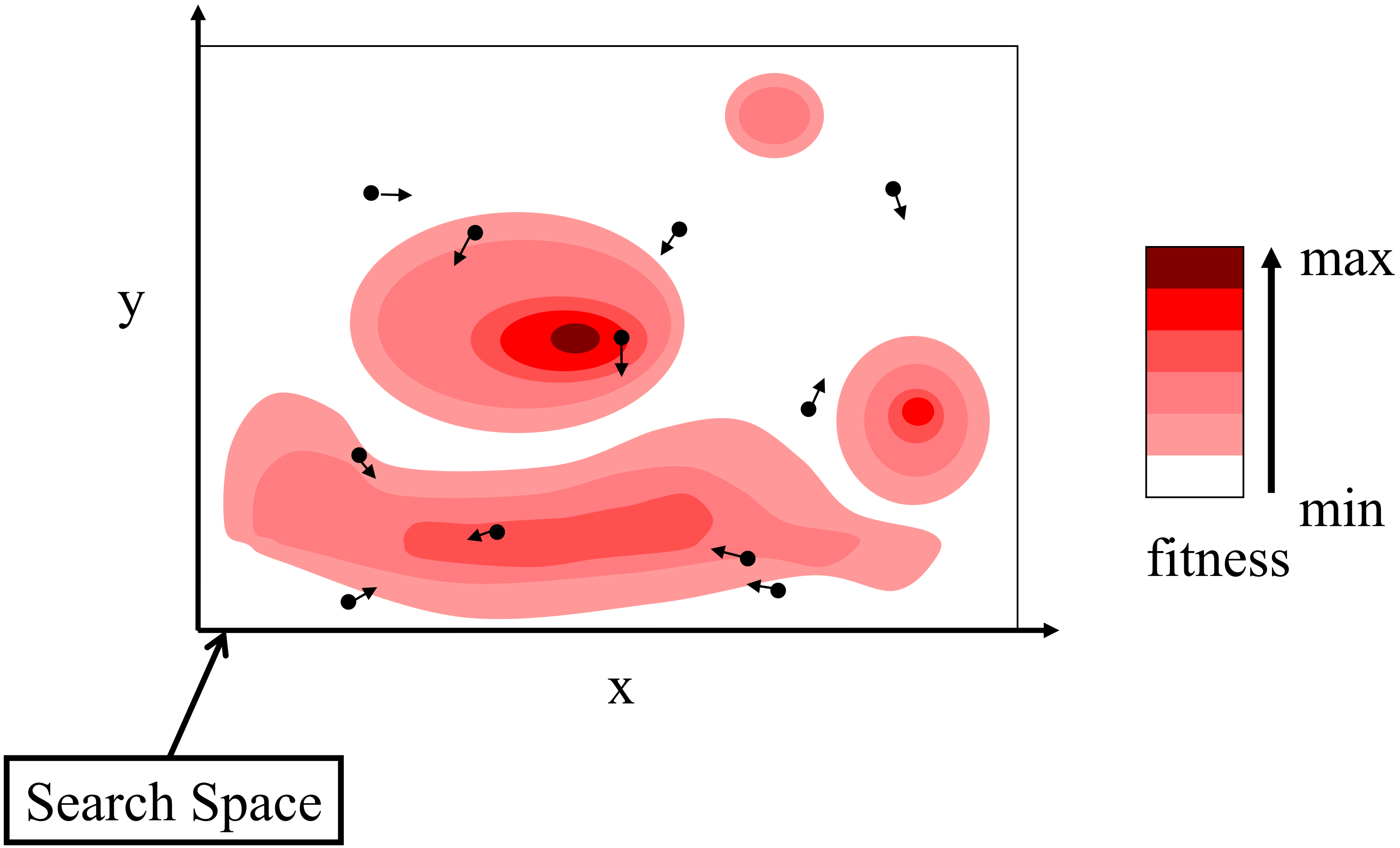
PSO Flow Chart



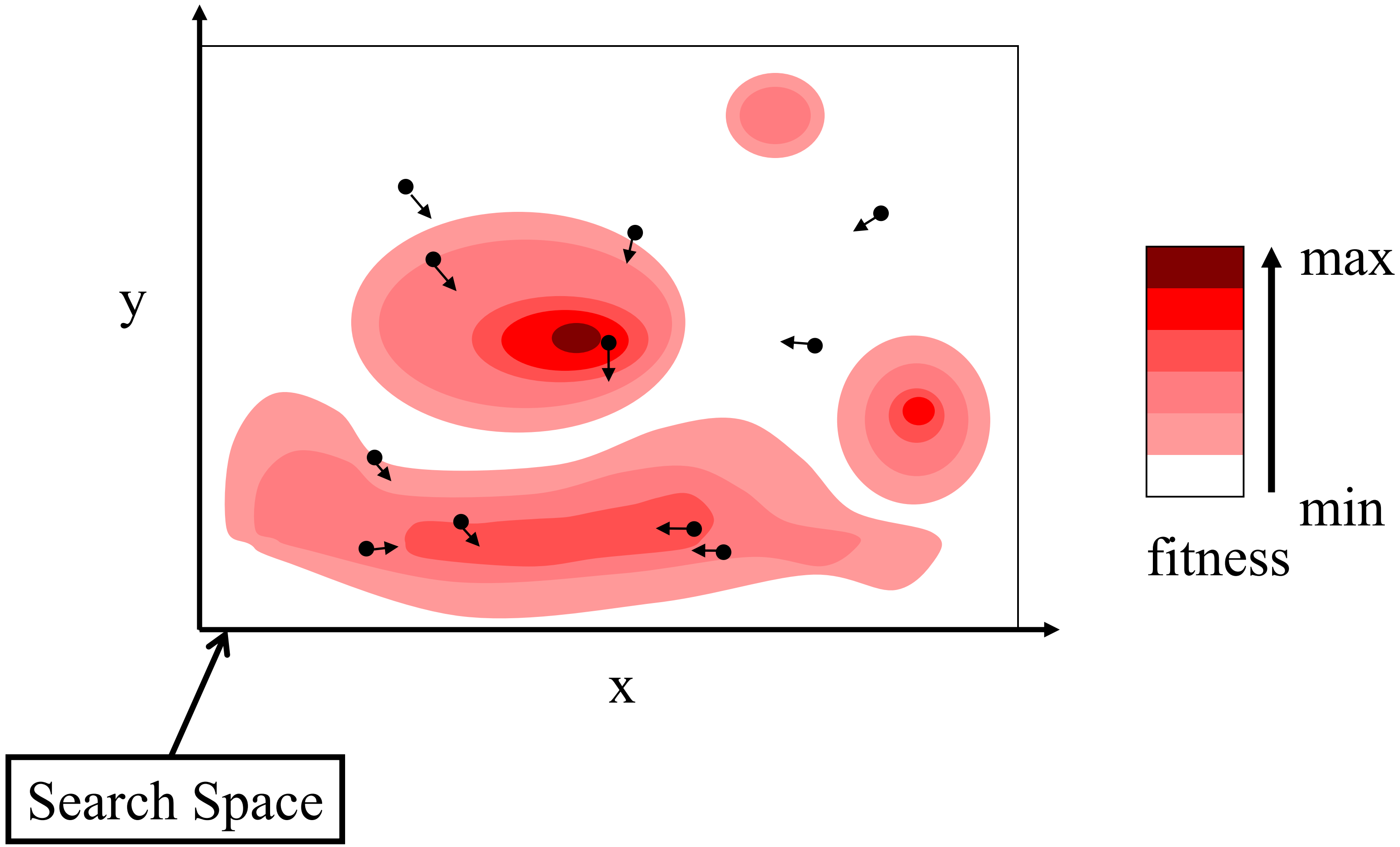
PSO Simulation 1



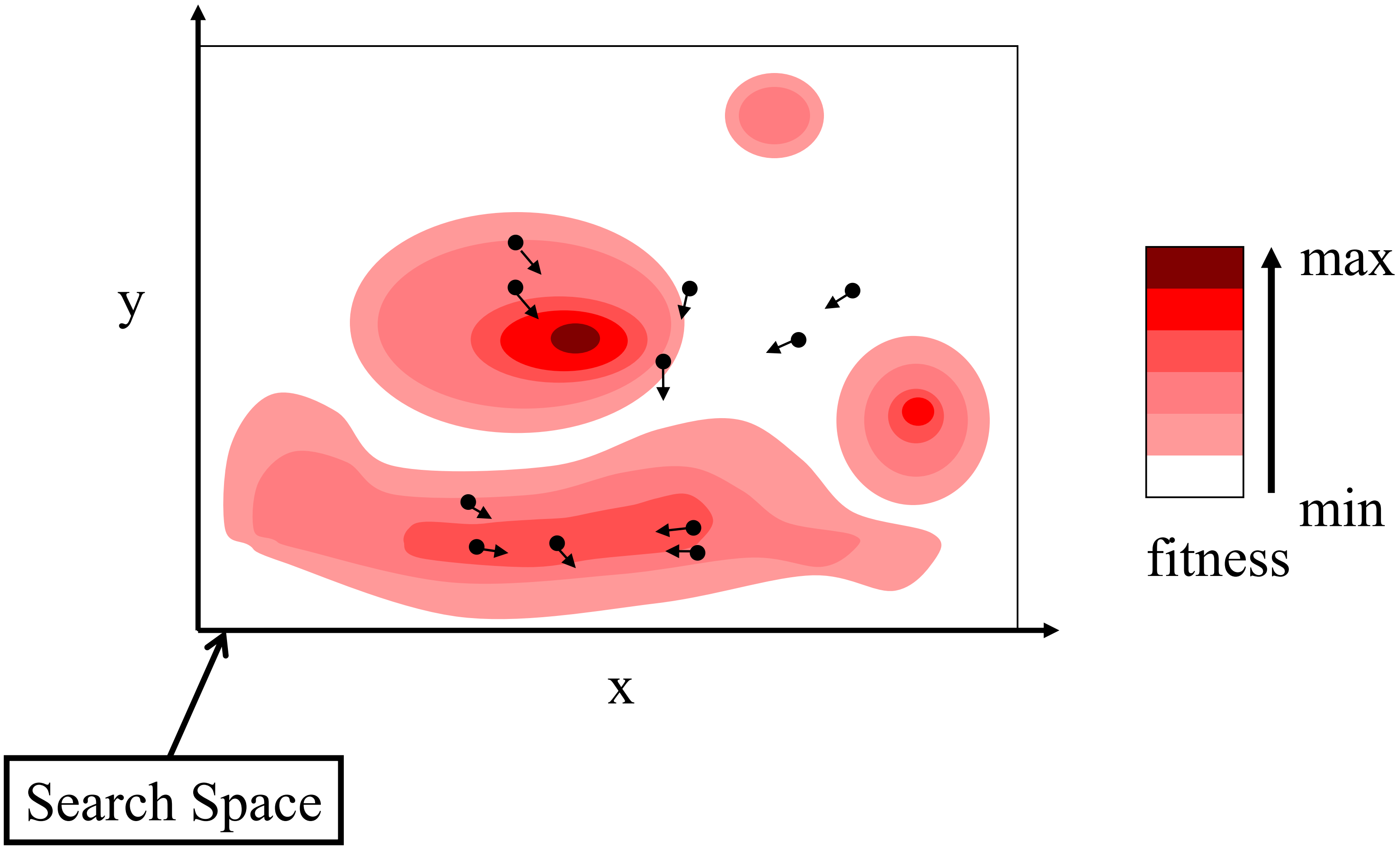
PSO Simulation 2



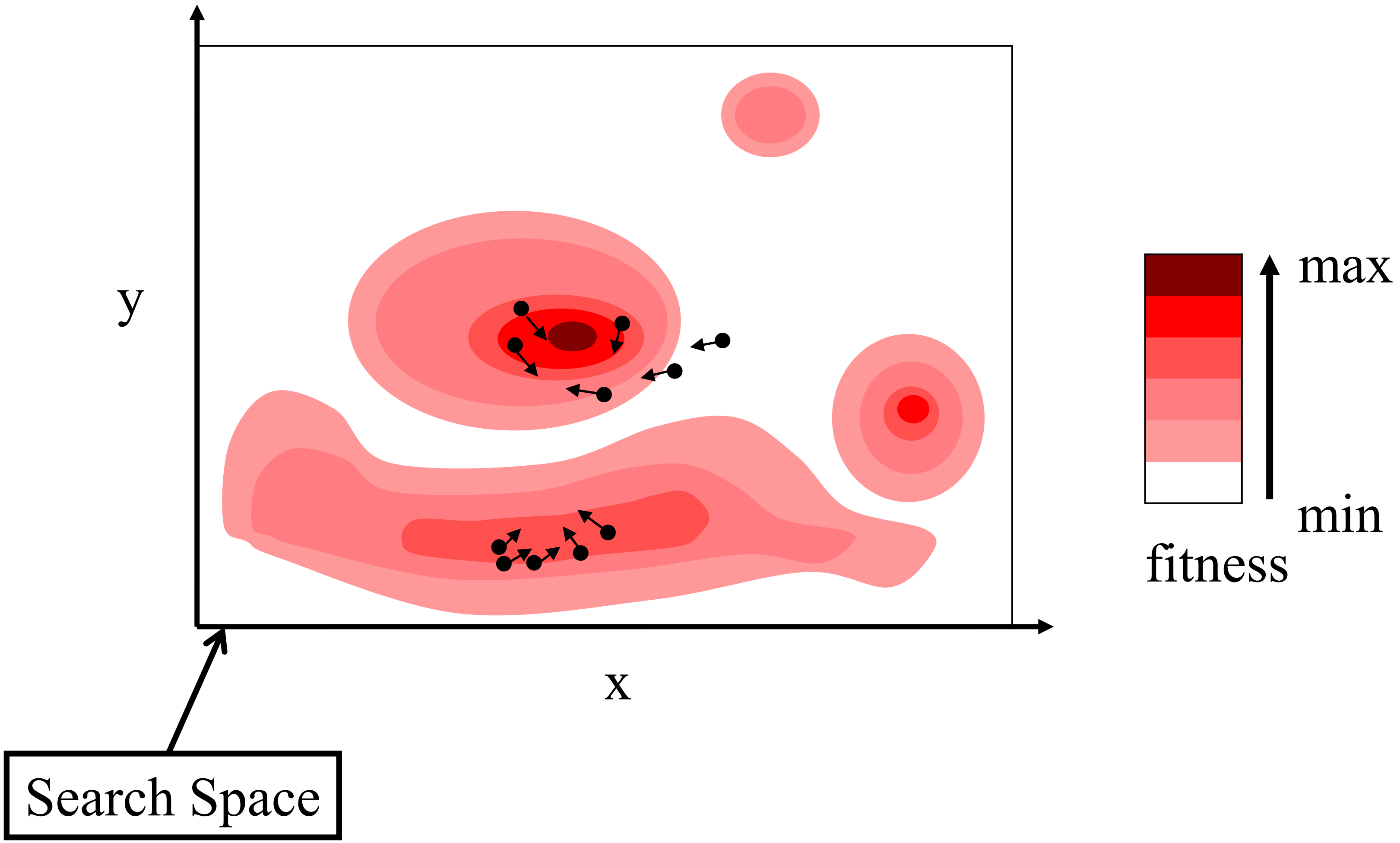
