计算思维

课程五

IEEE Computational Intelligence Society

Definition of Computational Intelligence

Any biologically, naturally, and linguistically motivated computational paradigms include, but not limited to,

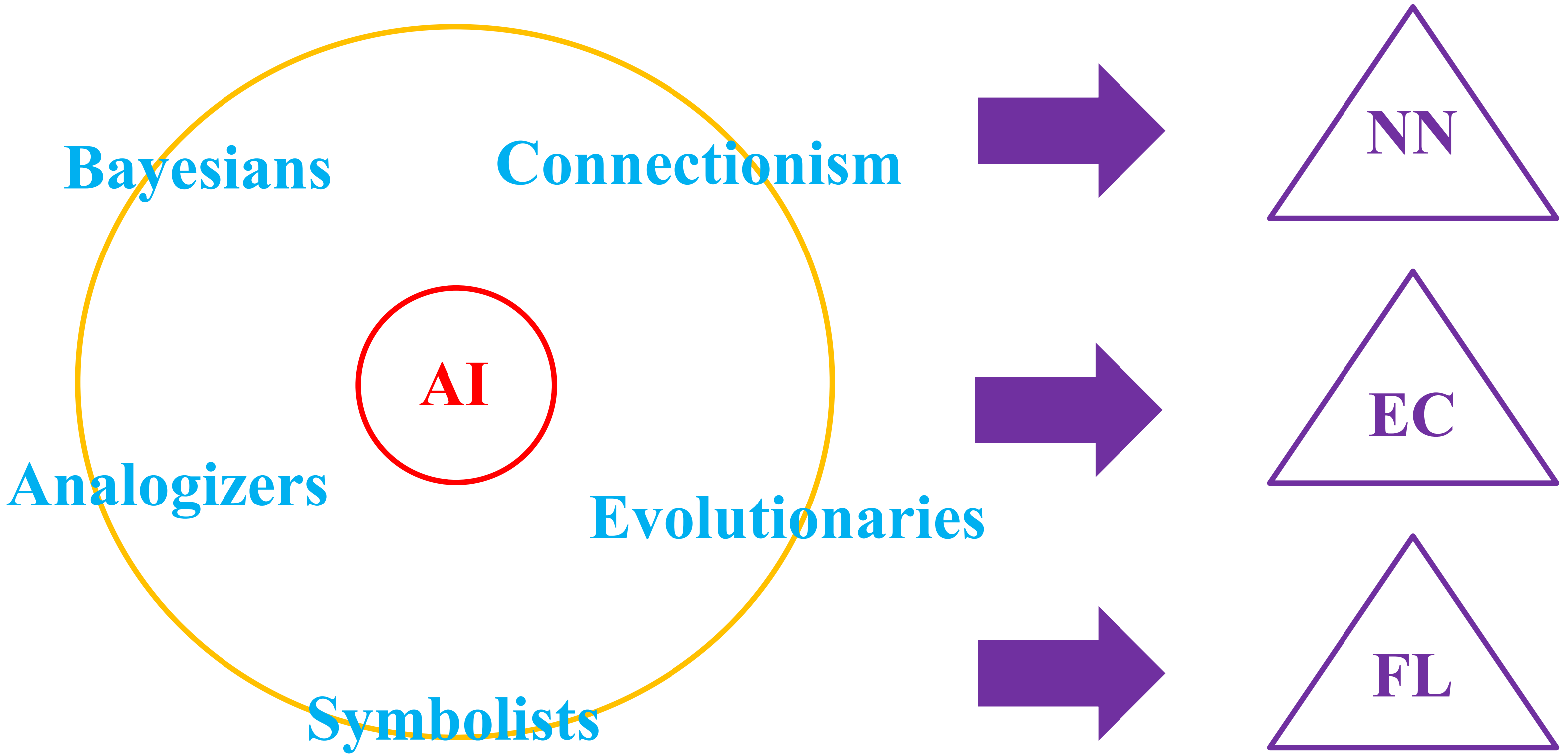
- **Neural Network,**
- **Connectionist machine,**
- **Fuzzy system,**
- **Evolutionary computation,**
- **Autonomous mental development,**

and hybrid intelligent systems in which these paradigms are contained.

