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Computational Intelligence

Subject 1: Fundamental Concepts

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Agenda

- What is Computational Intelligence?
- Artificial Neural Networks
- Fuzzy Systems
- Evolutionary Computation
- Swarm Intelligence

What is Computational Intelligence?

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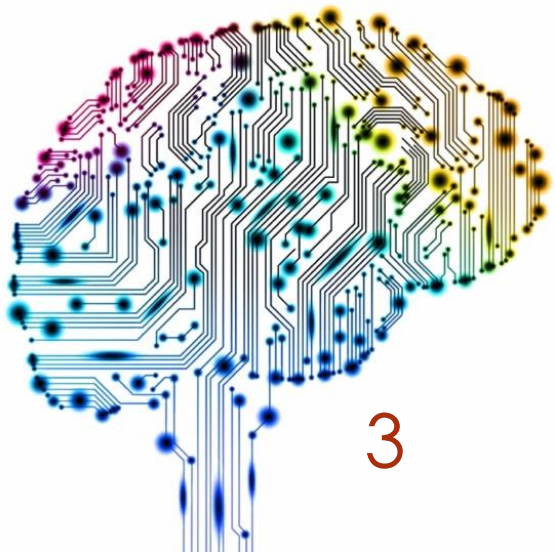
- A new concept for **advanced information processing**
- **Biologically** motivated computational paradigms
- Developing successful Intelligent Systems

Artificial Intelligence vs. Computational Intelligence:

- Two research efforts working on similar problems
- CI ➔ bio-inspired computing
- AI ➔ techniques with stronger theoretical guarantees



What is Computational Intelligence?

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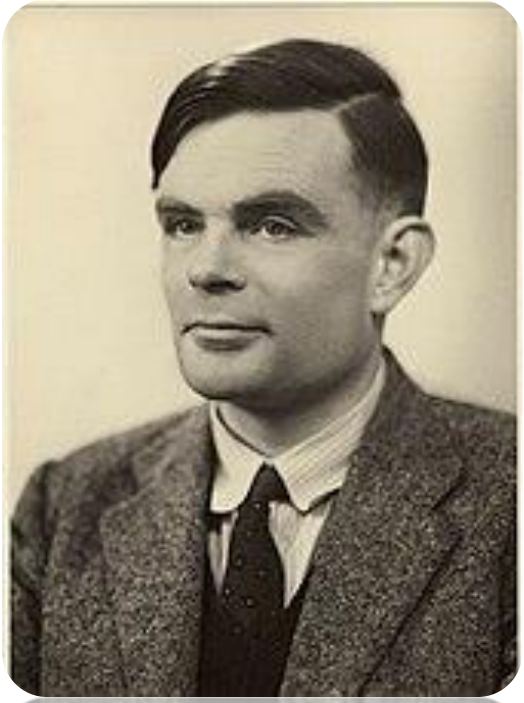
Computers and Intelligence?

- Alan Mathison Turing
  - An abstract computing machine consisting of a limitless memory and a scanner

"What we want is a machine that can learn from experience,"



What is Computational Intelligence?

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Artificial Intelligence (defined by IEEE in 1996)

- Studying how can computers do what humans can do in a better way
- ***Sample:*** Auto-pilot systems in an airplane

What is Computational Intelligence?

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CI and Probabilistic Methods

- Almost nothing in our world is not definite
- Powerful tools used for designing efficient randomized algorithms
- Leads to **Soft Computing** instead of Traditional Computing
  - Theories like Fuzzy Systems
  - Introduced by Dr. Lotfi Ali Asker Zadeh (1921-2017)

Lotfi A. Zadeh

Professor Emeritus, EECS, UC Berkeley
Verified email at eecs.berkeley.edu - Homepage
Fuzzy Logic Soft Computing Artificial Intelligence Human-Level Machine Intel...

What is Computational Intelligence?

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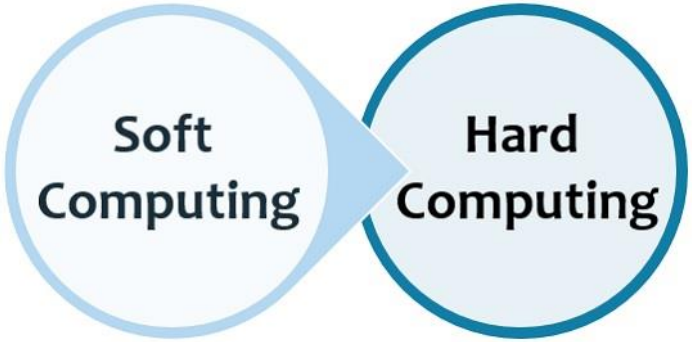
CI and Soft Computing

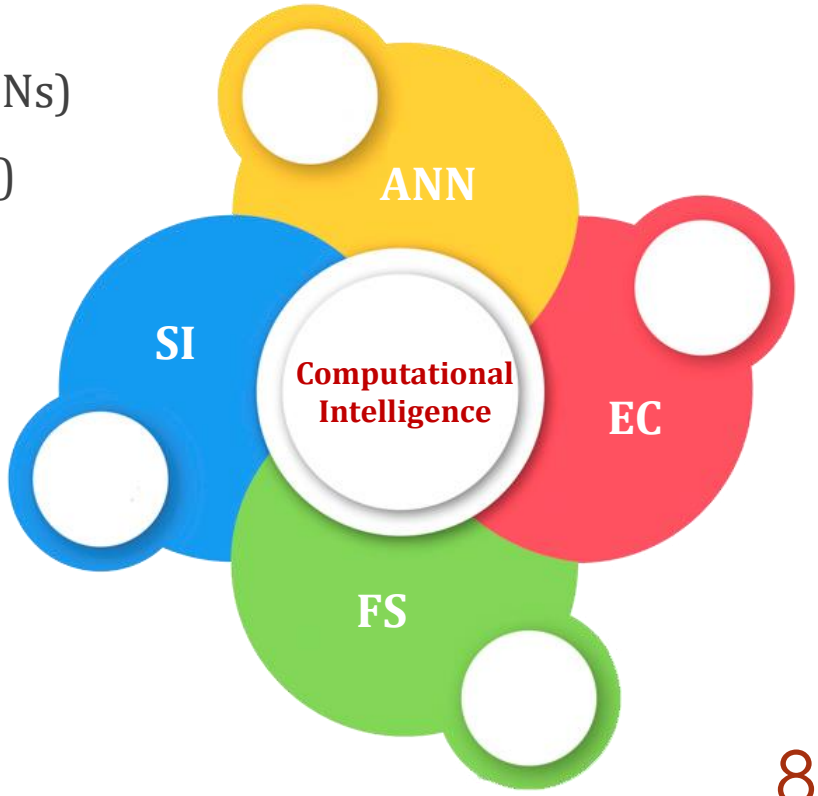
- In contrast with Hard Computing, where everything is inflexible and definite, in Soft Computing there is:
  - Approximation
  - Uncertainty
  - Imprecision
  - Partial truth
- **HC:** precisely state analytics model
- **SC:** multi-valued or fuzzy logic



