# Nature Inspired Search and Optimisation
# Advanced Aspects of Nature Inspired Search and Optimisation
# Lecture 10: Swarm Intelligence and Particle Swarm Optimisation

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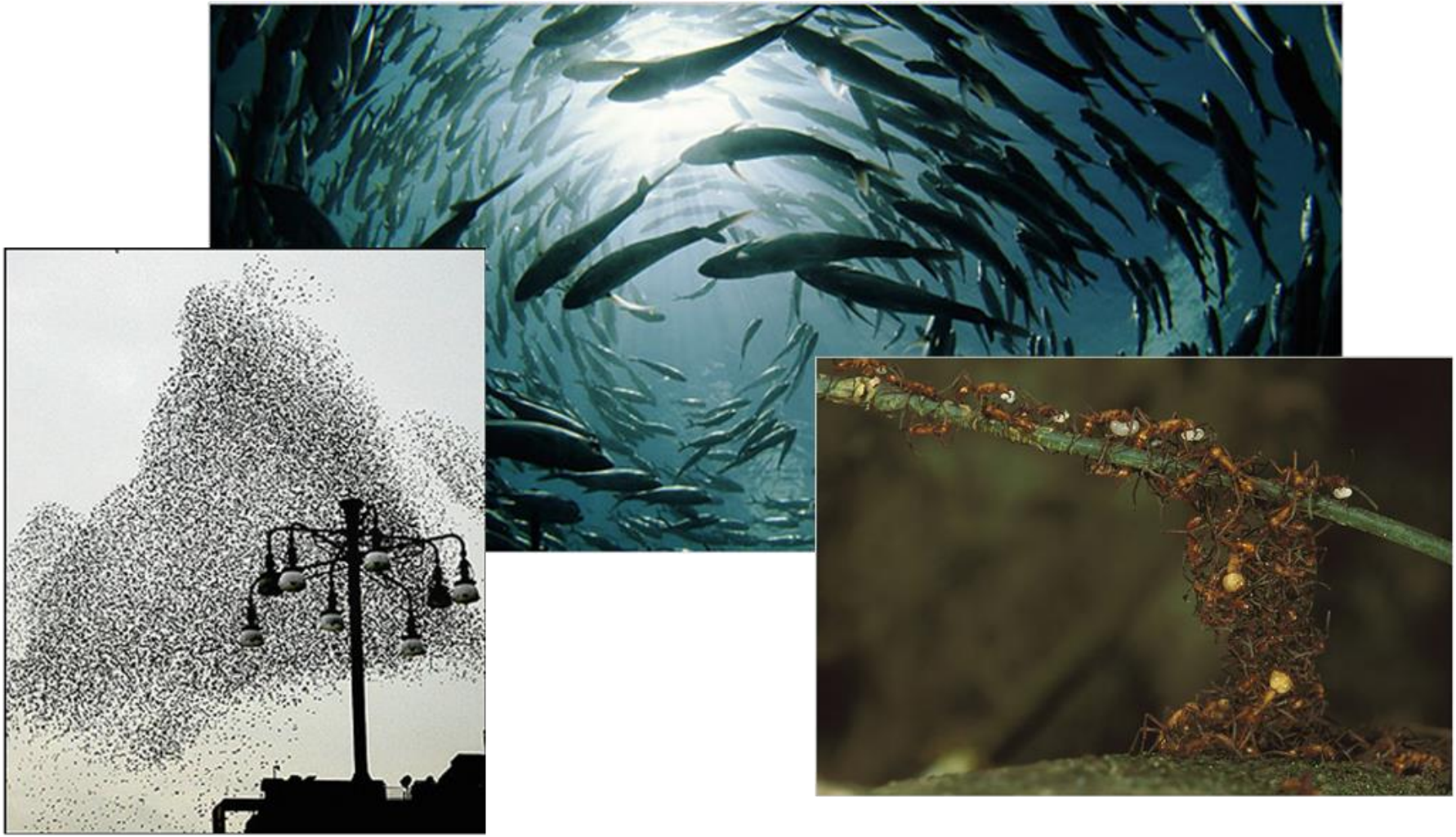
# Outline of Topics