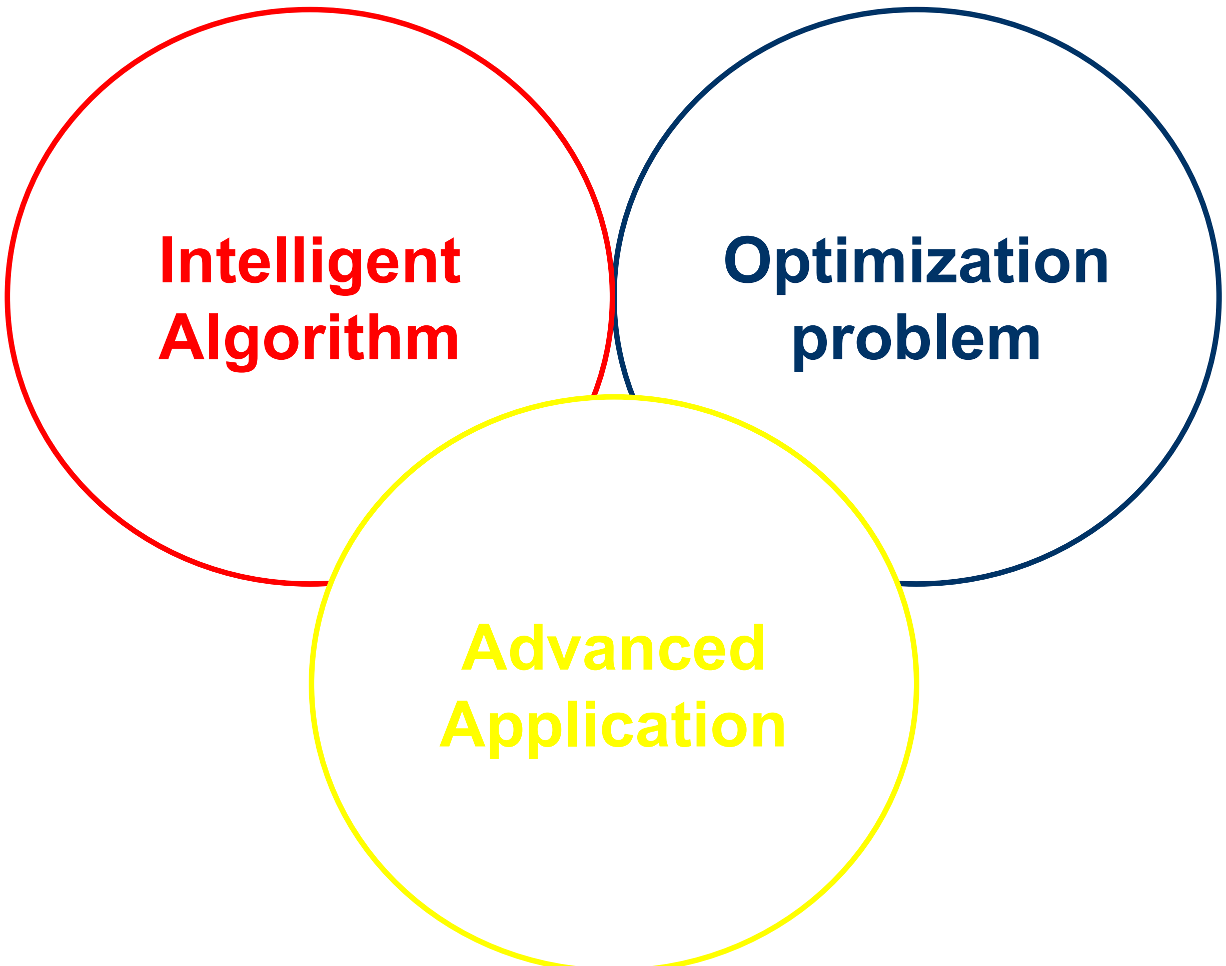
Relation between CI and AI

CI is one branch of AI

CI is the computational part of AI



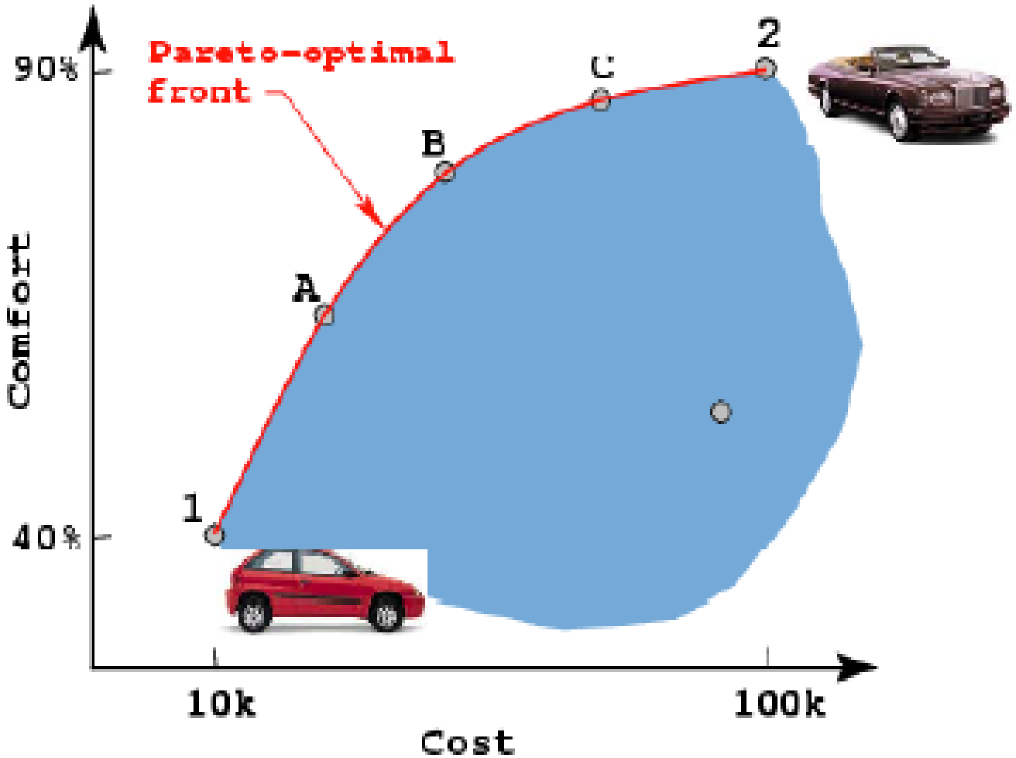
Intelligent Optimization



Multiobjective Optimization

- Optimization problems involve more than one objectives
- Very common, yet difficult problems in the field of science, engineering, and business management
- Non-conflicting objectives: achieve a single optimal solution satisfies all objectives simultaneously
- Competing objectives: cannot be optimized simultaneously
- MOP– find a set of “acceptable”– maybe only suboptimal for one objective– solutions is our goal

Example: Buying an Automobile



Objectives

- Minimize cost
- Maximize comfort

Trade off

- No single optimal solution
- Both objectives cannot be optimized simultaneously

Which solution (1, A, B, C, 2) is the best ???

Problem Formulation

Objective vectors

Decision vectors

Equality constraints

Inequality constraints

Variable bounds

$$\min_{\mathbf{x}\in\Re^n} \{\mathbf{y} = \mathbf{f}(\mathbf{x}) : \mathbf{h}(\mathbf{x}) = 0, \mathbf{g}(\mathbf{x}) \le 0, x^L \le x \le x^U\}$$

Mathematical Definition

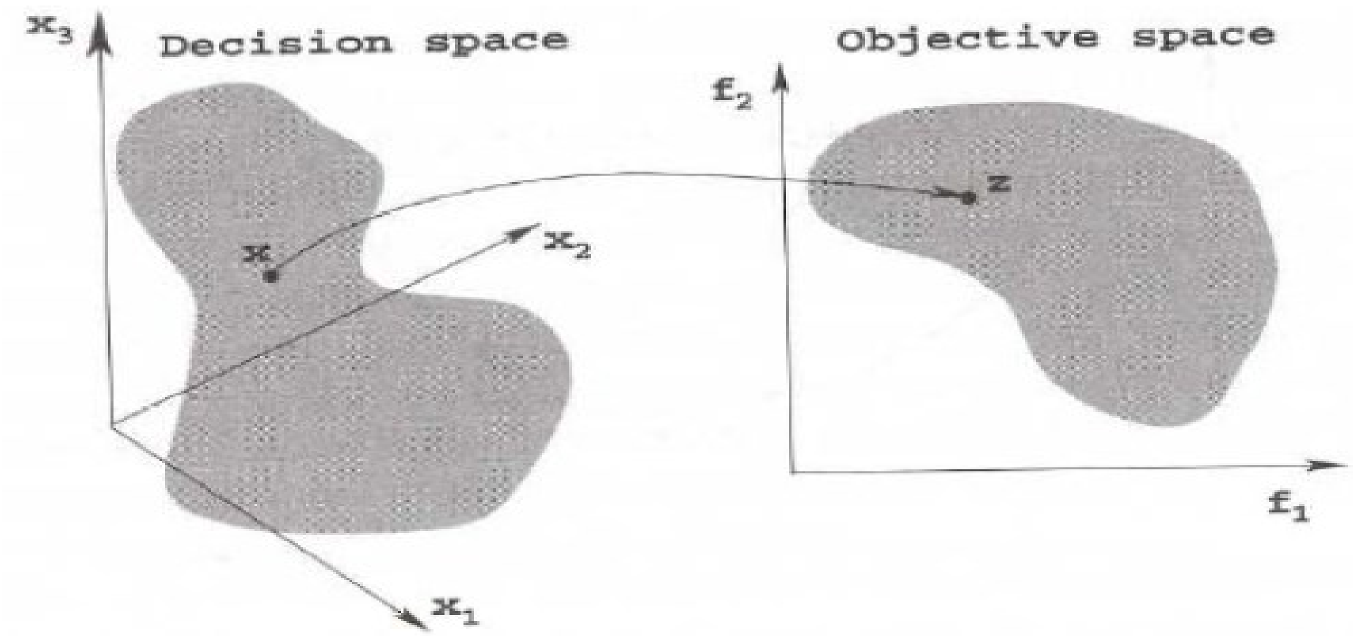
Three basic ingredients

- A set of objective functions
- A set of decision variables
- A set of equality/inequality constraints