What is Computational Intelligence?

Core Technologies of CI

- Artificial Neural Networks (ANNs)
- Evolutionary Computation (EC)
- Swarm Intelligence (SI)
- Fuzzy Systems (FS)



Artificial Neural Networks

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- **Human brain**: non-linear and parallel architecture
- Significantly fast for recognition and matching goals
- The concept of Neural Network
  - A circuit of **neurons**
- The abilities to learn, memorize,

and make decision

- Inspiration in computers world
  - The advent of **Artificial Neural Networks**

Artificial Neural Networks

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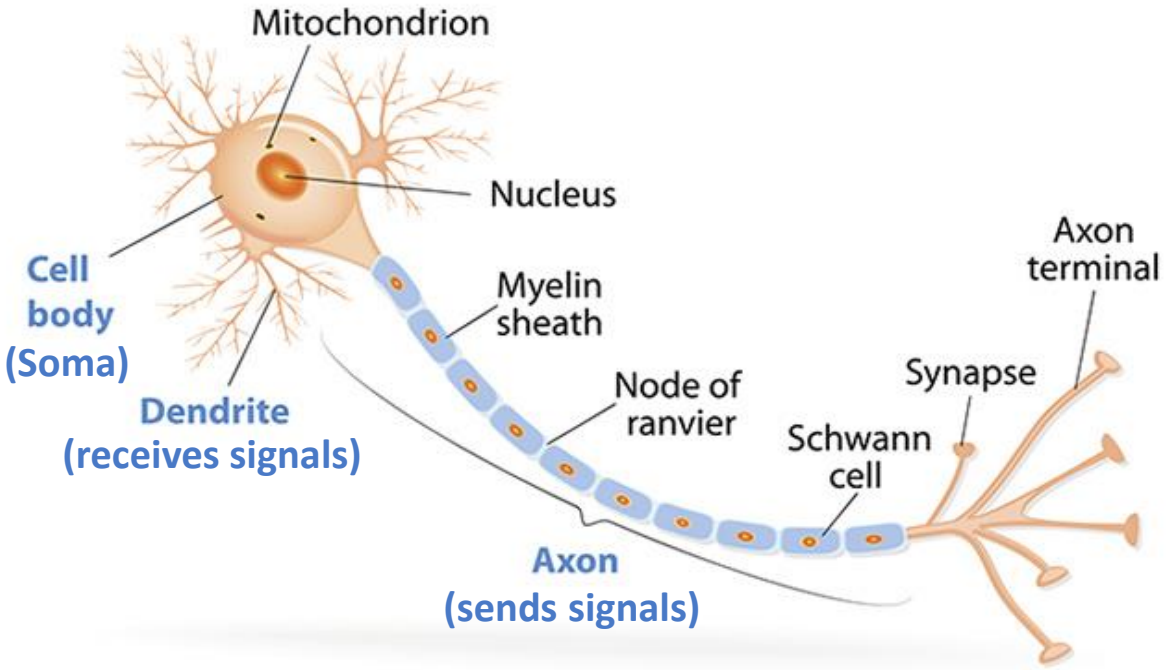
- Neuron (nerve cell), the main component of nervous system



Artificial Neural Networks

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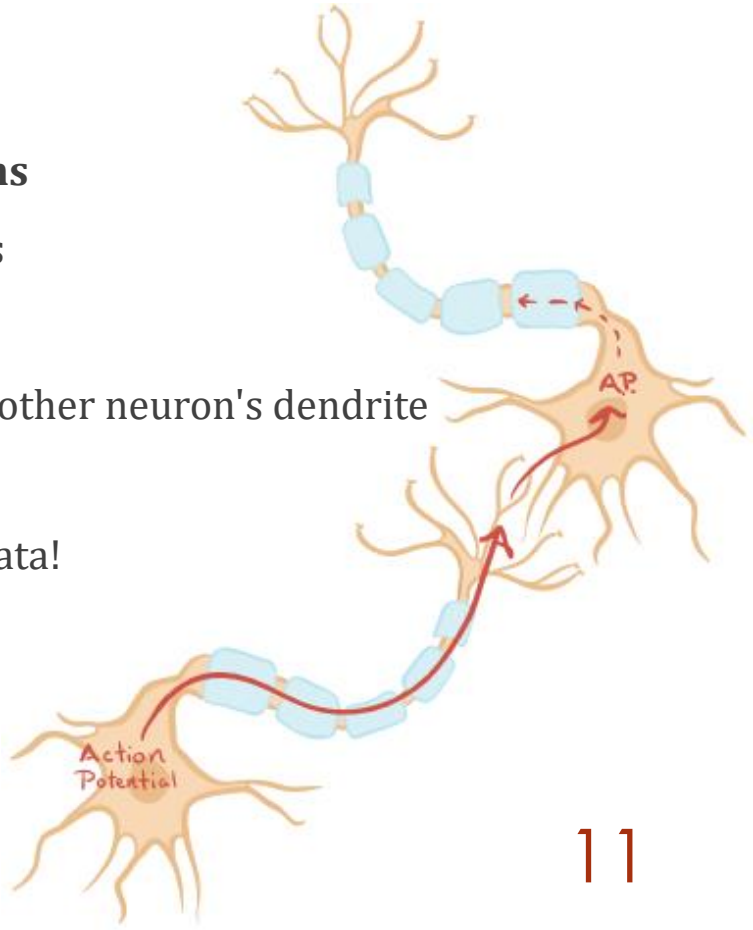
- **Signal propagation**
  - Human brain contains **86 billion neurons**
  - Each neuron has about 7000 connections
  - **How?**
  - The axon terminal of one cell contacts another neuron's dendrite
  - Inspiration: a fantastic way to transmit data!



