Evolutionary Algorithms:
Operational Procedures of GAs

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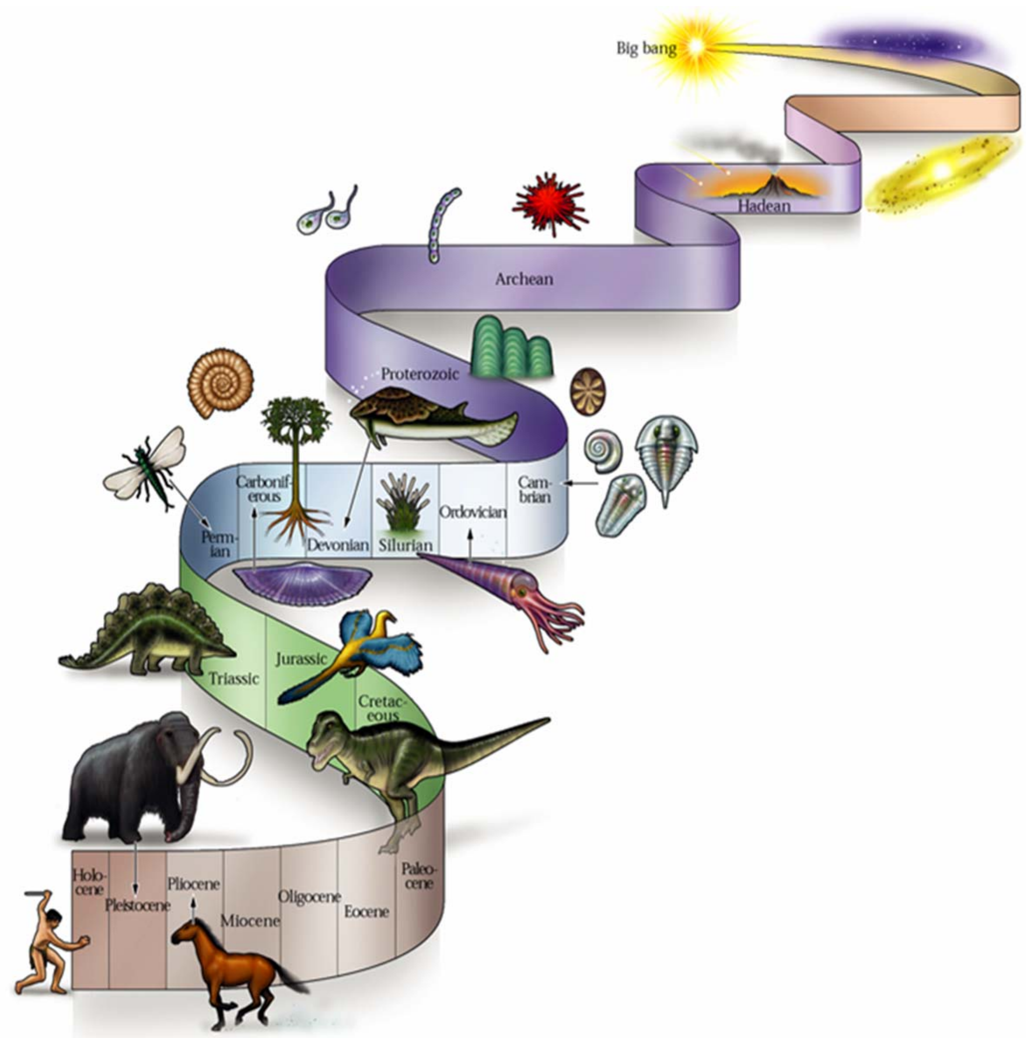
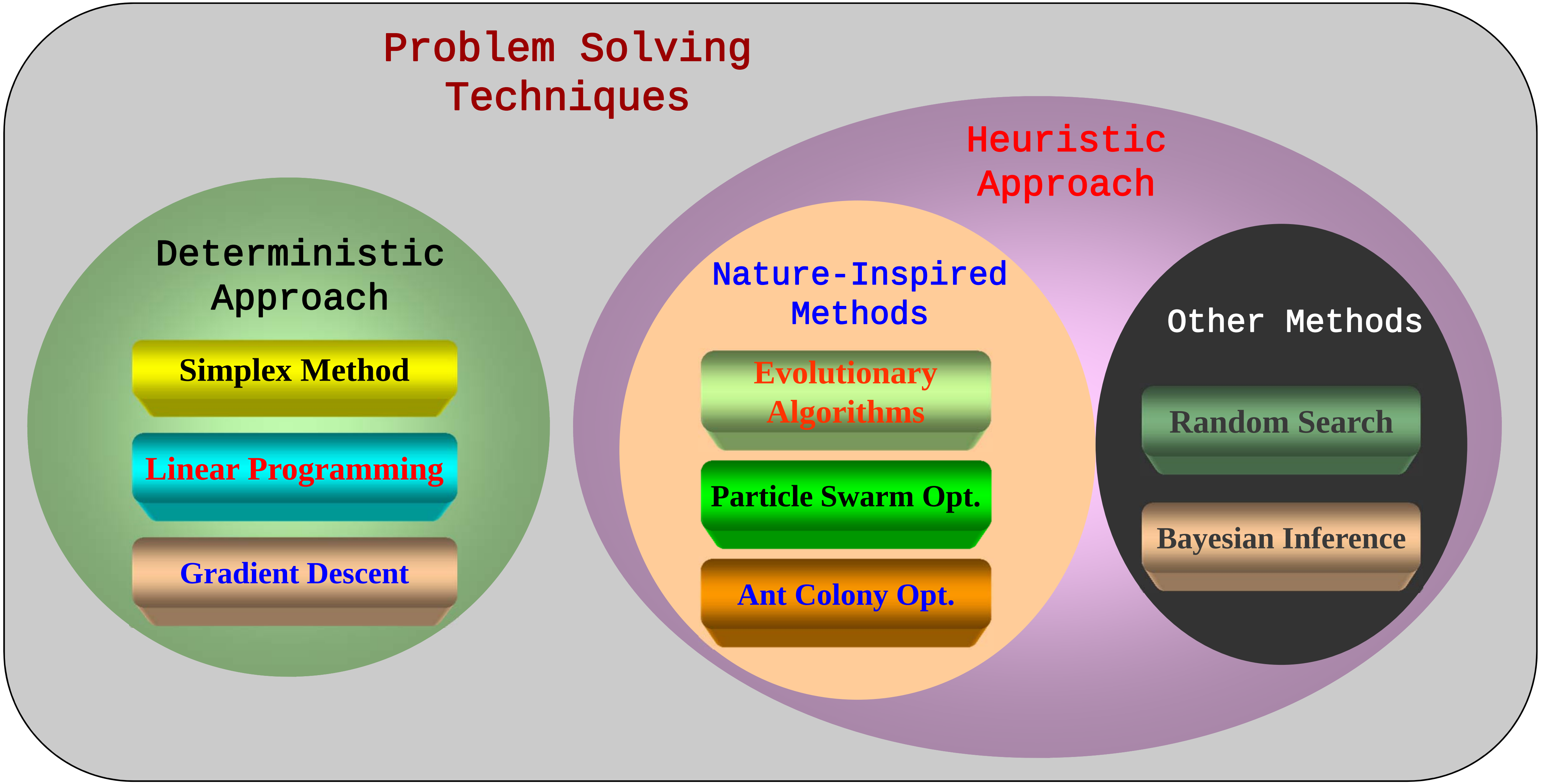
Principle of Evolutionary Algorithms