Goal

- Search for the values of the decision variables that minimize or maximize the objective functions while satisfying the constraints

Mapping



- Mapping takes place between an n-dimensional decision space and an M-dimensional objective space

Evolutionary Computation (EC)

- Any biologically, naturally, and linguistically motivated computational paradigms
- The theory of evolution has been translated into an algorithm to search for solutions to problems in a more ‘natural’ way
- Darwinian’s Evolution

  1) Individuals within species are variables

  2) Some of the variations are passed onto offspring

  3) In every generation, more offspring are produced than survive

  4) Individuals who survive and go on to reproduce, are those with the most favorable variations.

EC Variants

- **Genetic Algorithm (GA)**
- **Particle Swarm Optimization (PSO)**
- **Ant Colony Optimization (ACO)**
- **Artificial Immune System (AIS)**
- Differential Evolution (DE)
- Evolutionary Programming (EP)
- Evolutionary Strategy (ES)
- Genetic Programming (GP)

Genetic Algorithms (GAs)

Inspired by Darwin's theory of evolution

- The new breeds of classes of living things come into existence through the process of reproduction, crossover, and mutation among existing organisms.

Biological Background

- Chromosome: strings of DNA (genes) and serve as a model for the whole organism
- Each gene encodes a particular protein and has its own position in the chromosome
- Crossover: genes from parents combine to form a new chromosome
- Mutation: elements of DNA are a bit changed
- The fitness of an organism is measured by success of the organism in its life (survival).

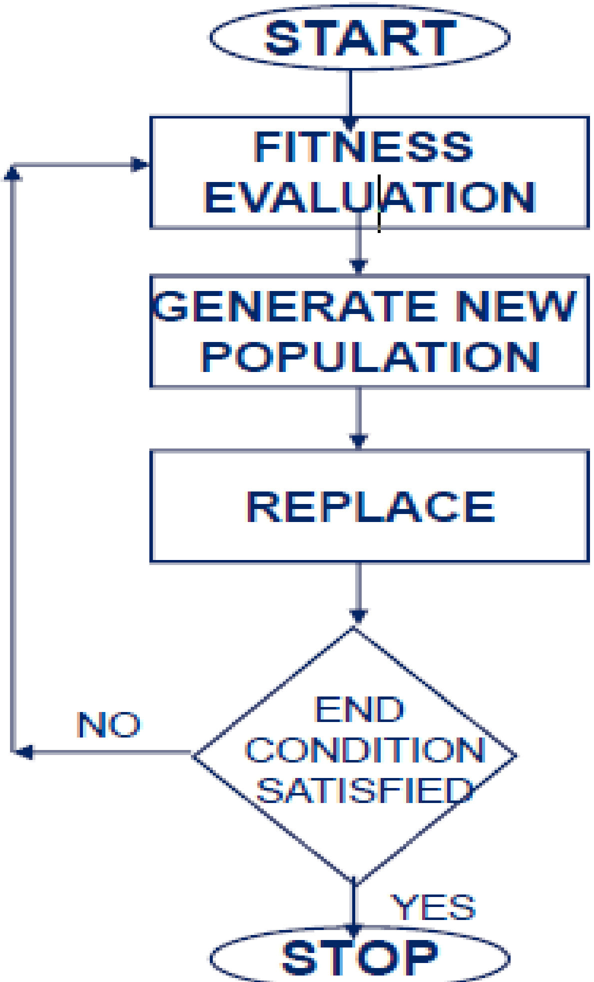
History

- GAs are originated from studies of cellular automata, conducted by John Holland and his colleagues at University of Michigan.
- Until the early 1980s, the research in GA was mainly theoretical, with few real applications.
- From the early 1980s the community of GA has experienced an **abundance of applications** which spread across a large range of disciplines. **Each and every additional application** gave a new perspective to the theory.
- Following the last couple of years of furious development of GA in the sciences, engineering and the business world, these algorithms in various guises have now been successfully applied to optimization problems, scheduling, data fitting and clustering, trend spotting and path finding.

The Process of GAs

- Algorithm begins with a set of solutions (represented by chromosomes) called population.
- Solutions from one population are evaluated for their goodness (fitness) and used to form a new population (reproduction). This is motivated by a hope, that the new population will be better than the old one.
- Solutions which are then selected to form new solutions. (offspring) are selected according to their fitness – the more suitable they are the more chances they have to reproduce (natural selection).
- This is repeated until some condition (for example number of populations or improvement of the best solution) is satisfied.

Flowchart



1. Generate random population
2. Evaluate the fitness of each chromosome in the population
3. Create a new population by repeating following steps until the new population is complete by means of selection and crossover or mutation
4. Replace unfit individuals in old population by new off springs
5. If the end condition is satisfied, stop, and return the best solution in current population, else Go to step 2

Design of GAs

- Design a representation
- Decide how to initialize a population
- Design a way of evaluating an individual
- Design mutation operators
- Design crossover operators
- Decide how to select parents for crossover
- Decide how to select individuals to be replaced

Representation

Binary Valued Representation

Chromosome 1: 1101 1001 0011 0110

Chromosome 2: 1101 1110 0001 1110

Real Valued Representation

Chromosome 1: 0.25 0.35 0.1   0.4

Chromosome 2: 1.2   1.3   0.23 0.43

Initialization of a Population

- Usually, at random
- Uniformly on the search space …. , *if possible*

  1) Binary representation: 0 and 1 with probability of 0.5

  2) Real-valued representation: uniformly on a given interval
- Seed the population with previously known values or those from heuristics. With care:

  1) Possible loss of genetic diversity

  2) Possible unrecoverable bias

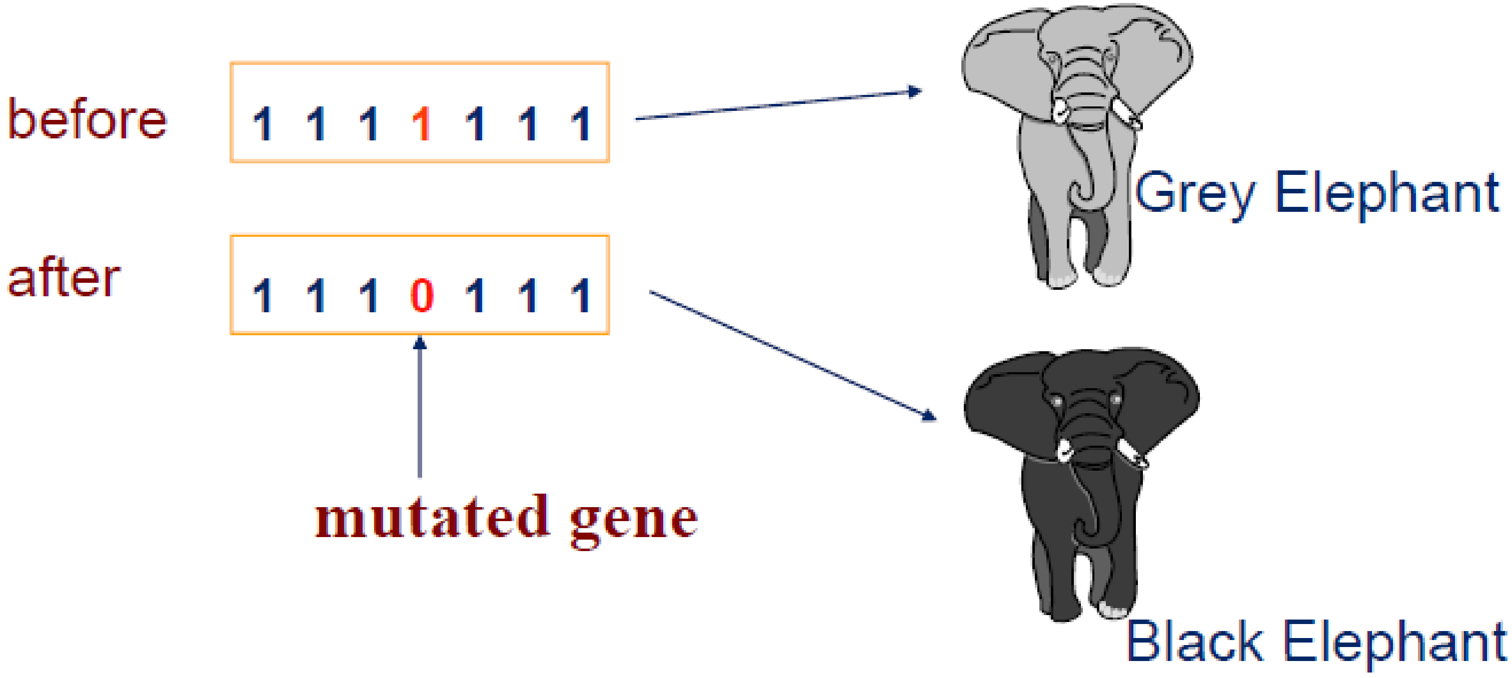
Evaluating an Individual

- By far the most costly step for real applications
- The effectiveness of the process depends on the choice of the fitness function.
- You could use approximate fitness, but not far too long
- Constraint handling- what if the phenotype breaks some constraint of the problem:

  1) Penalize the fitness

  2) Specific evolutionary method

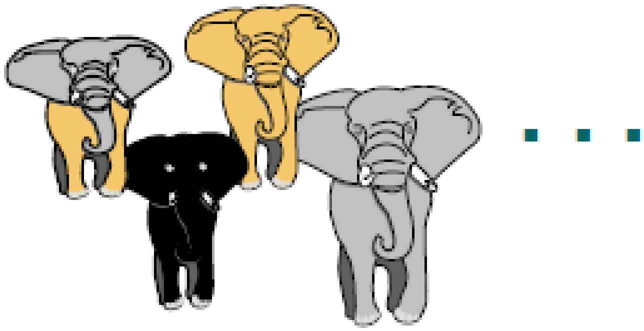
Mutation

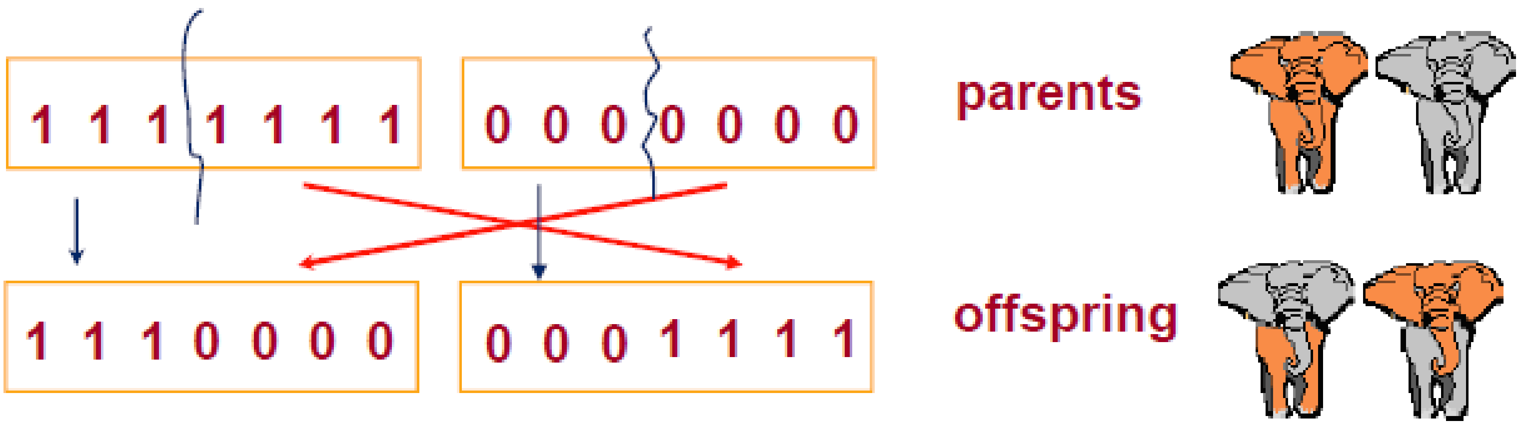


Mutation probability for each gene

Crossover

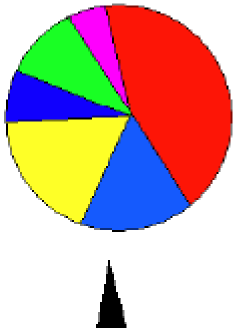
Whole Population:



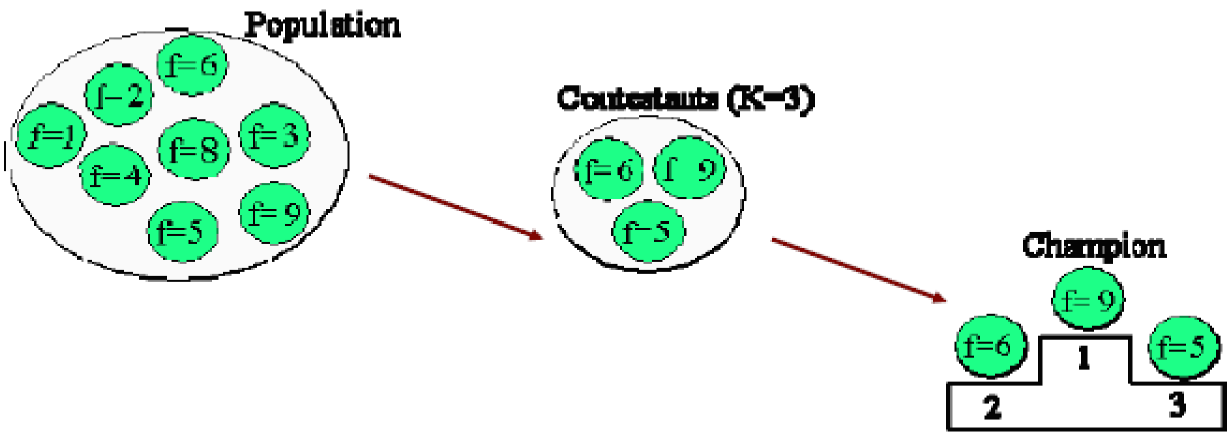


Select Parents for Crossover

Roulette Wheel Selection



Tournament Selection

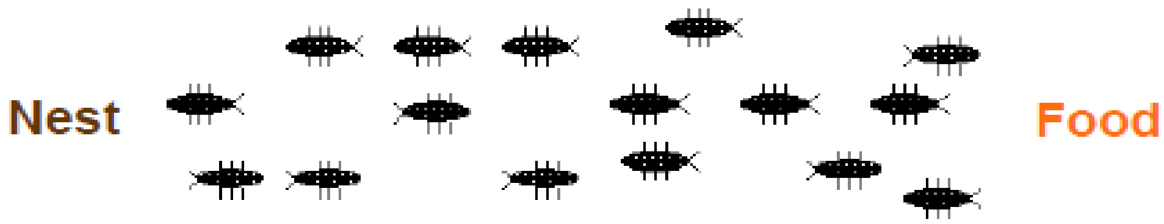


Replacement Strategy

- The selection pressure is affected by the way in which we decide which members of the population to eliminate in order to make space for new individuals.
- Elitism: decide never to replace the best in the population
- This is the main research step in design of GAs
- MOP: achieve convergence and diversity simultaneously

Ant Colony Optimization (ACO)

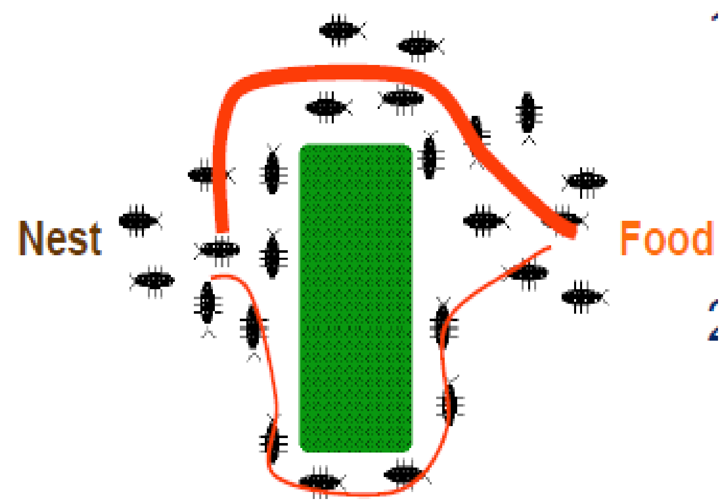
- Inspired by the behavior of how natural ants find the shortest path from their nest to the food source

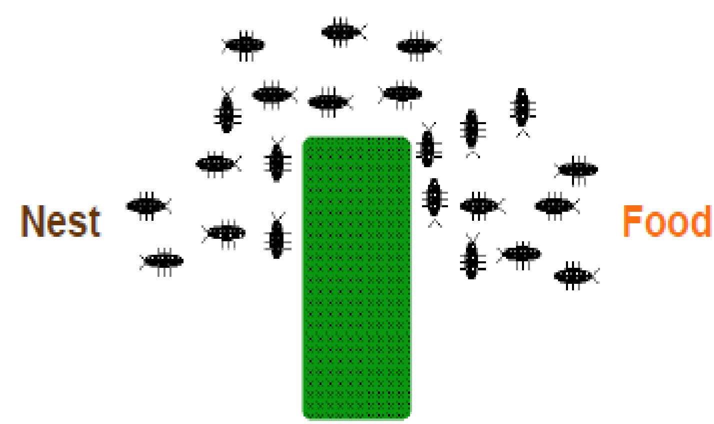


- ACO is effective in finding optimum path for optimization problems with graph related such as network routine

How ACO Works

- When there is an obstacle, the ants will randomly choose some way around it.
- The ants will leave a trail of pheromones behind them as they pass through their chosen path.
- If shortest path is found, more ants will go to the shortest path. Hence, increase the pheromone concentration
- The strong pheromone will cause more and more ants to use the shortest path and eventually all the ants have found the shortest path





Particle Swarm Optimization (PSO)

- In nature, how do the birds know where to locate food when they are hundred feet in the air?
- knowledge is shared within the flock!
- They also include the “mind of social” viewpoint:

  1) Individuals want to be individualistic, i.e. to improve themselves

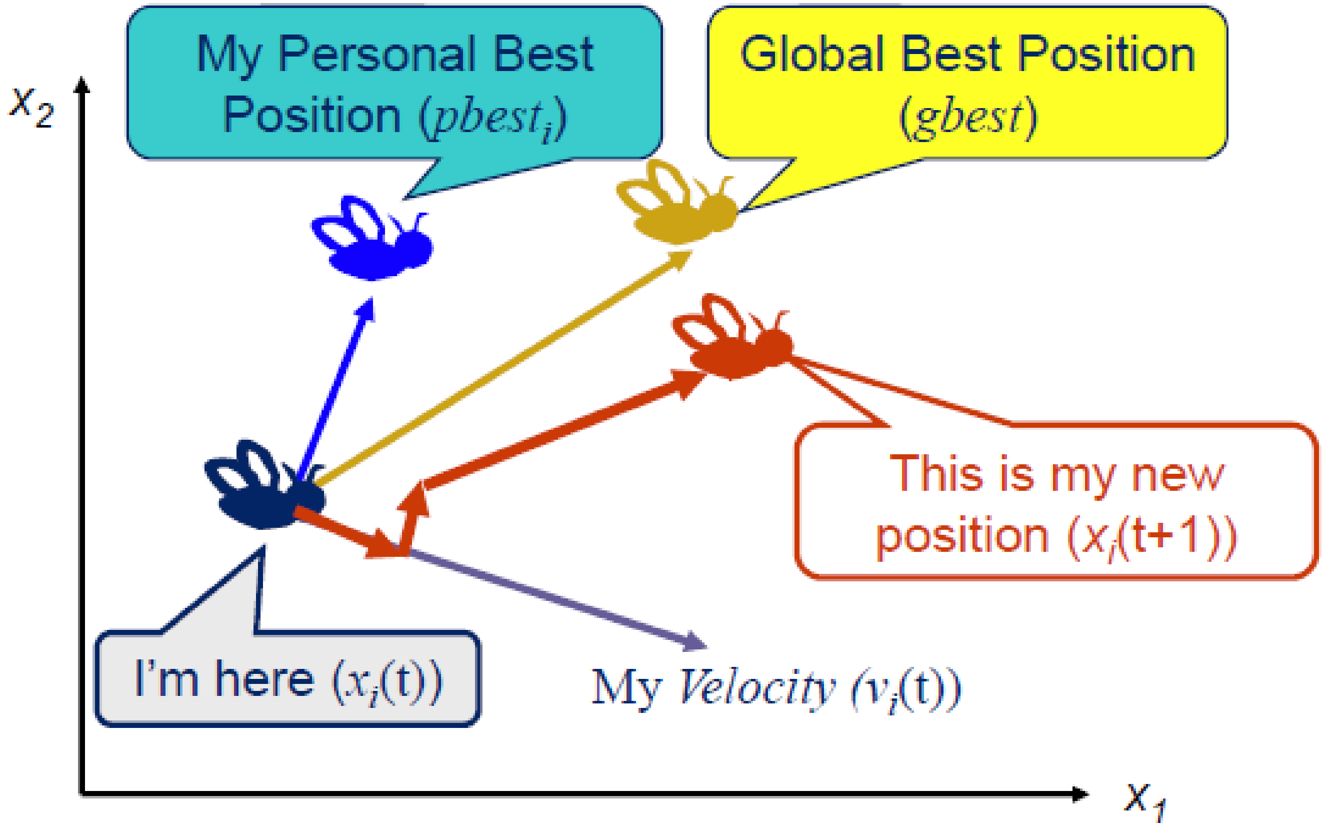
  2) Individuals want to learn the success of their neighbors (both locally and globally), primarily learn their “experiences”.