Artificial Neural Networks

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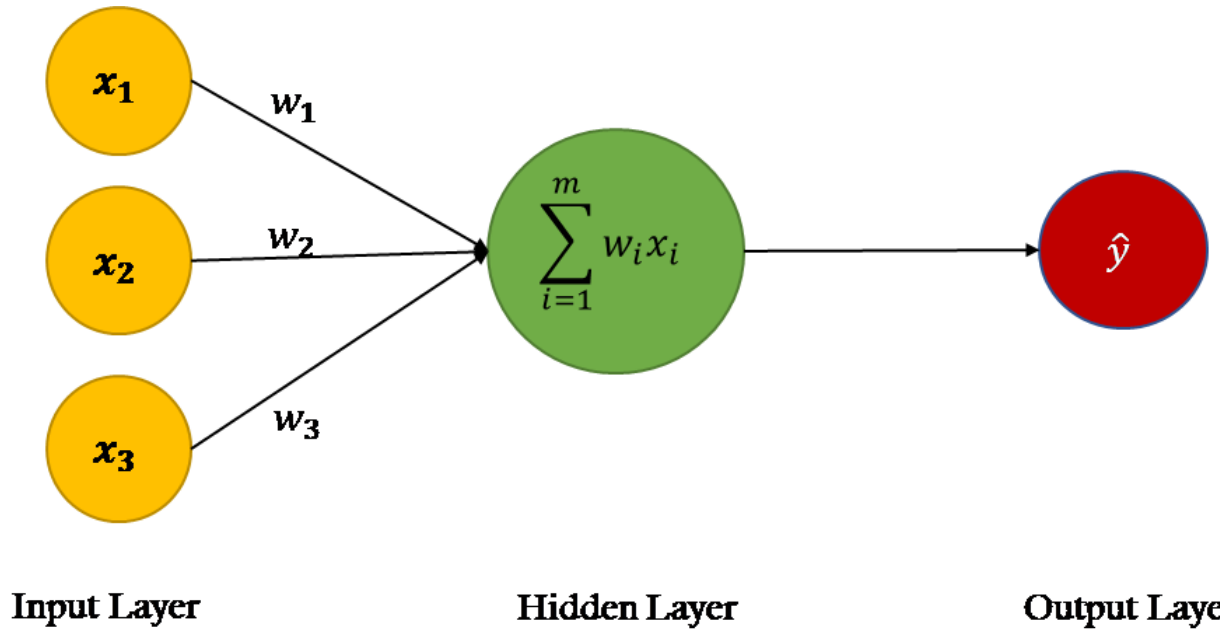
- **Artificial Neurons**
  - Elementary units in an artificial neural network
  - **One or more inputs** are needed to produce an output
  - Inputs are **weighted** separately (often)
    - Each input signal has a unique weight
  - **Sum** of the weighted input signals is calculated
  - Then, the value passes through a non-linear function, called Activation Function
    - Common types: Step function, Sigmoid, Rectifier, etc.

Artificial Neural Networks

- **Artificial Neurons**



Artificial Neural Networks

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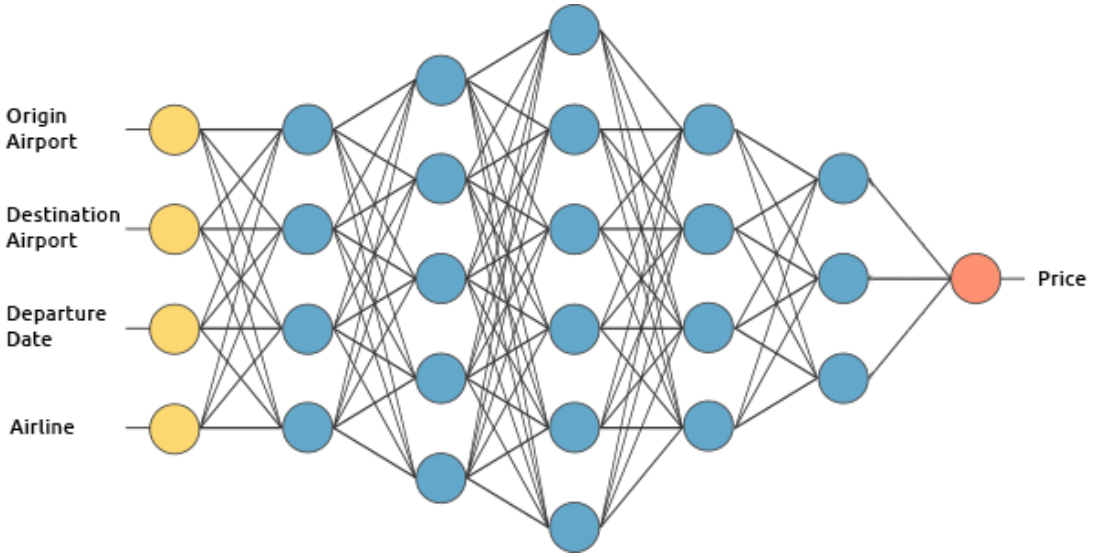
- **Artificial Neural Networks**
  - Consist of several connected neurons
  - Layers: input, output, and at least one hidden layer