PSO Simulation 3



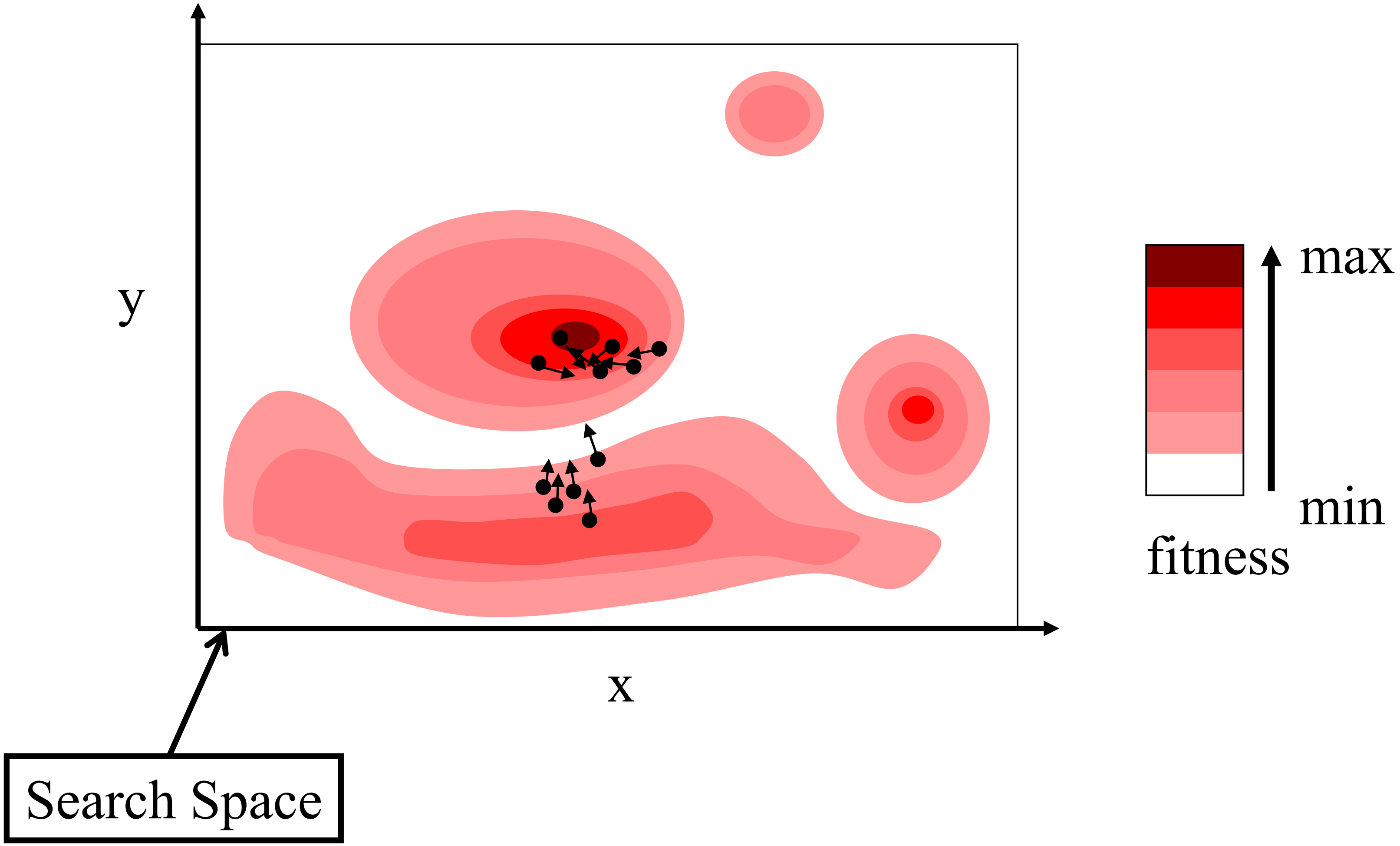
PSO Simulation 4



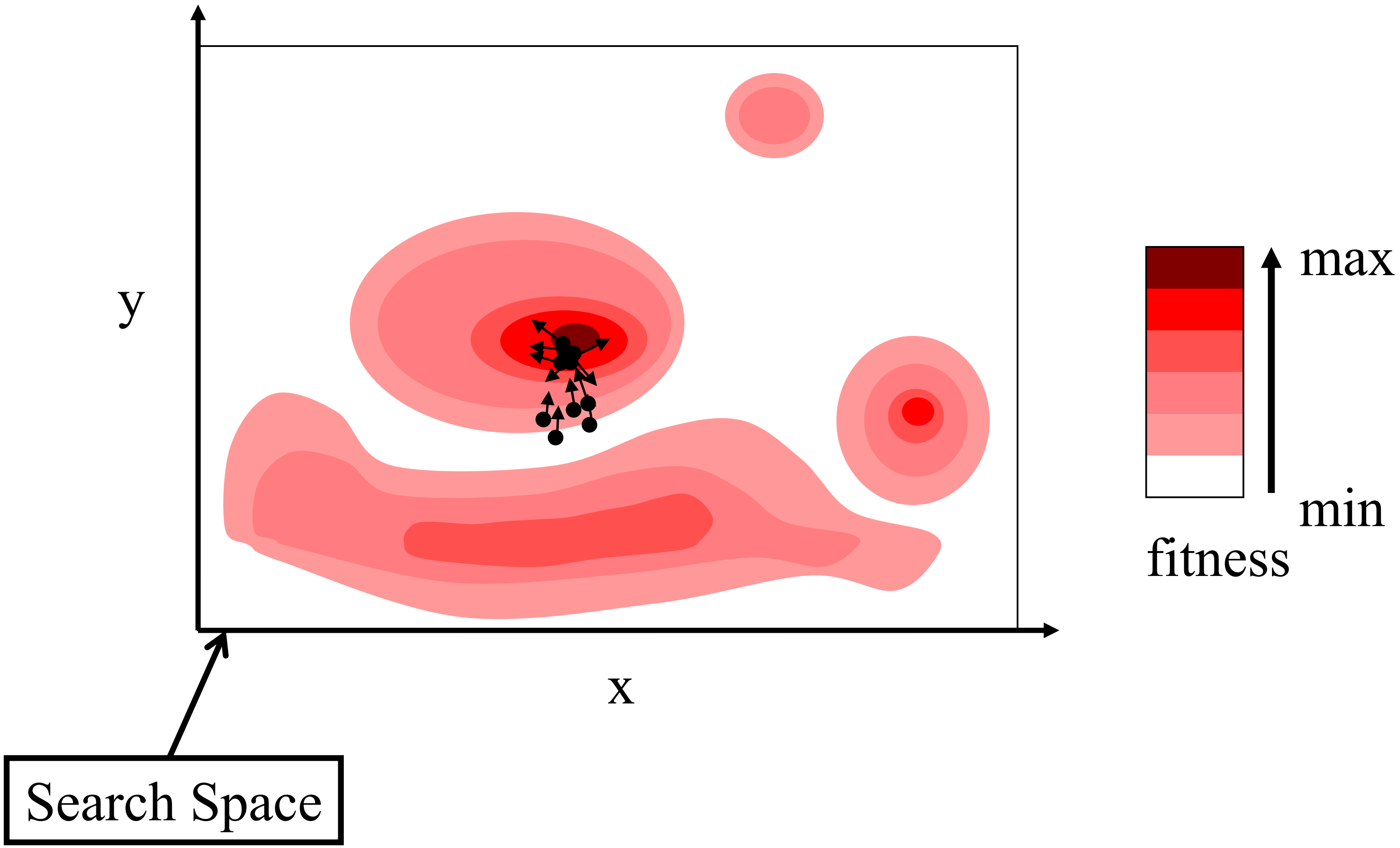
PSO Simulation 5



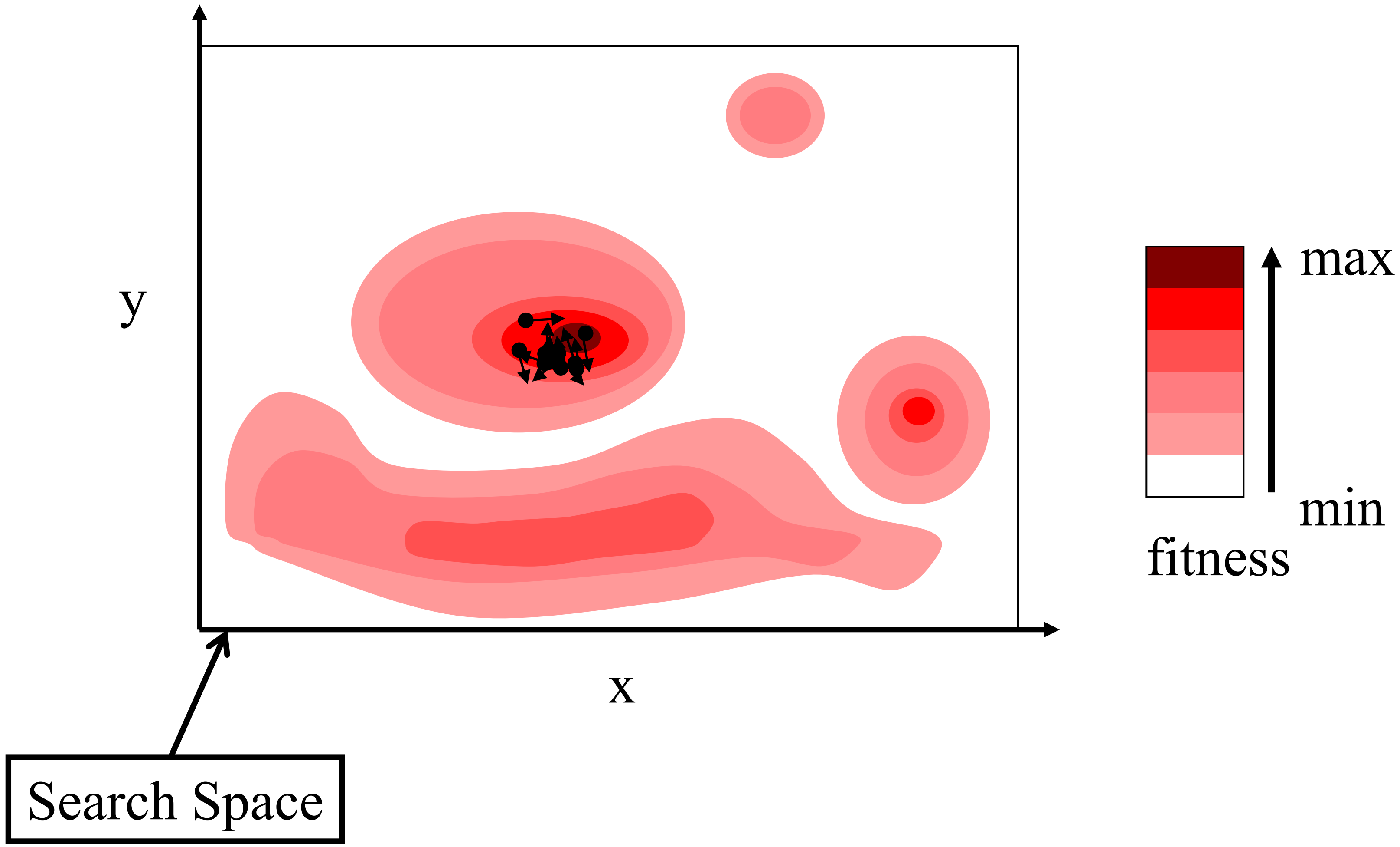
PSO Simulation 6