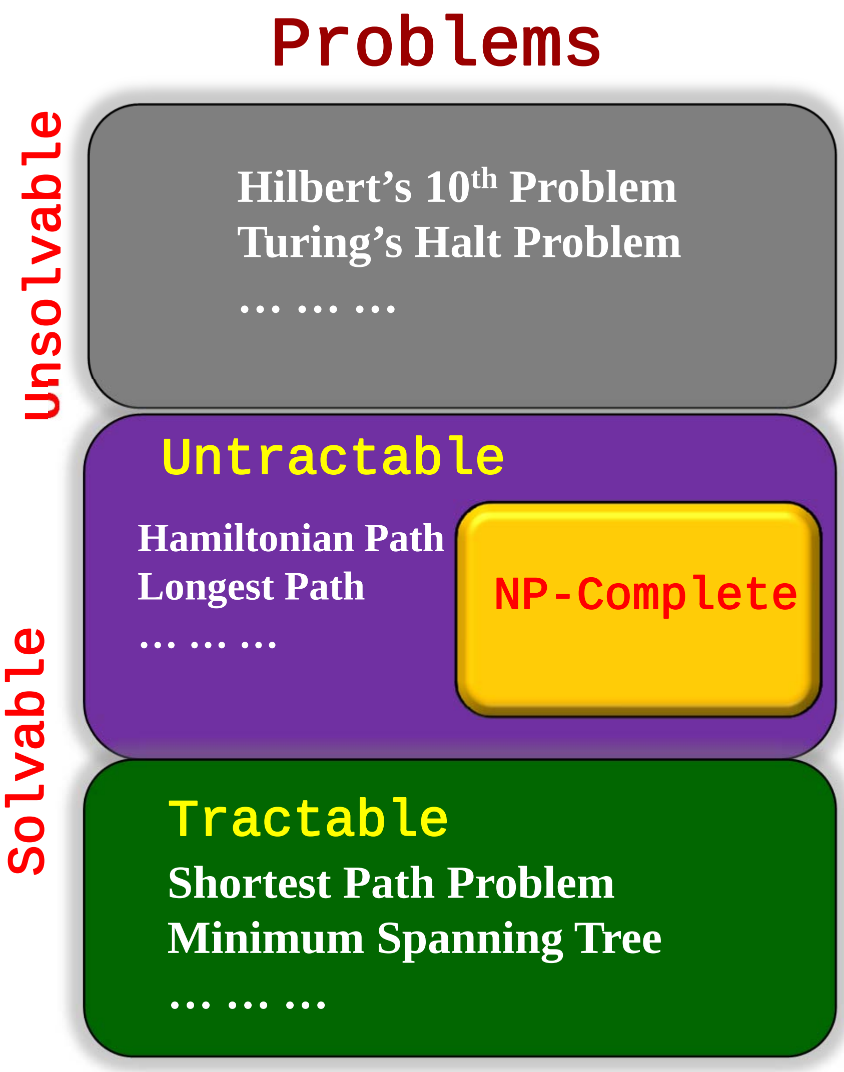
Prologue (1)

- **Where are Evolutionary Algorithms placed?**



Prologue (2)

● Where to be Applied?

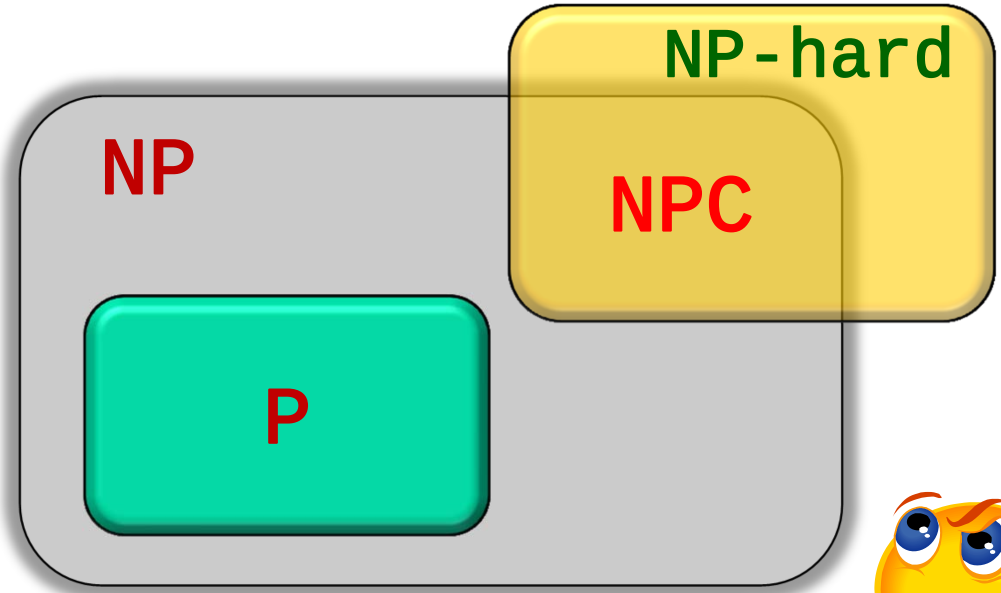


Tractable:

- Solve the problems in a polynomial time; $O(n^k)$, not $O(n!)$ or $O(2^n)$

P: Polynomial

NP: Nondeterministic Polynomial



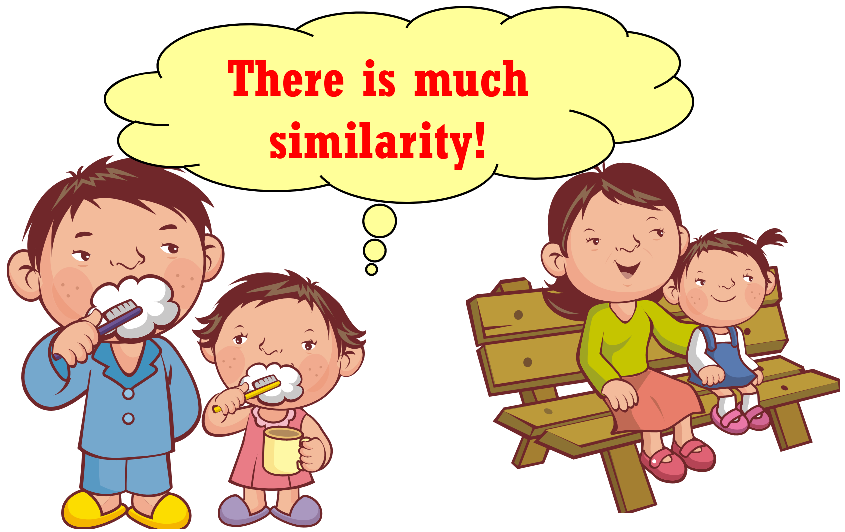
If a problem turns out to be NPC/NP-hard,
Stop to find a deterministic algorithm!
In this case, EAs become a good tool!

Principle (1)

- **What are Evolutionary Algorithms (EAs) ?**
  - **An algorithmic abstraction inspired from the theory of biological evolution, usually implemented on computers, which is employed for resolving problems**

Key Components of Biological Evolution

Natural Selection | **Genetic Inheritance**



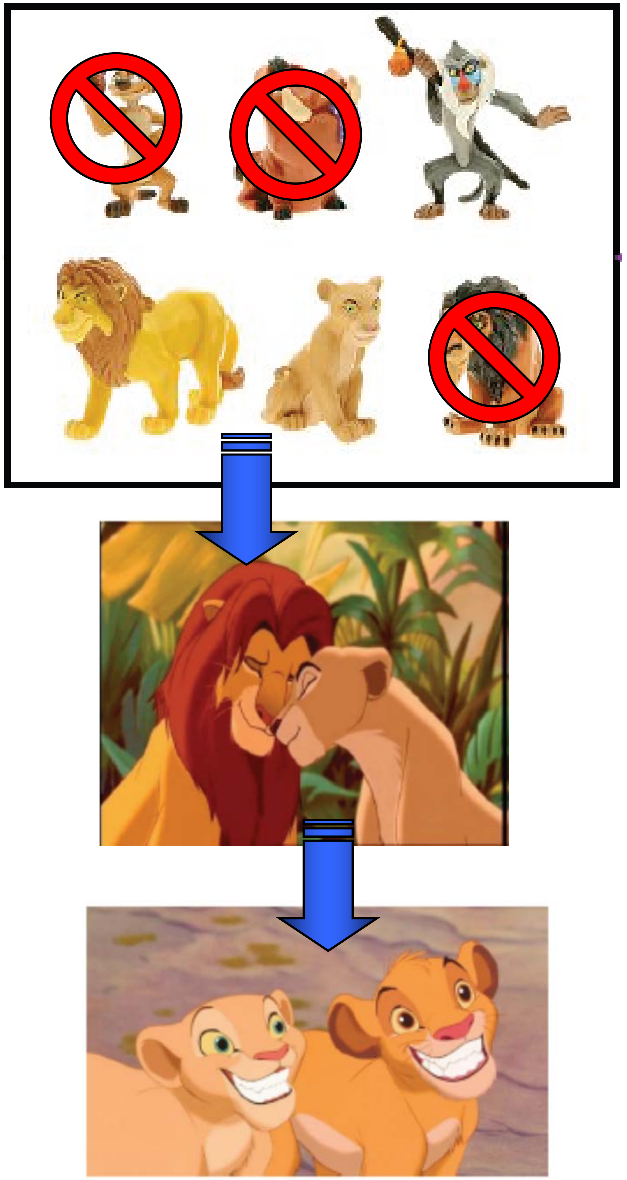
Principle (2)

- **Lessons from Biological Evolution**

Implications for applying to computing techs.