Artificial Neural Networks

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- **History of Artificial Neural Networks**
  - 1943: McCulloch and Pitts and their basic computational model
  - 1948: Hebb and the unsupervised learning process
  - 1958: Perceptron, a pattern recognition algorithm
  - 1969: Minsky and Papert, improvement of perceptron
  - 1975: Backpropagation for partial training
  - 1985: NNs for prediction and processing complicated structures
  - 1992: Max-pooling for 3D object recognition
  - 2006: deep neural networks with their magnificent outputs

Artificial Neural Networks

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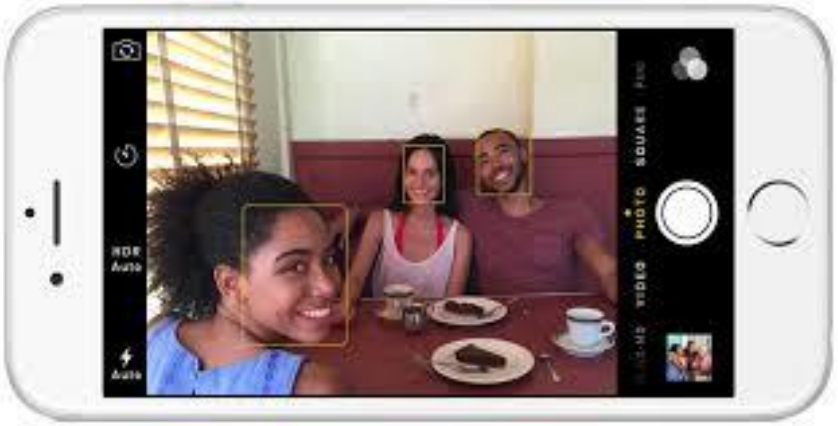
Areas of Application

- Deep Learning
- Image processing
- Prediction
- Data mining
- Speech Recognition
- Human Face Recognition
- Chemical problems



Fuzzy Systems

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Some students are good at Python!

- Can computers understand this?!
- The world is not a **binary** or a **Boolean** system!

"To be, or not to be, that is the question."

- **Fuzzy logic**
  - An approach to computing based on "degrees of truth"

Fuzzy Systems

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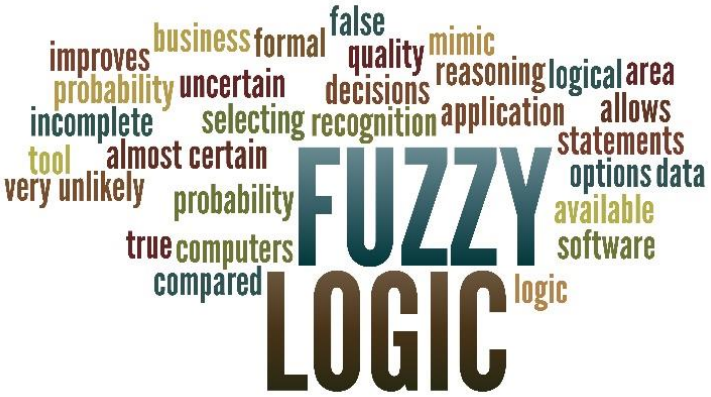
- **Fuzzy logic description**
  - An extension of multi-valued logic
  - Conceptually easy to understand
  - High flexibility
  - Based on natural language
  - Related to Approximate Reasoning
  - Non-statistical uncertainty



Fuzzy Systems

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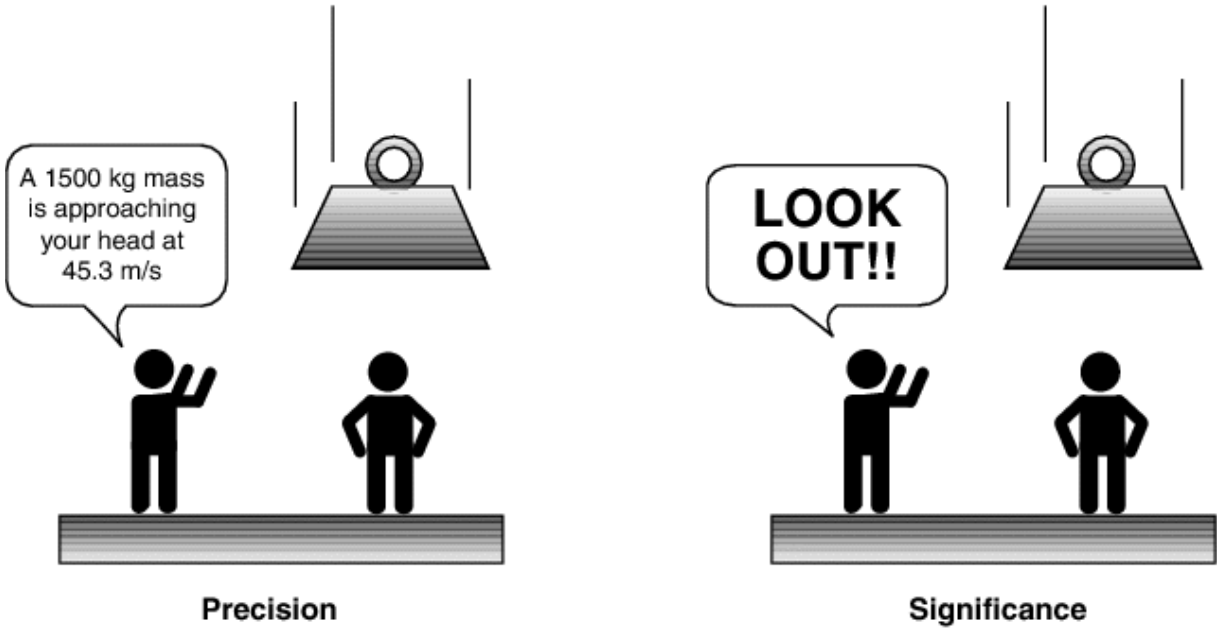
How much is it important?!