# What is swarm in nature?



Picture from NY Times

# What is swarm in nature?

- Starlings swarm in Rome
- Sardine run

# What is Swarm Intelligence?

- General definition: Collective behaviour of decentralized, self-organized natural or artificial systems
- Self-organized system: an initially disordered system, but **global phenomena** such as order or coordination will arise out of the **local interactions** between its components
- A swarm intelligence system typically consists of simple agents interacting with each other and their environment following simple rules
- Emergence: global phenomena such as functions, order or coordination emerges from these local interactions

# Why animals evolved swarm?

- There is no clear, unique explanation to the evolution of swarm behaviour.
- Some possible explanations:
  - Better defence, e.g., early warning, confuse predator
  - Better foraging efficiency
  - Saving energy, e.g., wile geese fly in formation (wedge or skein)
- Outcomes of natural selection
- Can we learn from animal swarm for designing computer systems and algorithms?

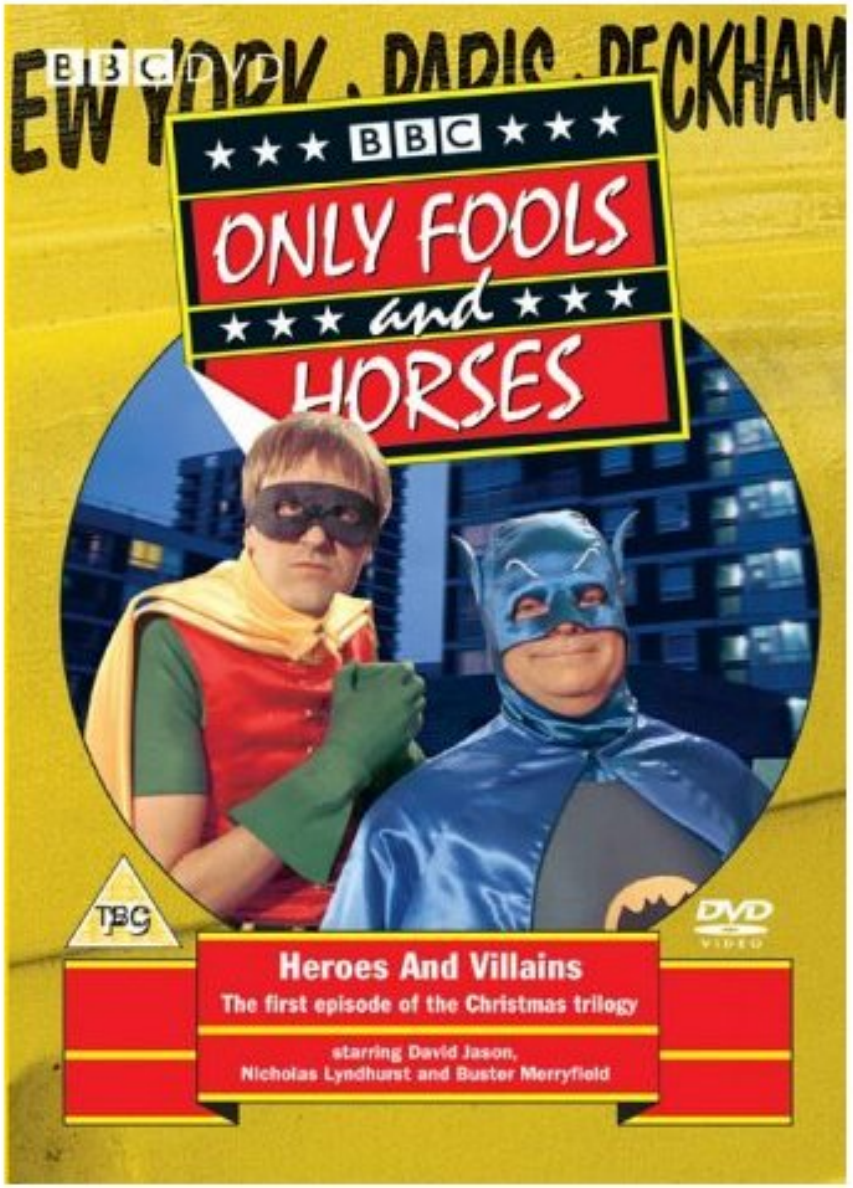
# What is Swarm Intelligence in CS?