- Multiple
- Surviving
- Mixing
- Generation

POPULATION
↓
MATING POOL
↓
MATES SELECTED
↓
MATING
↓
OFFSPRING
↓
NEW POPULATION

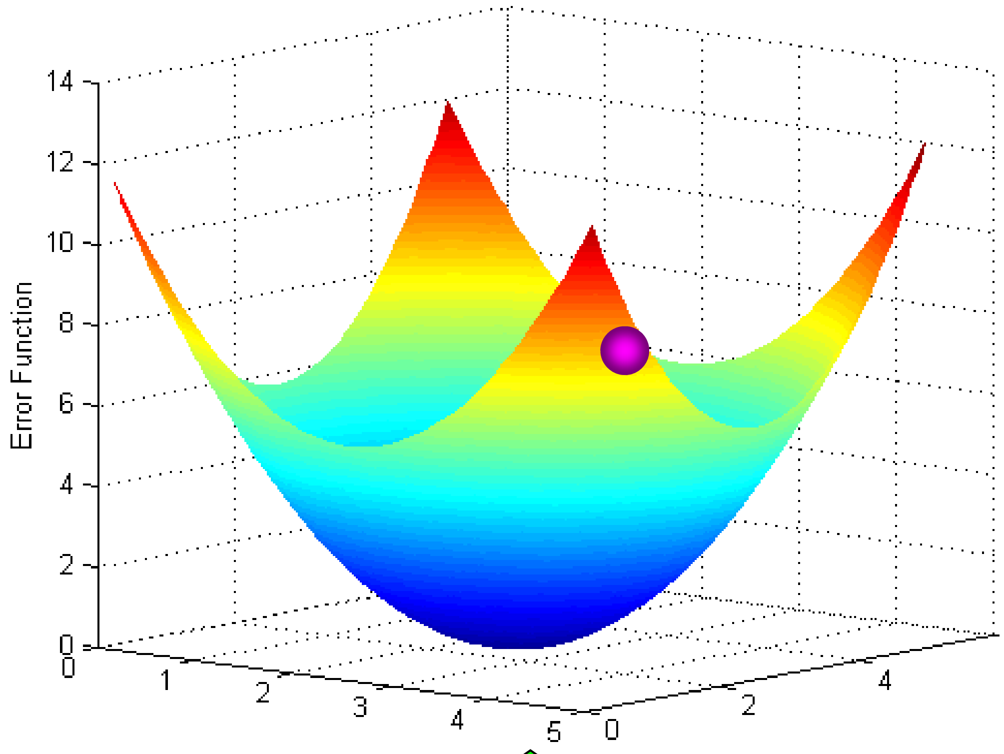


Conventional Approach

- **What's the Problem of Conventional (Search) Approaches?**

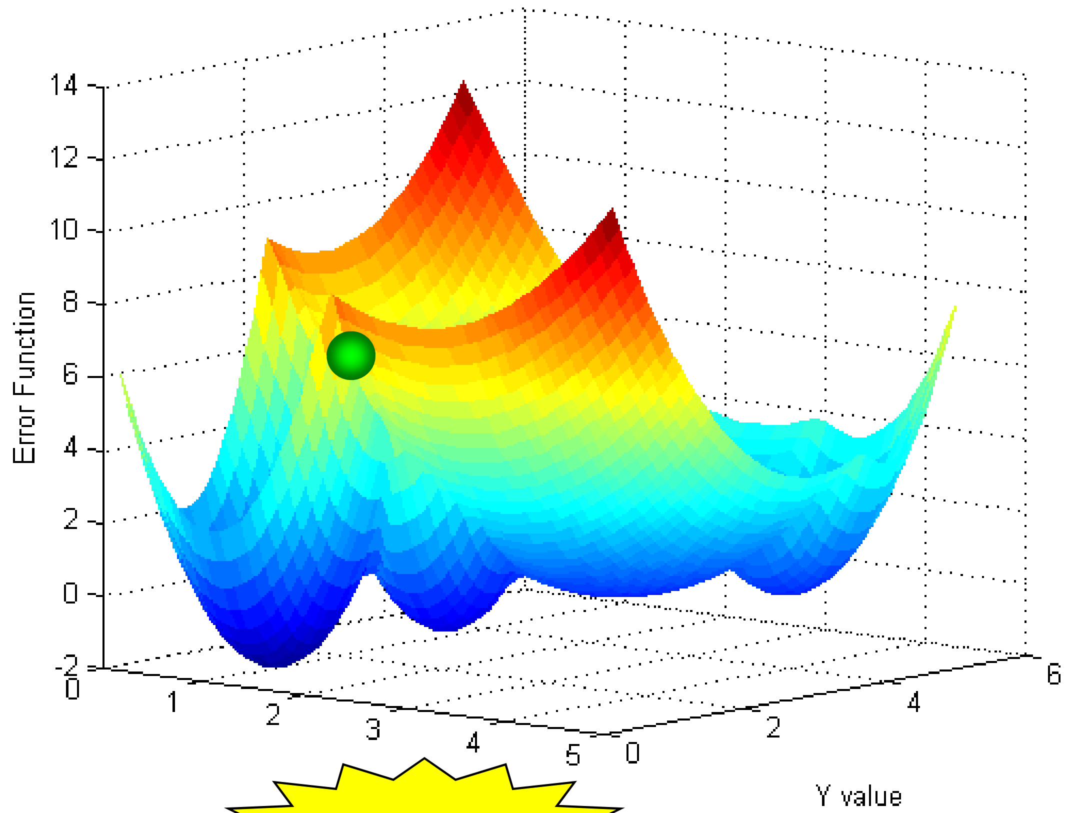
Gradient descent, Neural networks, etc.