Fuzzy Systems

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Some Fuzzy sentences we use in our lives

- The man seems to be very young.
- The weather was extremely hot today.
- Too many students in the class …
- The painting is magnificent.
- This method is computationally intensive.

Fuzzy Systems

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Paradox of the heap

- One grain of sugar is not a heap
- It is not the difference between a heap and a non-heap!
- Taking one grain of sugar away from the heap
- Do the above action for 2000 grains
- After a while, you do not call the remaining grains a heap of sugar

How did it become a non-heap?

How many grains of sugar is needed to call them a heap of sugar?

Fuzzy Systems

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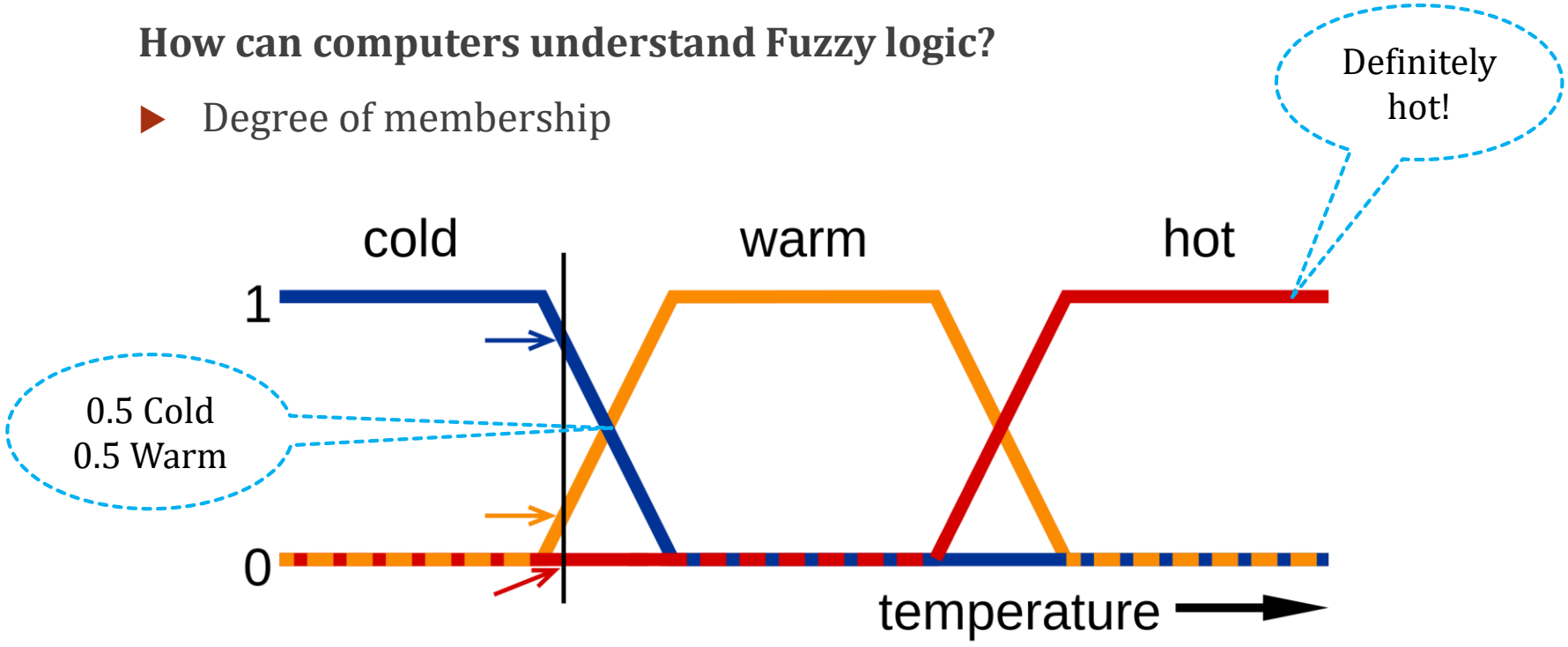
How can computers understand Fuzzy logic?

- Degree of membership



Fuzzy Systems

- Applications of Fuzzy Systems
  - Automatic Transmission Cars
  - Controllers of an elevator
  - Smart TV and washing machine
  - Speech recognition software
  - Decision making in business
  - Train schedules
  - etc.

Evolutionary Computation

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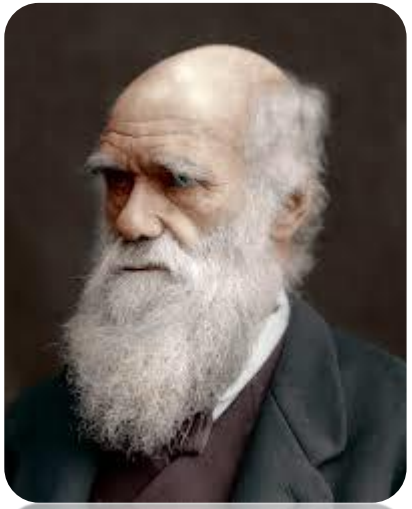
Darwinism, the theory of biological evolution

- The concept of Natural Selection
- # of produced individuals > # of survived individuals
- Existence of Phenotypic variation
- Ones better suited to the environment ➔ survival
- Reproduction isolation and new species



Evolutionary Computation

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Natural Selection and Evolution?