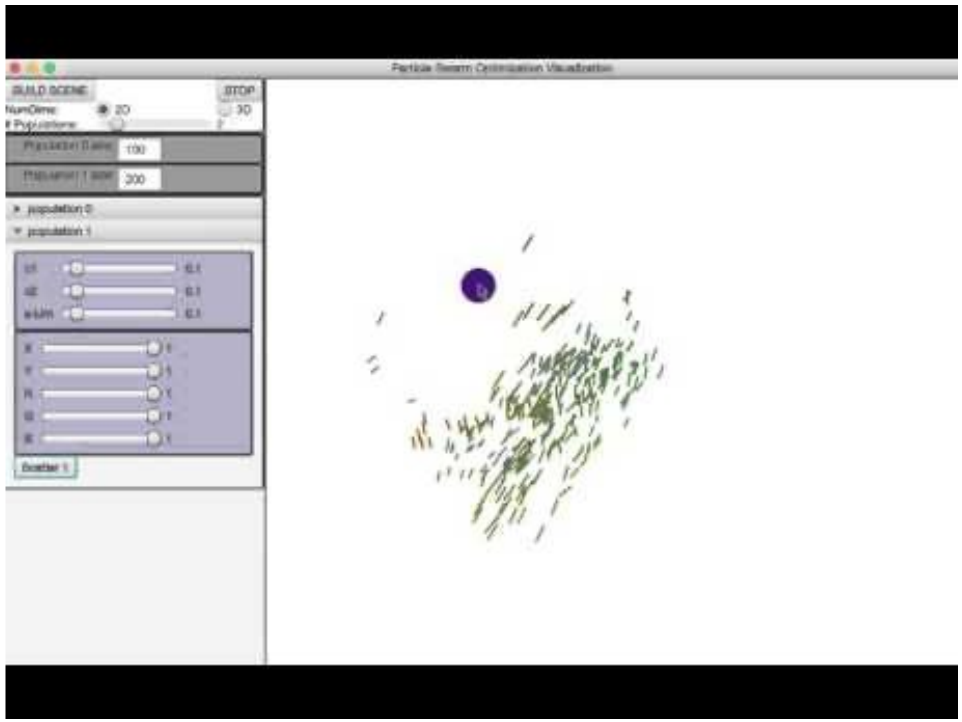
PSO Simulation 7



PSO Simulation 8



PSO Simulation[8]



https://www.youtube.com/watch?v=gkGa6WZpcQg

PSO Comparison With EC

- No selection operation in PSO
  - All particles in PSO are kept as members of the population
  - PSO [and ACO] is [are] the only algorithm [s] (population based Heuristic search) that does [do] not implement the survival of the fittest operator
- No crossover operator in PSO
- The PSO update formulae resembles mutation in EP

PSO Advantages and Disadvantages

- Advantages
  - Many optimisation applications in science and industry, including; where GA can be applied, image recognition, training ANN, etc…
  - Simple implementation and less parameter tunning
  - Easily parallelized
- Disadvantages
  - Tendency to a fast and premature convergence
  - Slow convergence

Next Lecture

- We will be looking at the Travelling Salesperson problem

Next Laboratory

- The laboratory will involve looking at a number of simulations of ACO and PSO
  - Not assessed but useful revision!