Single nodal case



Optimum

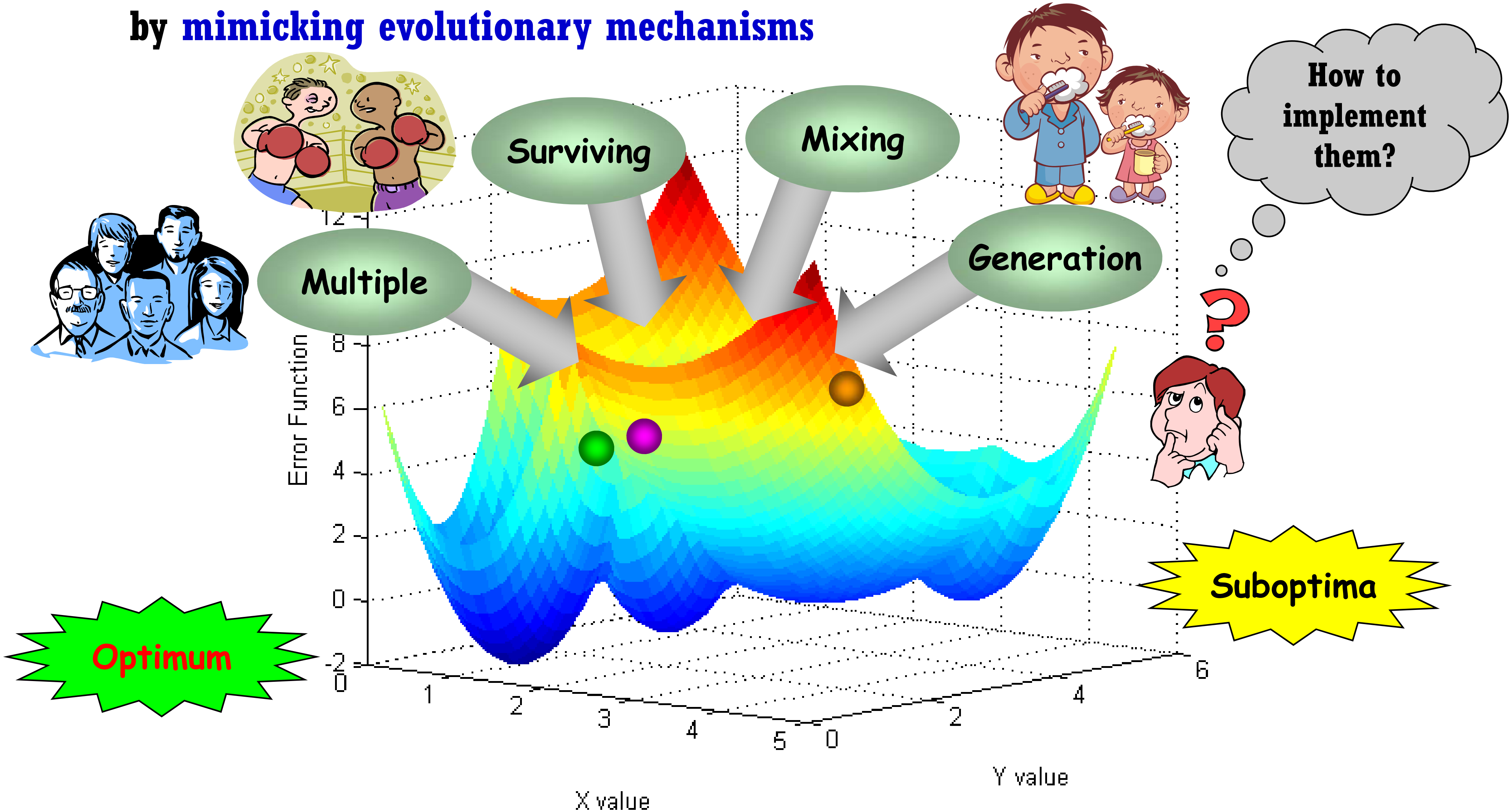
Multiple nodal case



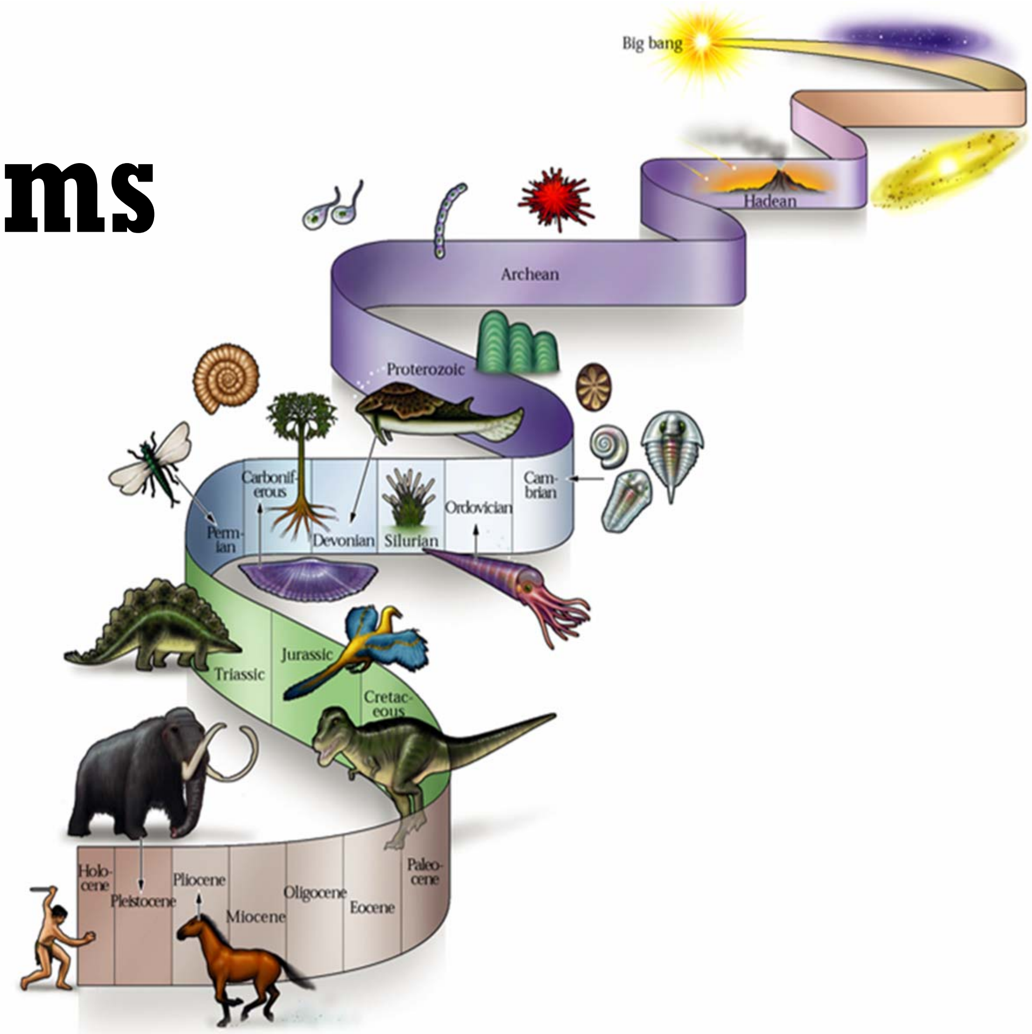
Suboptimum

Operational Concept

- **Main Principle of Evolutionary Algorithms**
  - Multiple individuals try to **cooperatively** resolve problems by **mimicking evolutionary mechanisms**



Genetic Algorithms



Genetic Algorithms (1)

- **What's the Target of Interest?**
  - **Optimization Problems**
    - ✓ Can be defined by specifying the set of all feasible candidates
    - ✓ The goal is to find the best solution(s)

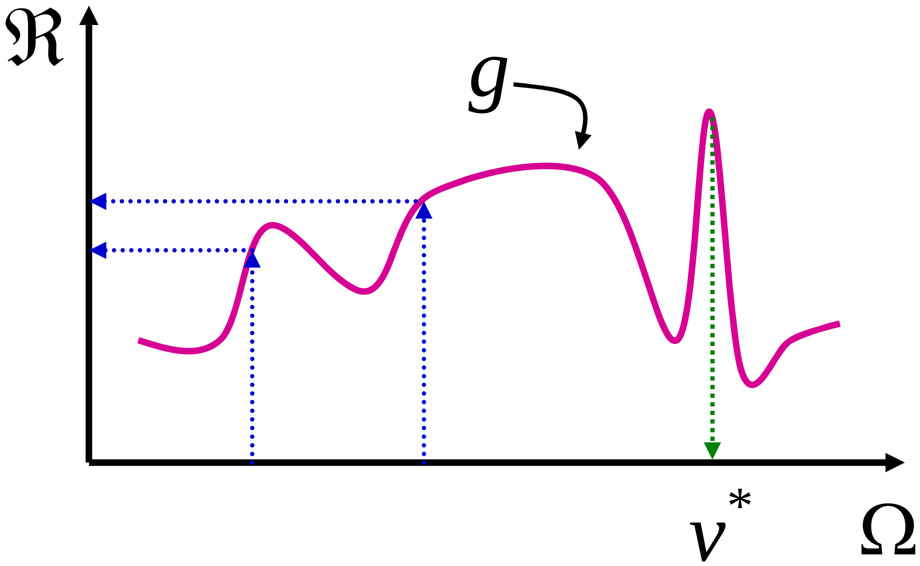
Formal Definition

For a search space Ω

There is a function $g : \Omega \mapsto \Re$

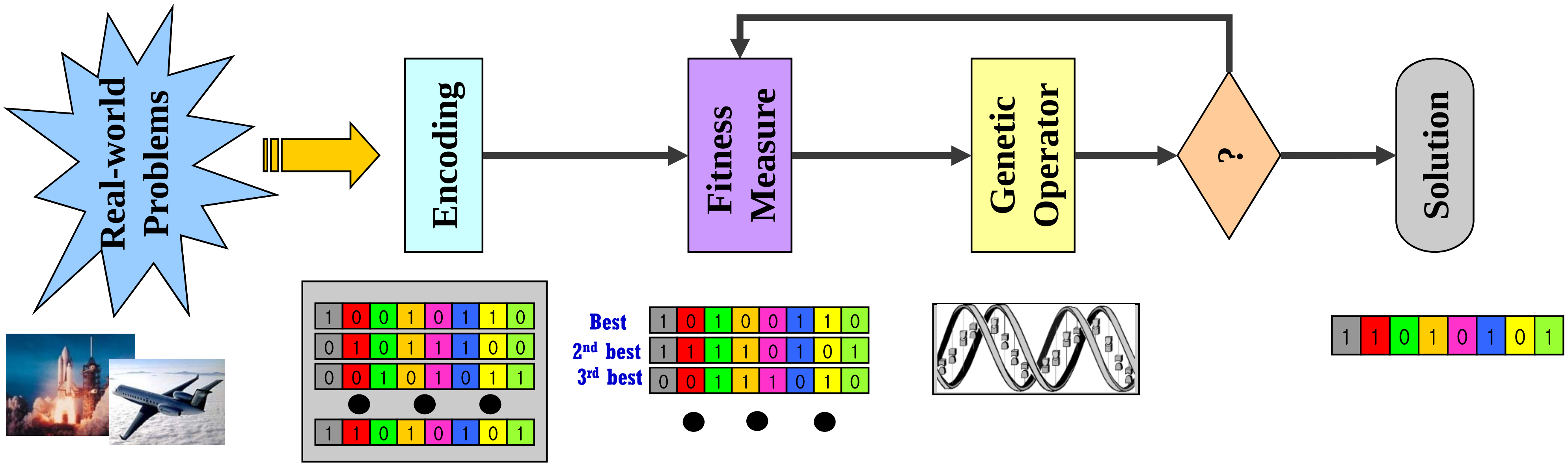
The task is to find $v^* = \arg\max_{v \in \Omega} g$