- The population is called a swarm (swarm population)
- The potential solutions (particles) form a swarm: “flying” around the search space to search for the best solution
- Particles = Candidate solutions (decision variables)
- Particles’ flights are governed by the historical information :

  1) Velocity (v)

  2) Own personal best position found so far (pbest)

  3) Global best position discovered so far by any particles in the swarm (gbest)



My Personal Best Position ($pbest_i$)
Global Best Position ($gbest$)
x_2
This is my new position ($x_i(t+1)$)
I'm here ($x_i(t)$)
My *Velocity* ($v_i(t)$)
x_1

Artificial Immune System (AIS)

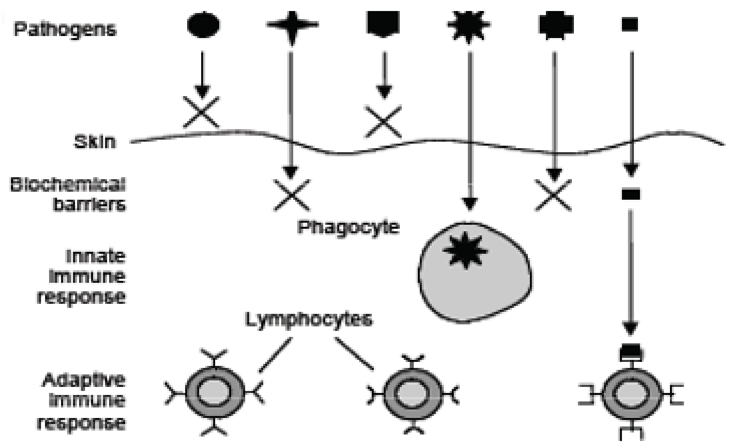
Immune system (IS)

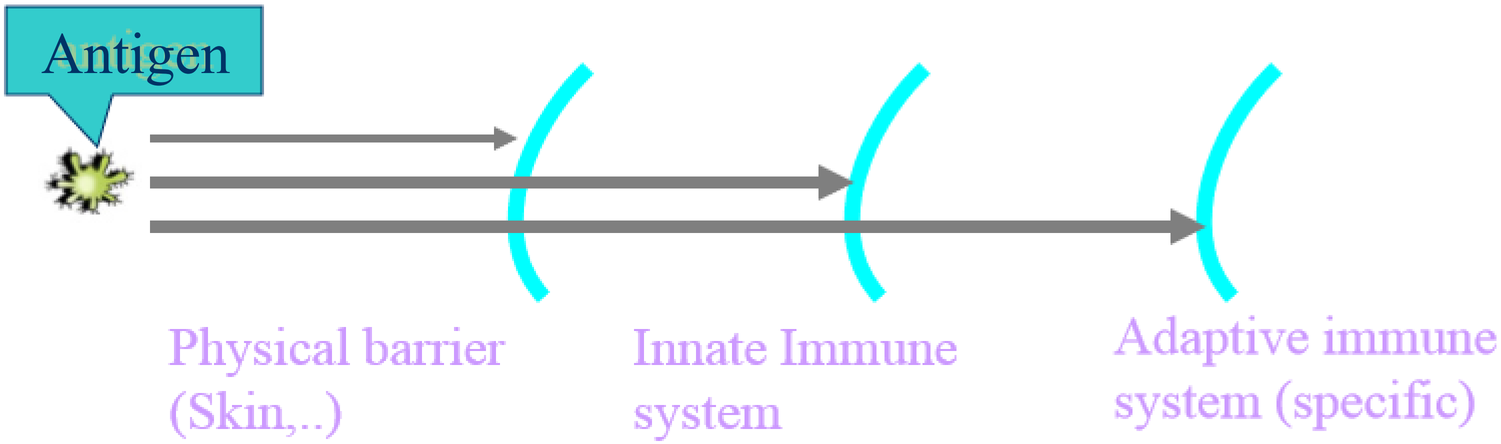
- A system within an organism that protects against disease by identifying and killing pathogens (bacteria, virus).
- Antigens: molecules/microorganisms that can stimulate the IS.
- Phagocytes (macrophage) and lymphocytes (B-cell, T-cell) are cells actively involved in the immune response.

IS works on three levels

- **Skin** (physical barrier)

  A first non-specific line of defense
- **Innate Immune response**
- **Adaptive Immune response**