Evolutionary Computation

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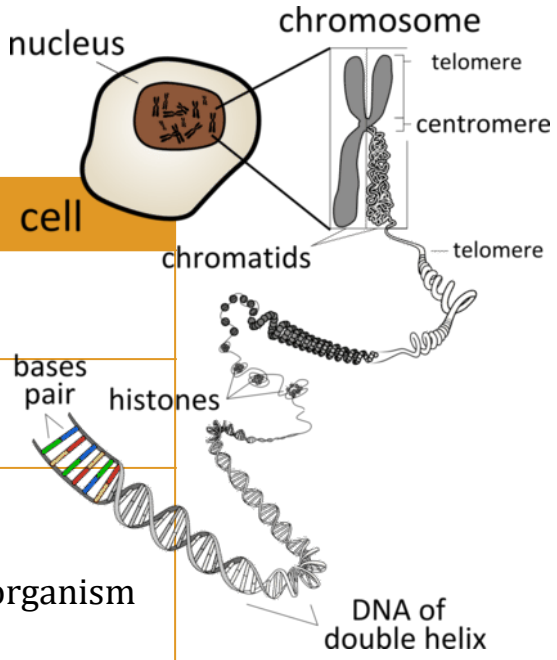
Main concepts in Evolution

Concept	Description
Chromosome	Thread-like structures located inside the nucleus Made of a very long stand of DNA
DNA	Contains many genes Stores genetic information
Gene	Segments of DNA • **Genotype**: an individual's collection of genes • **Phenotype**: observable characteristics of an organism • **Allele**: one of several versions of a gene • **Fitness**: the ability of organisms to survive/reproduce



Evolutionary Computation

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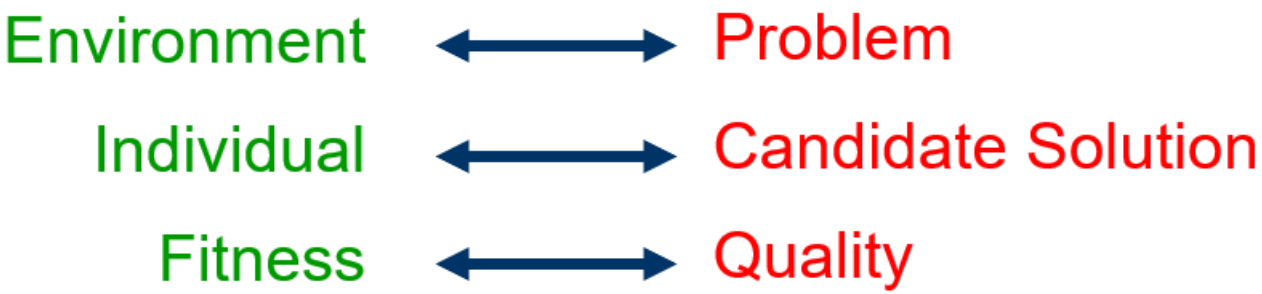
The concept of Evolutionary Computation (EC)

- Computational intelligence techniques inspired from natural evolution
- Individuals (chromosomes) inherit features from their parents
- Fitness: chances for survival and reproduction



Evolutionary Computation

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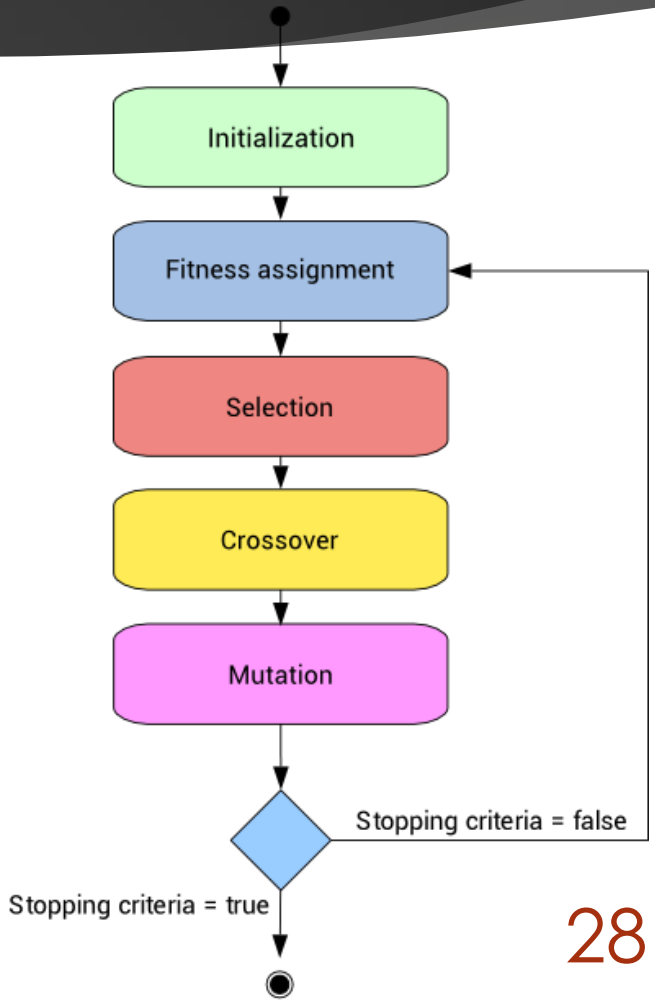
The general steps of an EC algorithm

- Creating the population
  - AKA solutions to the problem
  - Might be created randomly
- Evaluation with a fitness function
- Selection
- Crossover
- Mutation
- Reproduction
- Termination criterion



Evolutionary Computation

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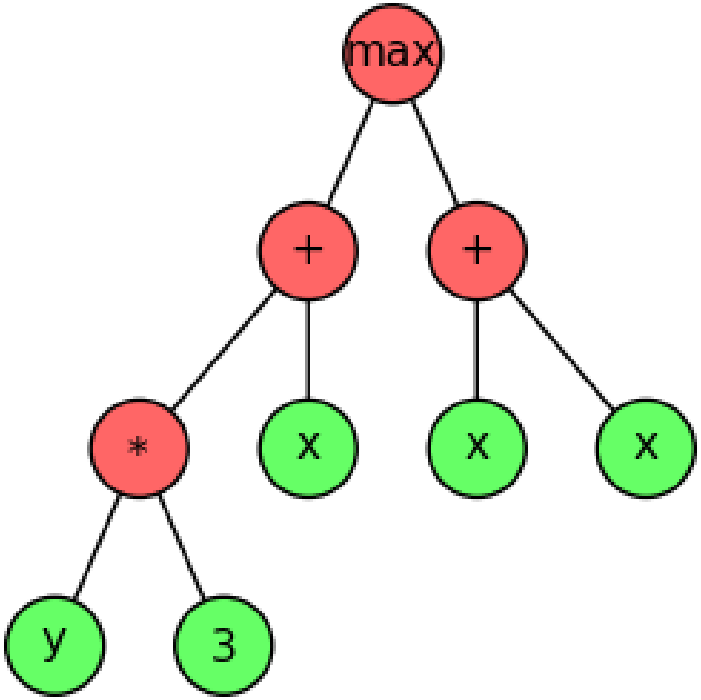
Various EC techniques