Here, v is a vector of decision variables,
and g is the objective function



Genetic Algorithms (2)

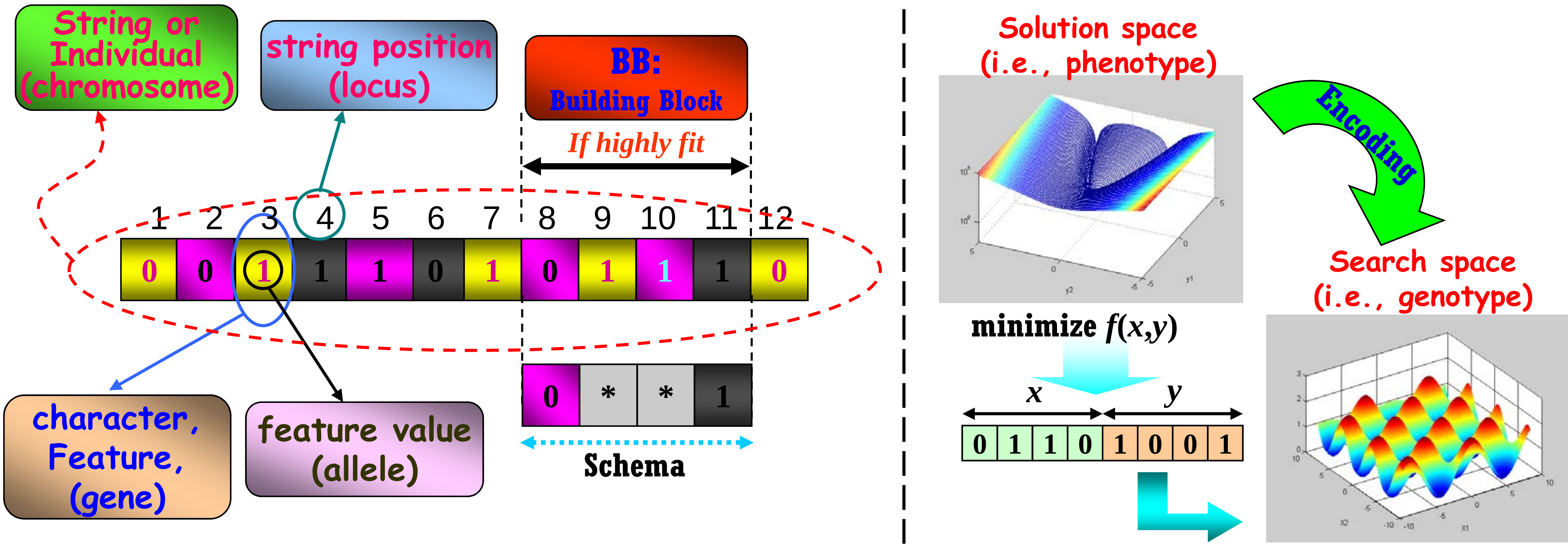
- **Key Components & Terminology**
  - **Encoding:** variables (phenotype) are encoded into a chromosome (genotype)
  - **Population:** a set of chromosomes (i.e., individuals or candidate solutions)
  - **Fitness function:** measure the goodness of each candidate solution: it can be mathematical terms, computer simulation, human evaluation
  - **Genetic operators:** boosting chromosomes up towards the optimum
    - ✓ **Selection:** realize the survival of the fittest
    - ✓ **Crossover:** realize the genetic inheritance
    - ✓ **Mutation:** realize the genetic mutation



Genetic Algorithms (3)

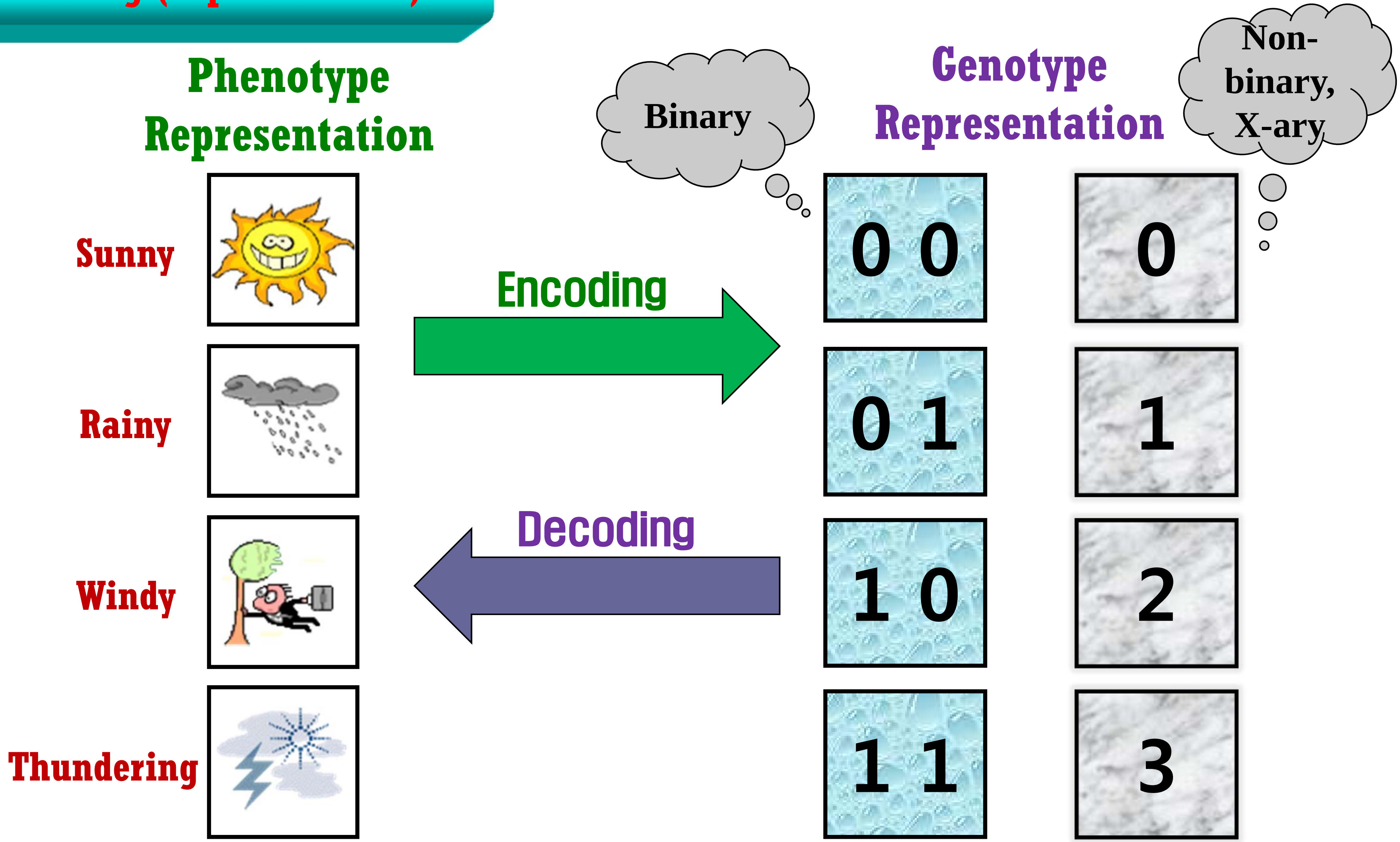
Encoding (Representation)

- It transforms the phenotypic problem into genotypic form
  - ✓ It determines the difficulty of problem
- Decision variables (in phenotype) are encoded into a chromosome (in genotype)
  - ✓ **Binary:** {0, 1} , **X-ary:** {0, 1, … , X-1} , **Real-coded:** {floating point numbers itself}



Genetic Algorithms (4)

Encoding (Representation)

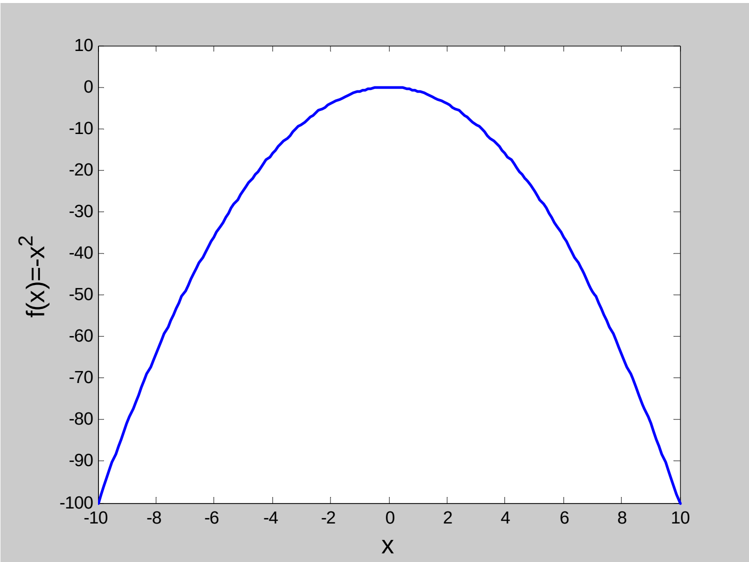


Genetic Algorithms (5)

Fitness Function

- Interpret the individual in terms of physical representation
- Evaluate its *fitness* based on desired traits
- Fully reflect the physical objective of the problem
- Thus, the definition of fitness function is very crucial!