- In CS, we define Swarm Intelligence as "a multi-agent system that has self-organized behaviour that shows some intelligent behaviour."
- Two main research fields:
  - Swarm Intelligence algorithms: a variety of novel algorithms inspired by natural swarm system:
    - Ant colony optimisation: an algorithm inspired by ants' collective behaviour, useful to solve combinatorial optimisation problems, such as finding better paths through graphs.
    - Particle Swarm Optimisation
  - Swarm Robotics: design coordination of multirobot systems which consist of large numbers of mostly simple physical robots.
    - Goes beyond distributed system, aims to promote scalability, e.g., controlling a large number of robots
    - Swarmanoid: Towards Humanoid Robotic Swarms
    - A Swarm of One Thousand Robots

# BOID

- Invented In 1986 by Craig Reynolds to simulate coordinated animal motion such as bird flocks and fish schools. Click here for his website
- Winner of technical Oscar: 1997 Sci-Tech Awards from Academy of Motion Pictures and Science
- Each individual of the model is called boid which is manoeuvred by three simple predefined behaviours: Let's take a look at the film
- BOID models have been used in many films
- One famous example Batman Returns (1992): BOID was used to create bat swarms and "army" of penguins marching through the streets of Gotham City

# Batman Returns (1992)



# BOID

Each individual of the model is called boid which is manoeuvred by three simple predefined behaviours:

- Separation
- Alignment
- Cohesion

# Separation

- Separation: Steer to avoid crowding local neighbour

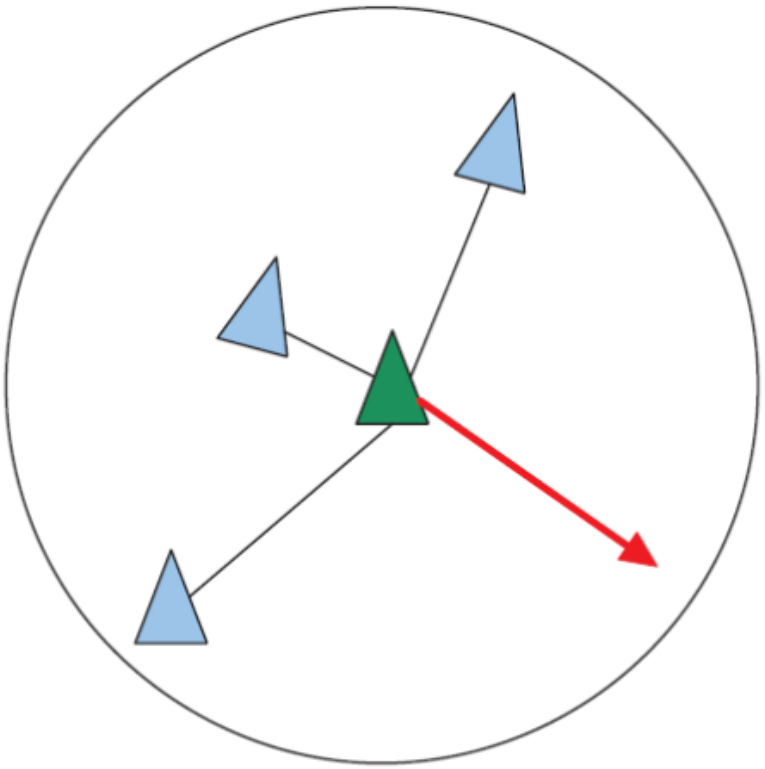


Figure 1.2: Separation.