- Genetic Programming (GP)
- Genetic Algorithms (GAs)
- Grammatical Evolution (GE)
- Evolutionary Algorithms (EA)
- And so on …



Swarm Intelligence

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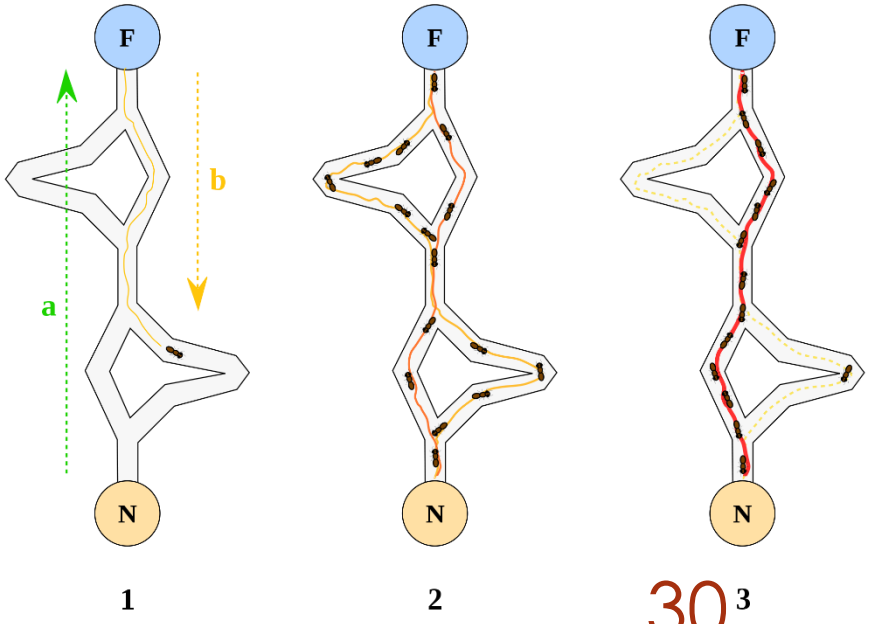
- The discipline that deals with natural and artificial systems
- Composed of many individuals that coordinate using:
  1. Decentralized Control
  2. Self-Organization
- Focuses on the collective behaviors
- Interactions of the individuals:
  1. With each other
  2. With their environment



Swarm Intelligence

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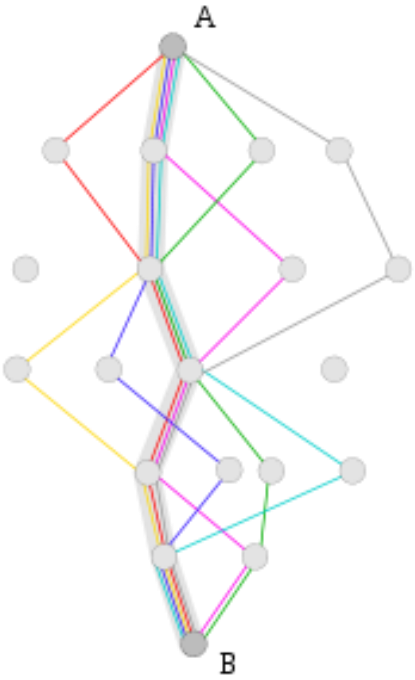
Particle Swarm Optimization (PSO)

- One of the most well-known metaheuristics
- Inspired from swarm behavior such as bird flocking
  - Each group member is a Particle
    - A candidate to solve an optimization problem
  - The combination makes the Swarm
- **Applications:**
  - Travelling Salesman Problem
  - Network routing



Swarm Intelligence

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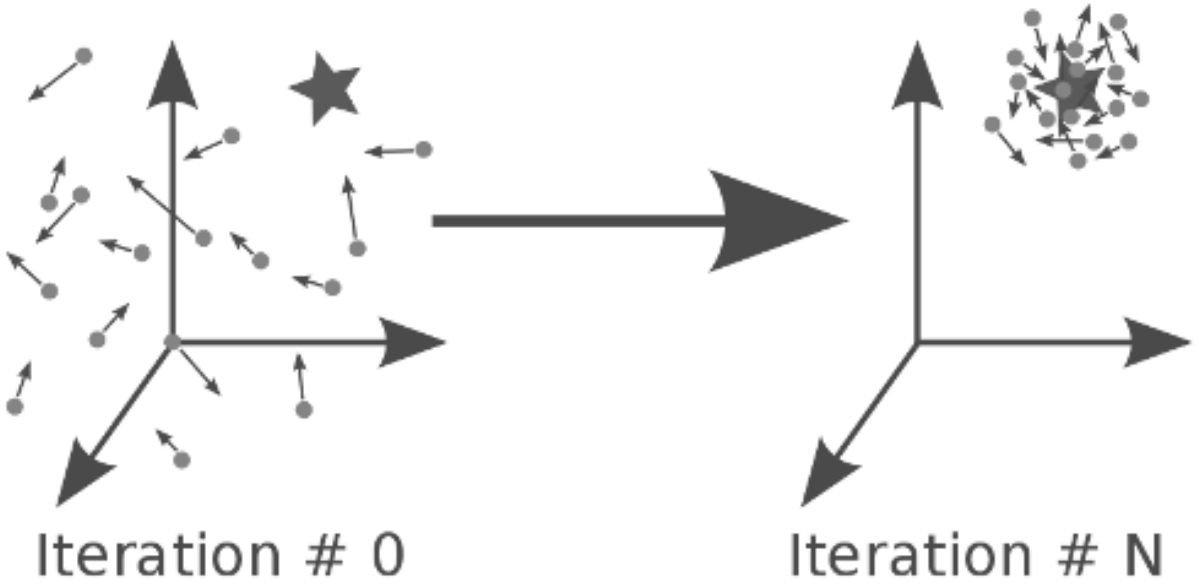
Particle Swarm Optimization (PSO)