It is the same as the objective function.



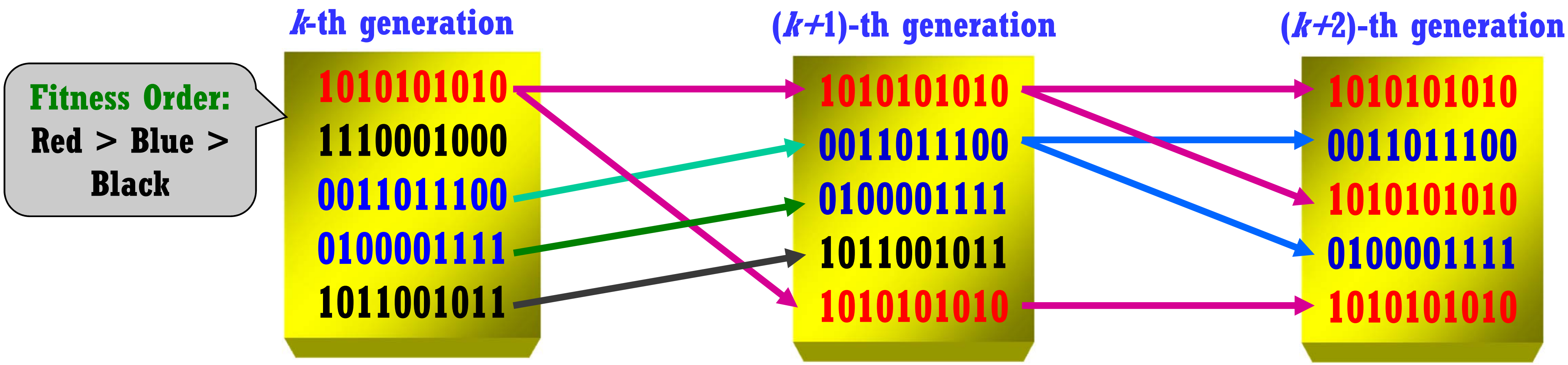
$$\arg\max f(x) = -x^2$$

Population (encoded)	x (decoded)	Fitness function	Fitness value
101 … 110	-2.6	$\max f(x) = -x^2$	-6.76
111 … 100	-8.5		-72.25
001 … 100	3.1		-9.61
010 … 111	5.5		-30.25
101 … 011	-7.0		-49.0

Genetic Algorithms (6)

Selection (Reproduction)

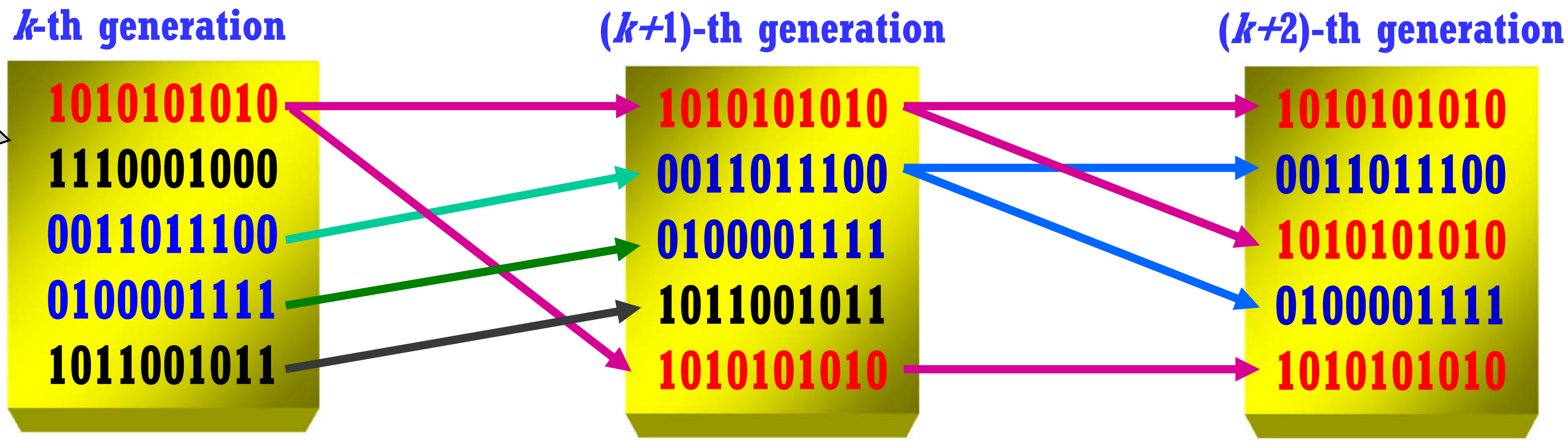
1. Mimicking the survival of the fittest
2. Improving the average quality of population
   (by copying better individuals into the next generation)
3. There are two kinds of selection schemes
   - ❖ Proportional selection – e.g., Roulette wheel selection (RWS)
   - ❖ Ordinal selection – e.g., Tournament selection

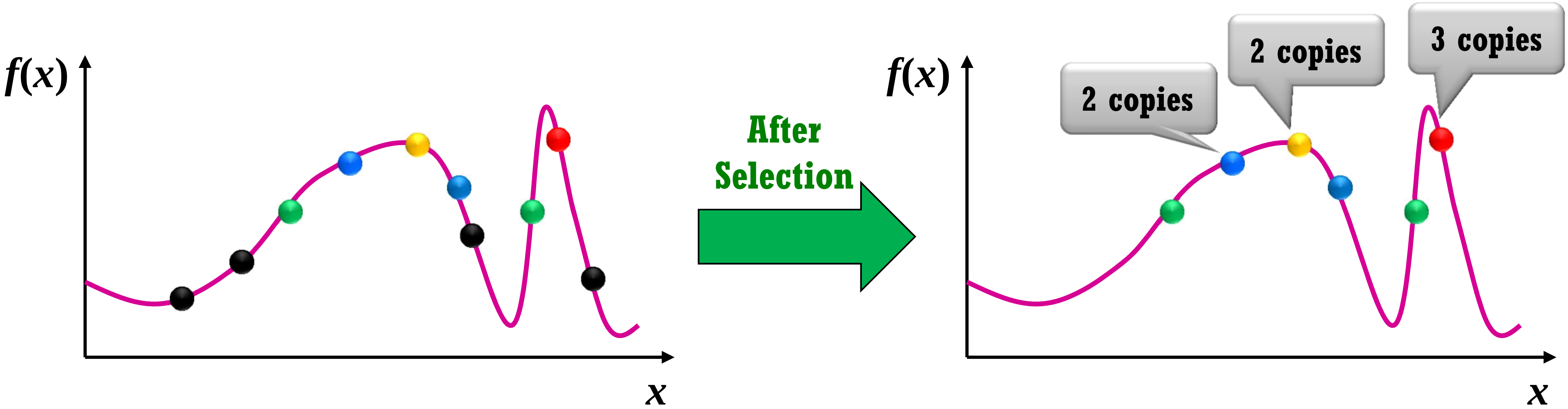


Genetic Algorithms (7)

Selection (Reproduction)