# Alignment

- Alignment: steer towards the average heading of local neighbour

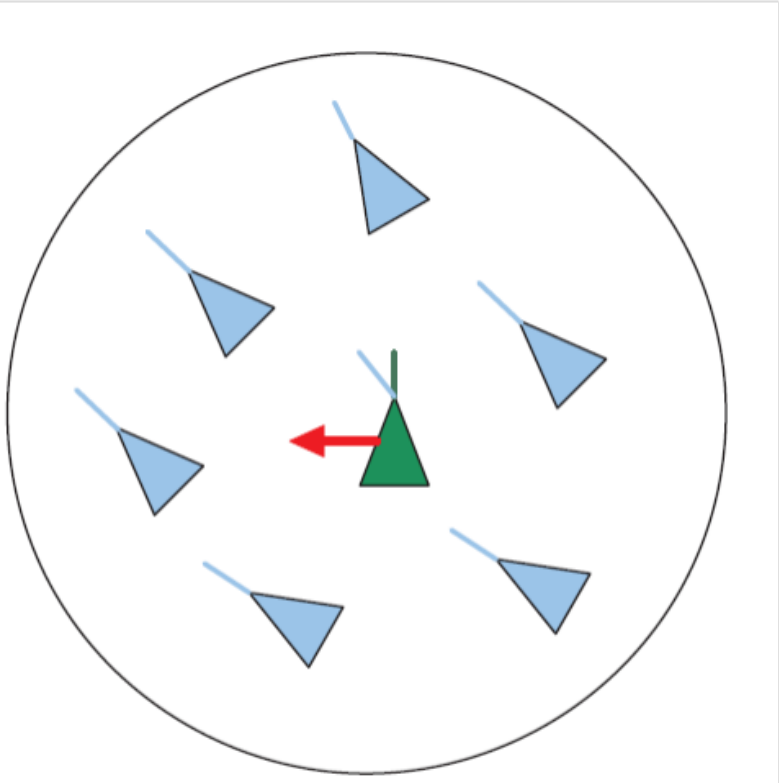


Figure 1.3: Alignment.

# Cohesion

- Cohesion: steer to move toward the average position of local neighbour

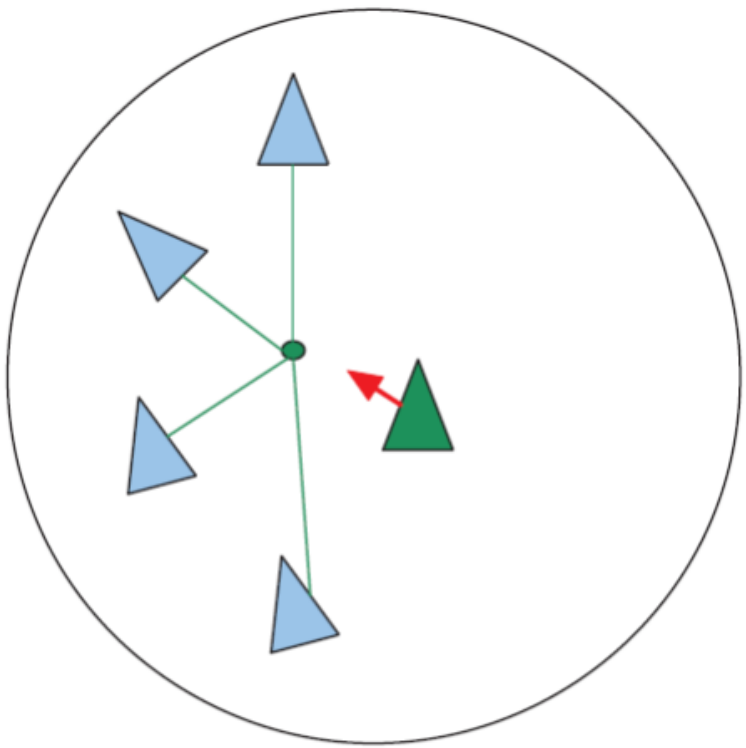


Figure 1.4: Cohesion.