Swarm Intelligence

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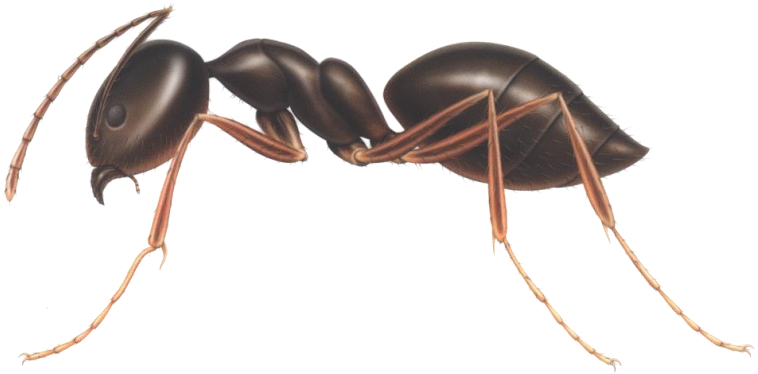
Evolutionary algorithms based on SI

- Interaction among several agents to find an optimized solution
- Individuals with a simple behavior, groups with a complicated one
  - Sample: an ant cannot understand how big a colony is



Swarm Intelligence

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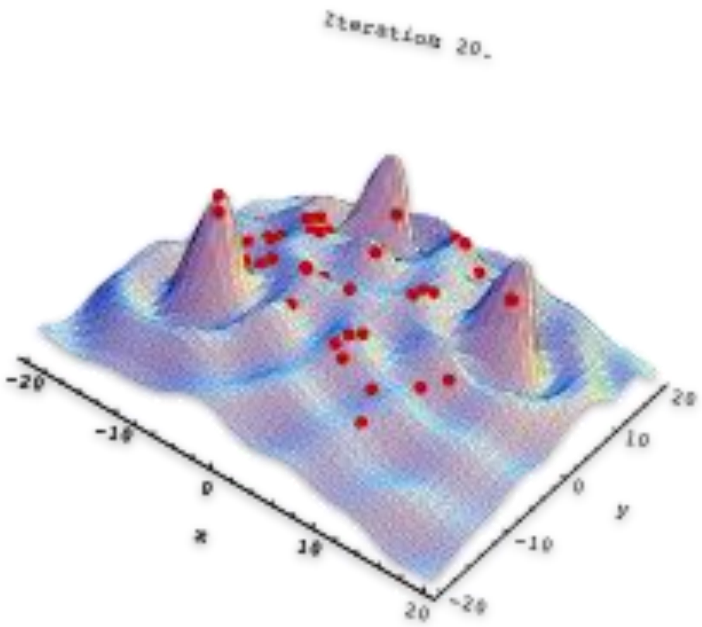
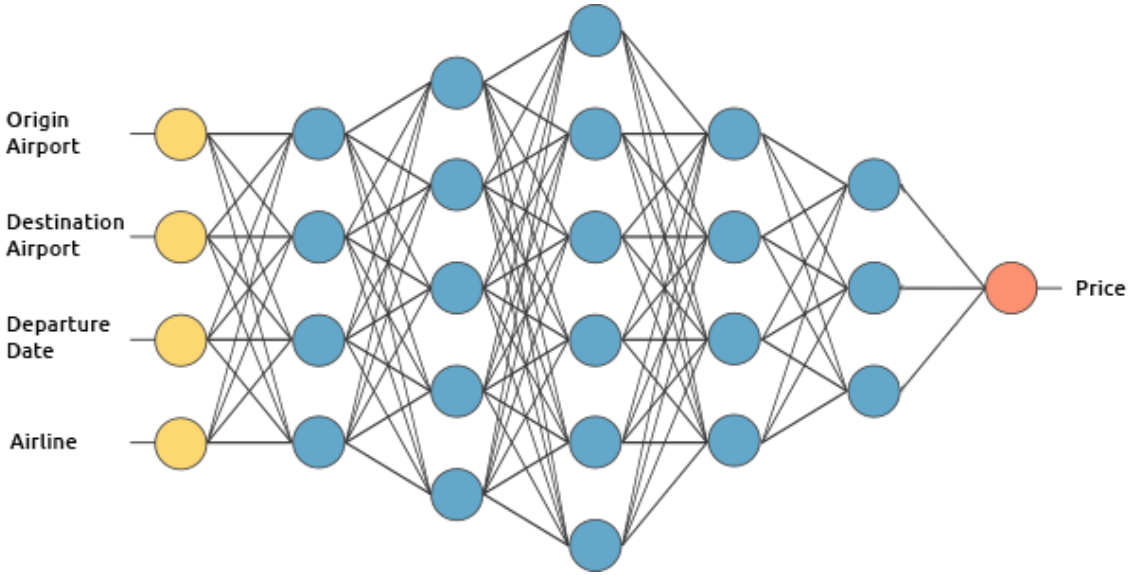
Some famous algorithms of SI

- Ant Colony Optimization
- Honeybee Hive Optimization
- Artificial Bee Colony
- Termite Colony Optimization
- Particle Swarm Optimization
- Cat Swarm Optimization
- Bat Algorithm



What's Next?

- Artificial Neural Networks



Questions?