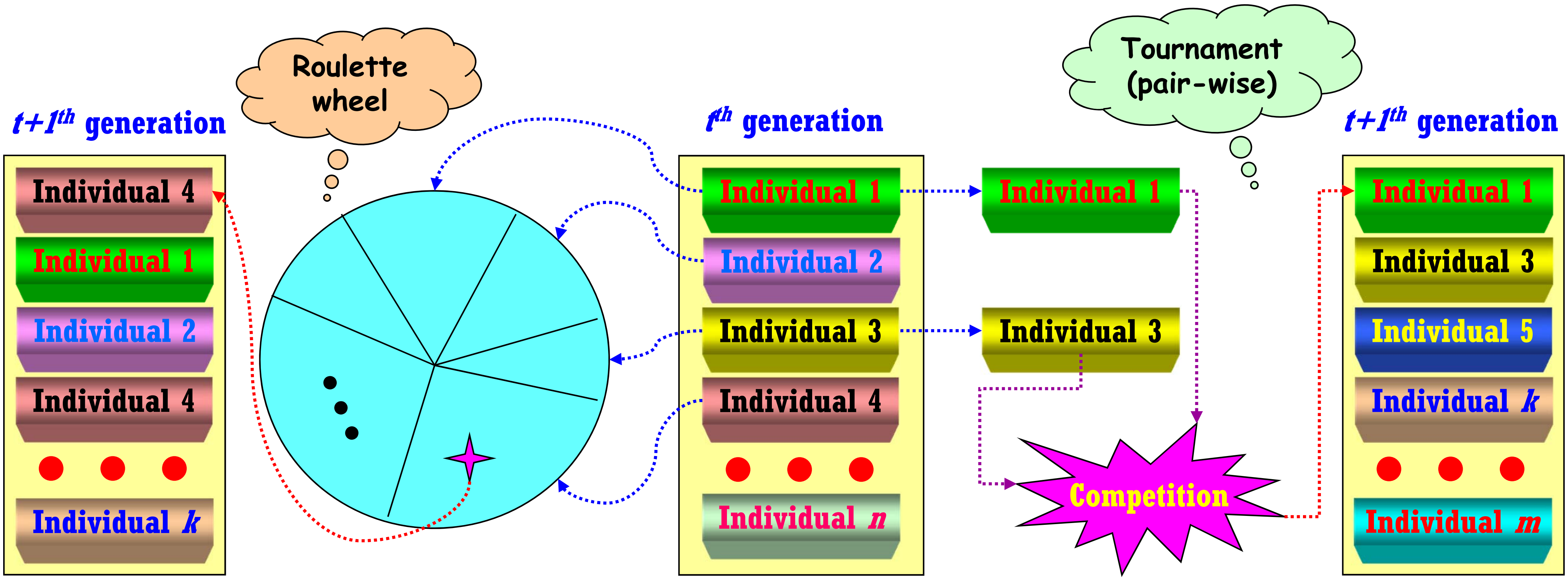
Fitness Order:
Red > Blue > Black





Genetic Algorithms (8)

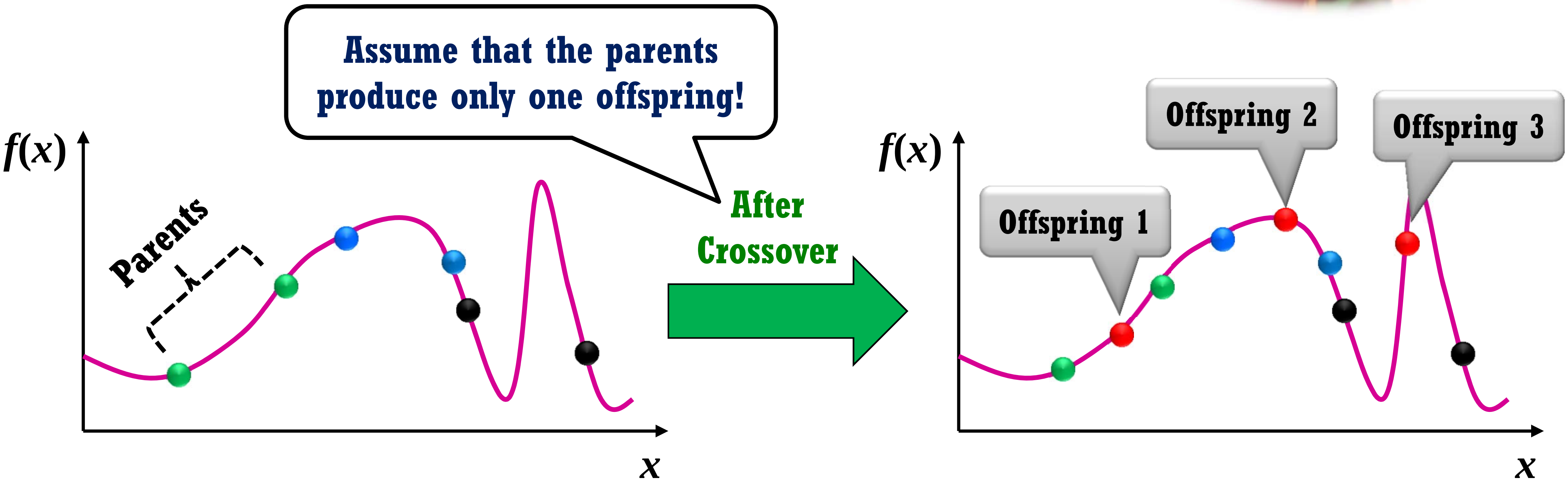
- **Roulette Wheel Selection**
  - The probability of selecting a given chromosome is proportional to its fitness
- **Tournament Selection**
  - Combine the fitness proportional concept with the random selection



Genetic Algorithms (9)

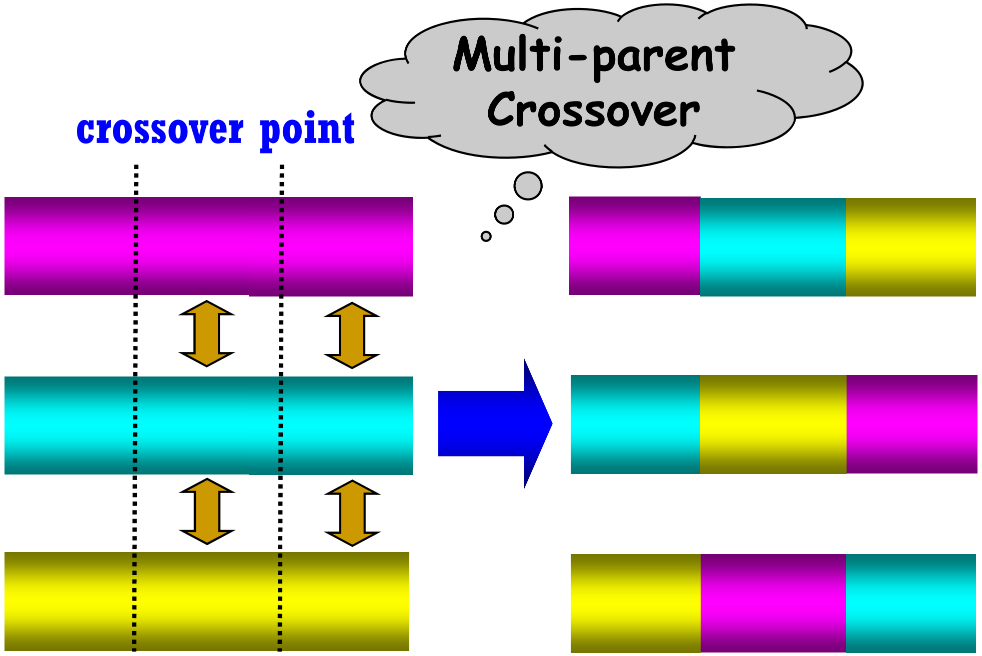
Crossover (Recombination)

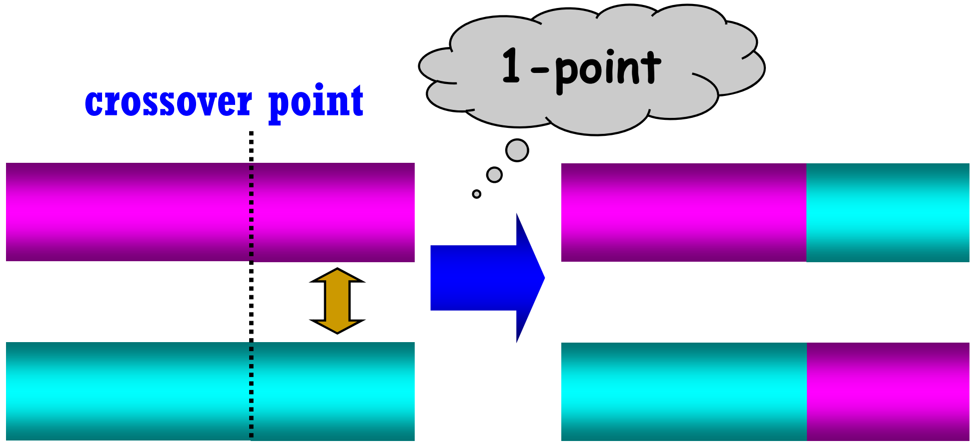
1. Imitating the genetic inheritance (by recombining segments belonging to the individuals corresponding to parents)
2. Ensuring the exploration of search space
3. One-point crossover, *n*-point crossover, Uniform crossover, etc.