# A much better BOID model

- Robert's amazing BOID model
- Made with Cinder
- If you want to learn Cinder to create your own model: Tutorial from Robert Hodgin

# Particle Swarm Optimiser (PSO)

- Invented by Kennedy and Eberhart 1995
- Inspired by bird flocking and fish schooling, more precisely, BIOD
- Simple rules for searching global optima
- Primarily for real-valued optimisation problems
- Simpler but sometimes better than GAs

# PSO: detailed algorithm

- Can be seen as a swarm of particles flying in the search space to find the optimal solution.
- Each particle is a solution to the problem, represented by position $X_i^t$ in the search space
- Each particle also has a velocity $V_i^{t+1}$, used to update its position
- The variation operator consists of only two equations:

$$V_i^{t+1} = \omega V_i^t + c_1 r_1 (P_i - X_i^t) + c_2 r_2 (P_g - X_i^t) \quad (1)$$

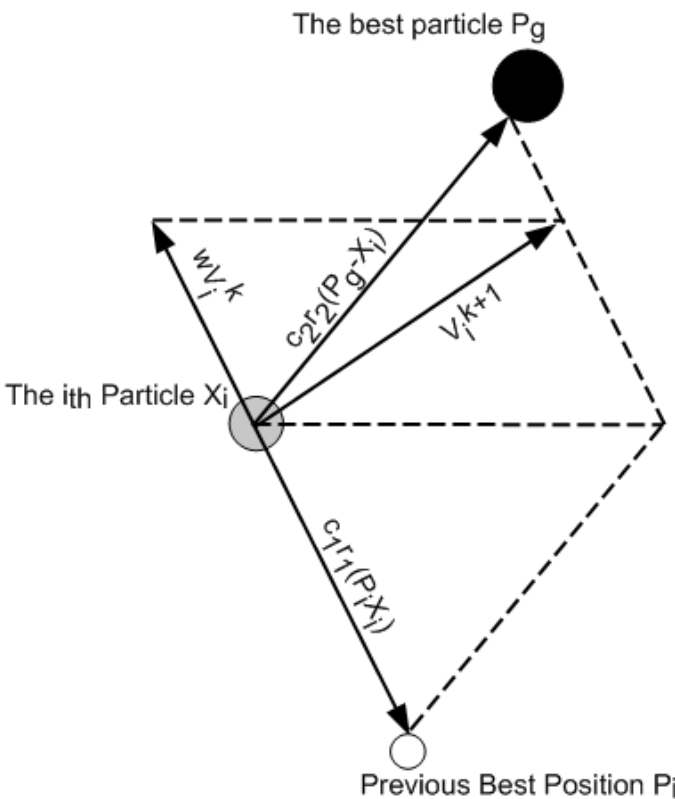
$$X_i^{t+1} = X_i^t + V_i^{t+1} \quad (2)$$

$P_i$ is the best previous position of the $i_{th}$ particle; $P_g$ is the global best position of the swarm; $\omega \in (0, 1]$ is inertia weight; $c_1$ and $c_2$ are constants, or so-called learning factors; $r_1$ and $r_2$ are random number in the range of $(0, 1)$

## Generic PSO Algorithm

$\mathbf{X}^0$ := generate an initial population of $M$ particles (solutions)
$\mathbf{P}^0 := \mathbf{X}^0$
terminationflag := false
t := 0
Evaluate the fitness of each particle in $\mathbf{X}^0$.
while (terminationflag != true)
    Select the best particle $P_g$ from $\mathbf{X}^t$ based on their fitness.
    For $i = 1 : M$
        If $X_i^t$ is better than $P_i$ then $P_i := X_i^t$; // Update $P_i$
        Calculate $V_i^{t+1}$ according equation (1)
        Update $X_i^{t+1}$ according equation (2)
    End For
    Evaluate the fitness of each particle in $\mathbf{X}^{t+1}$.
    $t := t + 1$
    If a termination criterion is met: terminationflag := true
Output $P_g$

# PSO: algorithm illustration




- For the $i_{th}$ particle $X_i$, its new search direction $V_i^{k+1}$ is determined by:
  - Its current direction $V_i^k$
  - Its autobiographical memory, which remembers the best position $P_i$ it has visited
  - The publicised knowledge, which is the best solution $P_g$ currently found by the population

# Conclusion

- One key problem faced by EC researcher is how to choose appropriate operators and parameters
- PSO: Plug-and-play optimisation algorithm
- Only 3 parameters, all not very sensitive
- My first paper: A particle swarm optimizer with passive congregation
- You can download my source code from Canvas