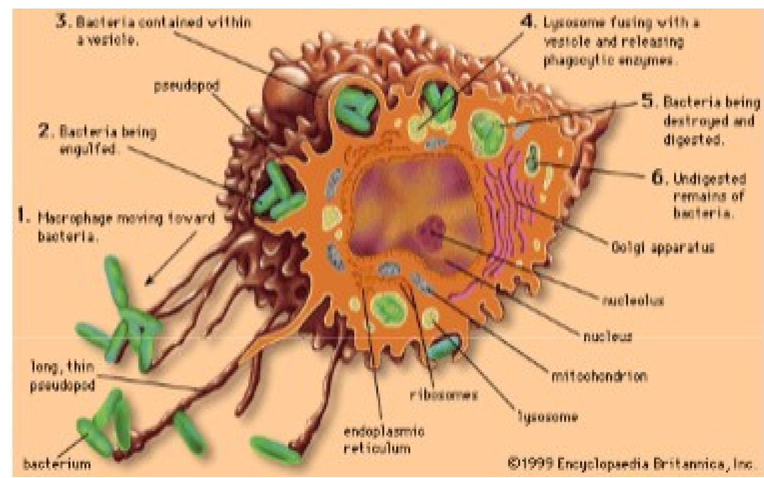


Innate Immune Response

Launches an immediate none specific response to attacking pathogens

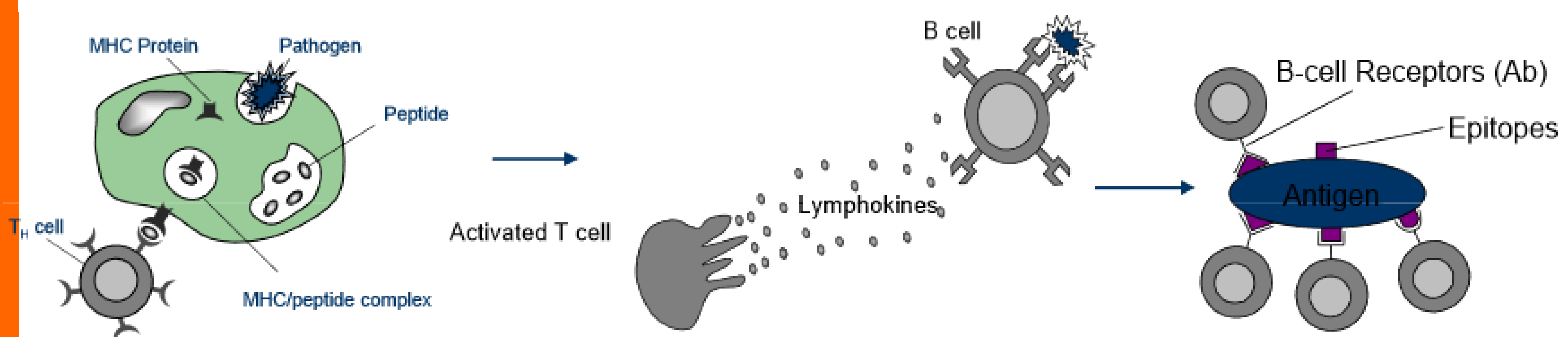
Activated directly by pathogens

- Mainly composed of phagocytic (cell-engulfing) cells.
- Releases chemical information about the attacking antigen
- Conveys information to adaptive immune response



Adaptive Immune Response

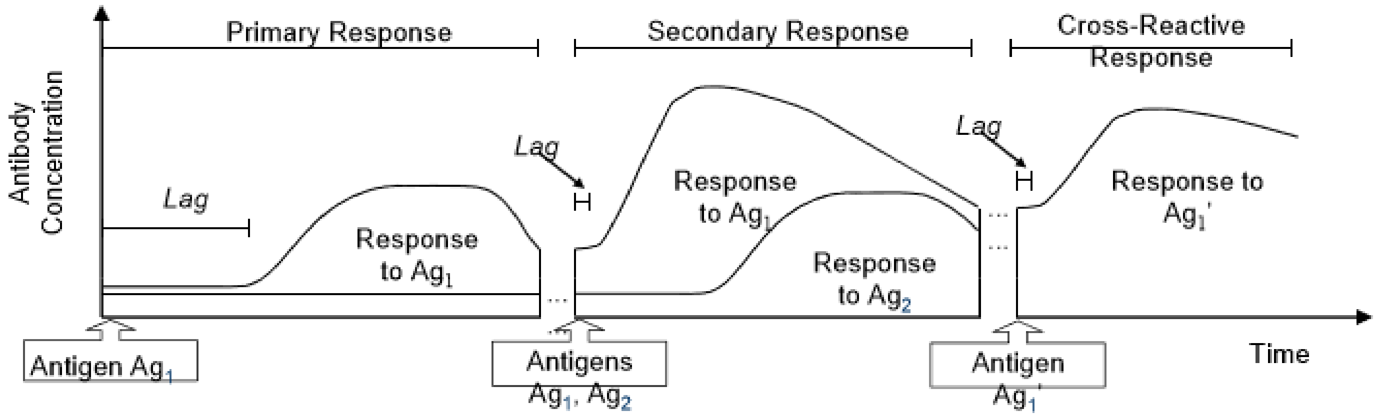
- Composed of lymphocytes (B-cells and T-cells).
- Interprets information conveyed by the innate response using T-cells.
- Produces antibodies (Ab) specific to the determined infectious foreign material by training B-cells.
- Provides resistance against future infections by the same or similar antigens using memory cells.



(Jon Timmis, 2004)

Capable of Learning

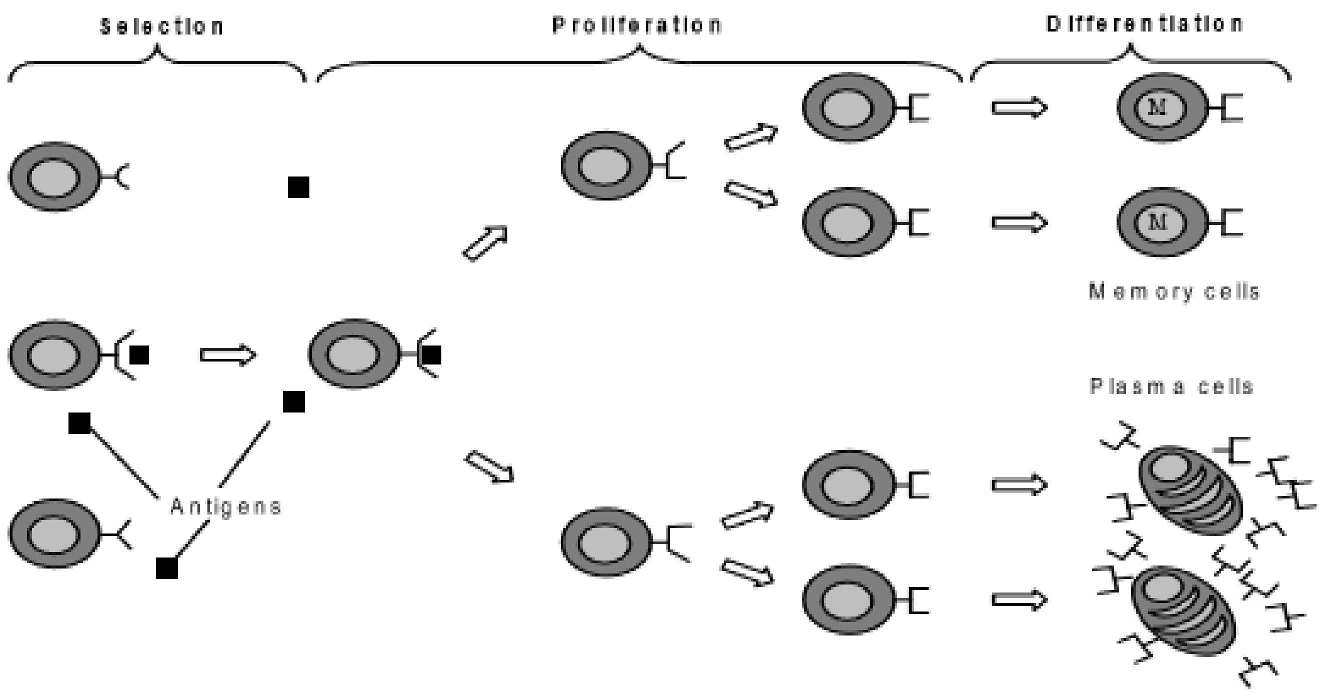
- Primary Immune Response: First time response to attacking pathogen.
- Secondary Immune Response: based on memory to previous encounter of a pathogen. Fast and more effective response.
- Cross-reactive response: fast response to an antigen similar to a previously recognized antigen.