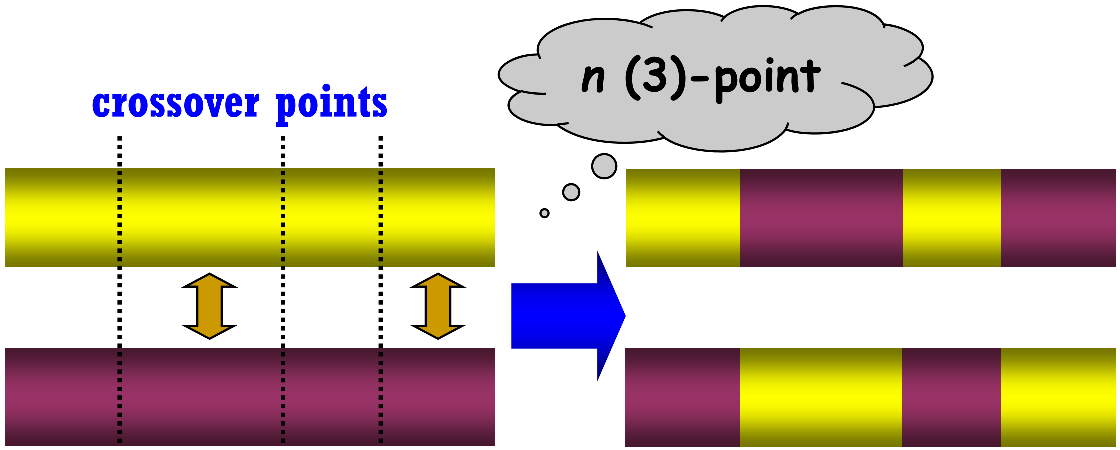


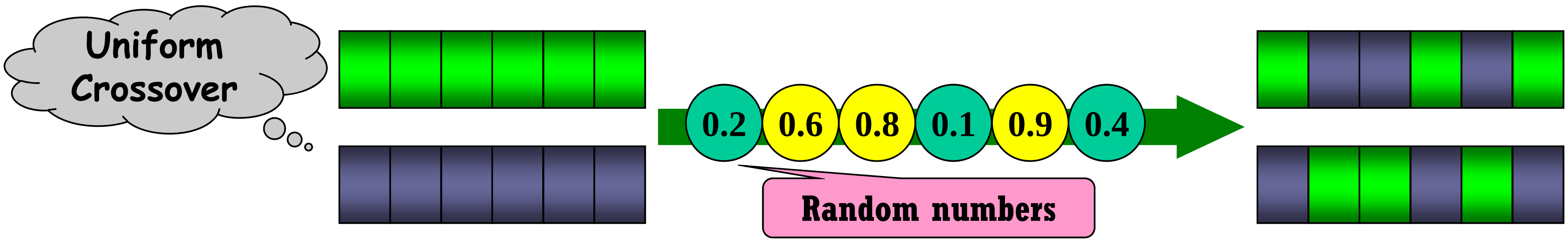
Genetic Algorithms (10)

Crossover (Recombination)









Genetic Algorithms (11)

Mutation

1. Realize the self-variation (mutation) of genetics
   (by changing the value of the considered gene into a different value)
2. The second way of exploring search space
   - Its portion must be very small.
   - But, very crucial for possibly escaping from local optima

X-ary Case

mutation point

72X540X16

72X580X16

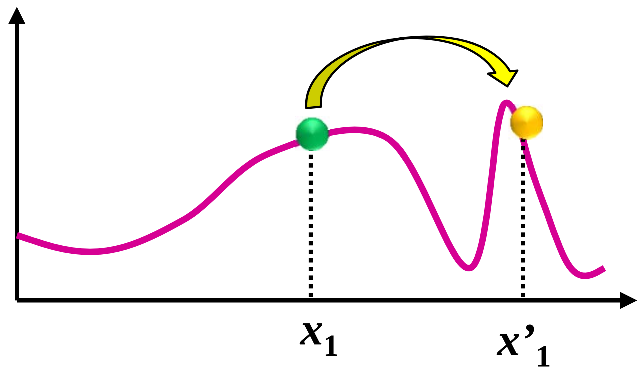
A number is randomly selected among {0, 1, 2, 3, 5, … , X-1, X}

Binary Case

mutation point

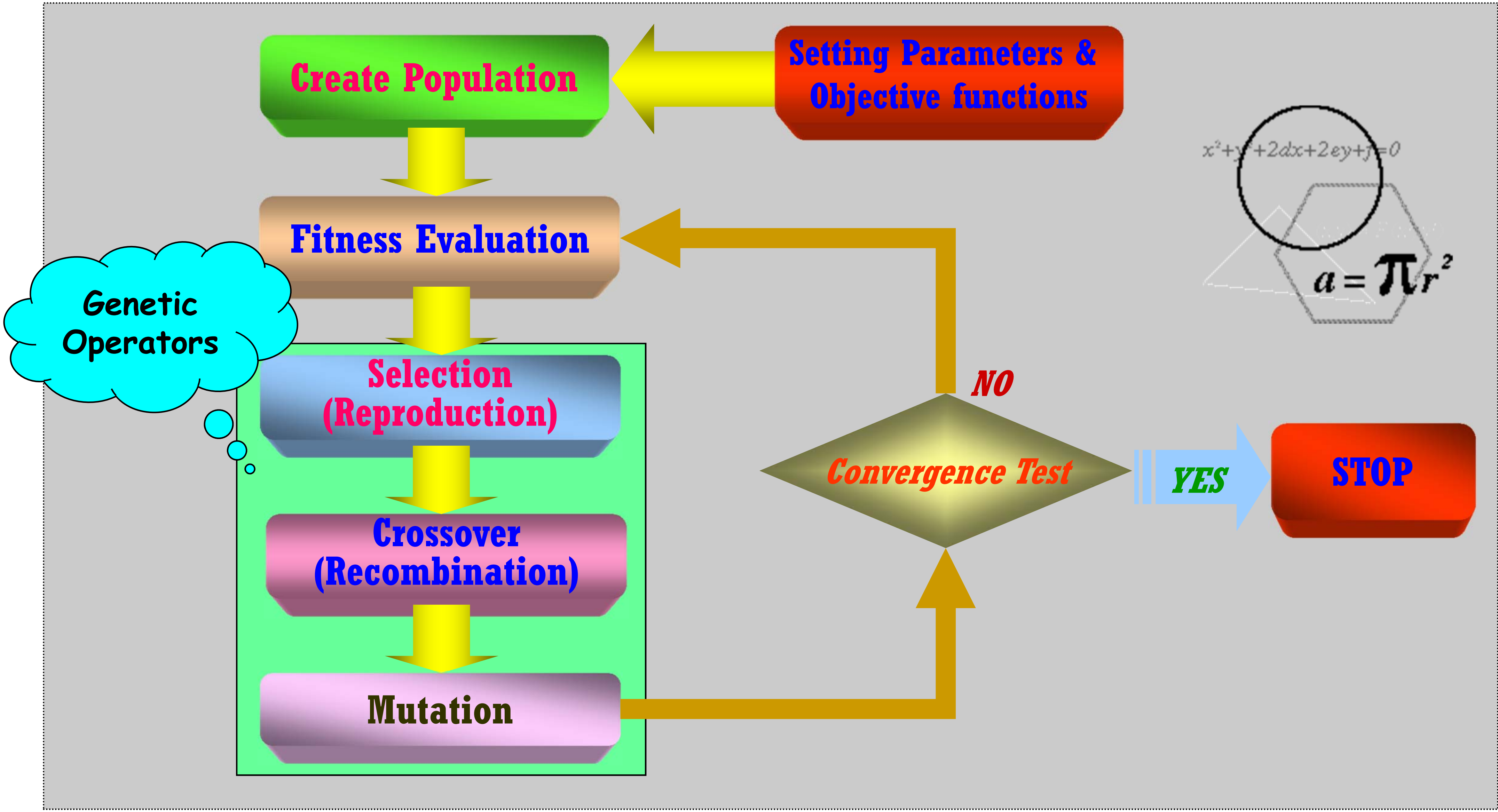
1001001010 → x_1 = 586

1101001010 → x'_1 = 842



Genetic Algorithms (12)

- **Overall Procedures of GAs**



Genetic Algorithms (13)

Population Behavior