(by De Castro and von Zuben, 2002)

Clonal Selection

- B-cells grow up in the bone marrow as naïve cells.
- Activation/selection, Affinity maturation, Differentiation



Effect of Vaccine

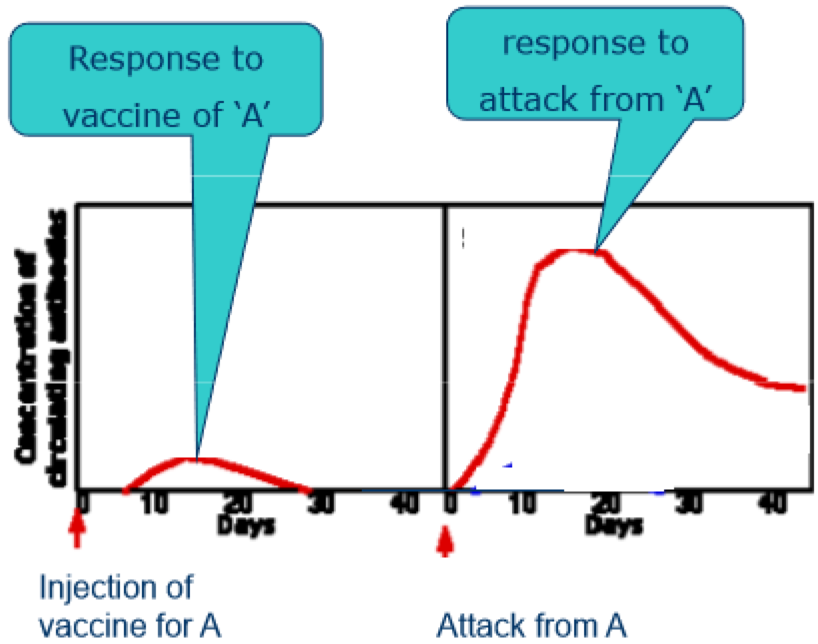
Vaccine is a killed or weakened pathogenic antigen , which introduces the body to harmful new antigens before they actually attack. It provokes memory.

Vaccine injection

- Introduces weak antigens to the body.
- Launches a response to weakened antigens.

Actual infection

- Body remembers past encounters from vaccine
- Faster response to the real infection



Artificial Immune system (AIS)

Mimics the adaptive immune system for problem solving:

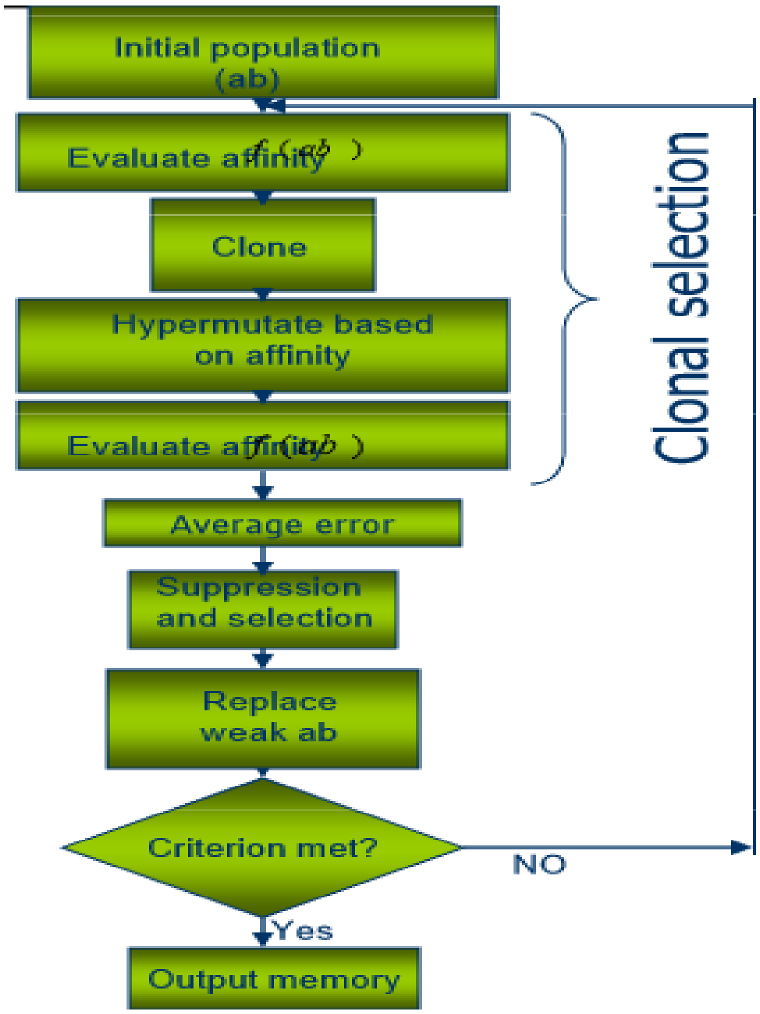
- AIS is an adaptive system, inspired by theoretical immunology and observed immune functions, principles and models

Features of immune system adopted in AIS:

- Learning, Diversity, and Memory
- Cloning, Hypermutation, Idiotypic network, Receptor editing

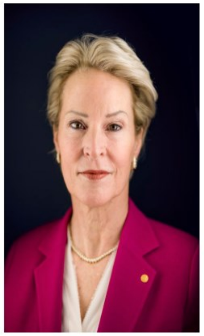
Immune Network Algorithm

- Dynamic population.
- An affine antibody is selected from a clone.
- Antibodies in different clones interact and only the best one goes to memory.
- Stopping criterion is the stagnation of antibodies.
- Used for optimization and pattern recognition.



Summary

The Nobel Prize in Chemistry 2018



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They harnessed the power of evolution

The power of evolution is revealed through the diversity of life. The 2018 Nobel Laureates in Chemistry have taken control of evolution and used it for purposes that bring the greatest benefit to humankind. Enzymes produced through directed

This year's Nobel Laureates in Chemistry have been inspired by the power of evolution and used the same principles – genetic change and selection – to develop proteins that solve mankind's chemical problems.

Take control of evolution in computing process:

Genetic variation
Natural selection

Global search ability on optimization problem