Evolutionary Algorithms:
Principle & Operational Procedures

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Contents

Principle of Evolutionary Algorithms

Principle (1)

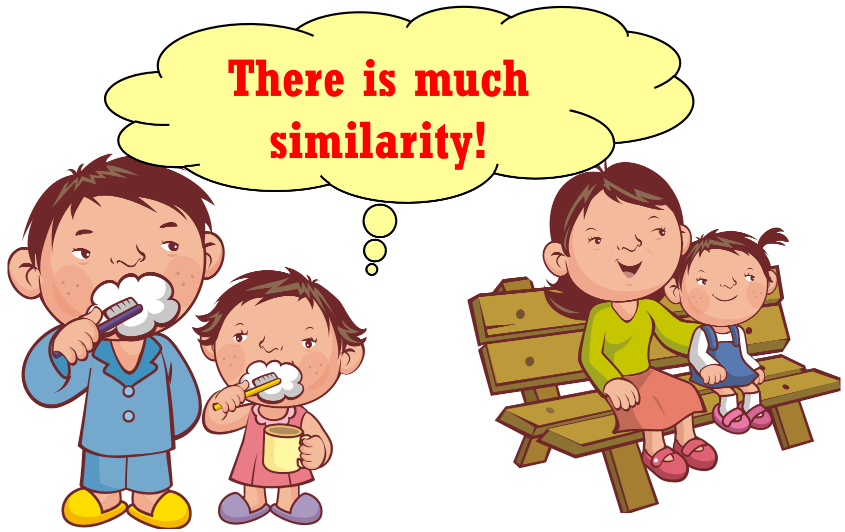
● What are Evolutionary Algorithms (EAs) ?

- **Any Problem-solving Method** 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



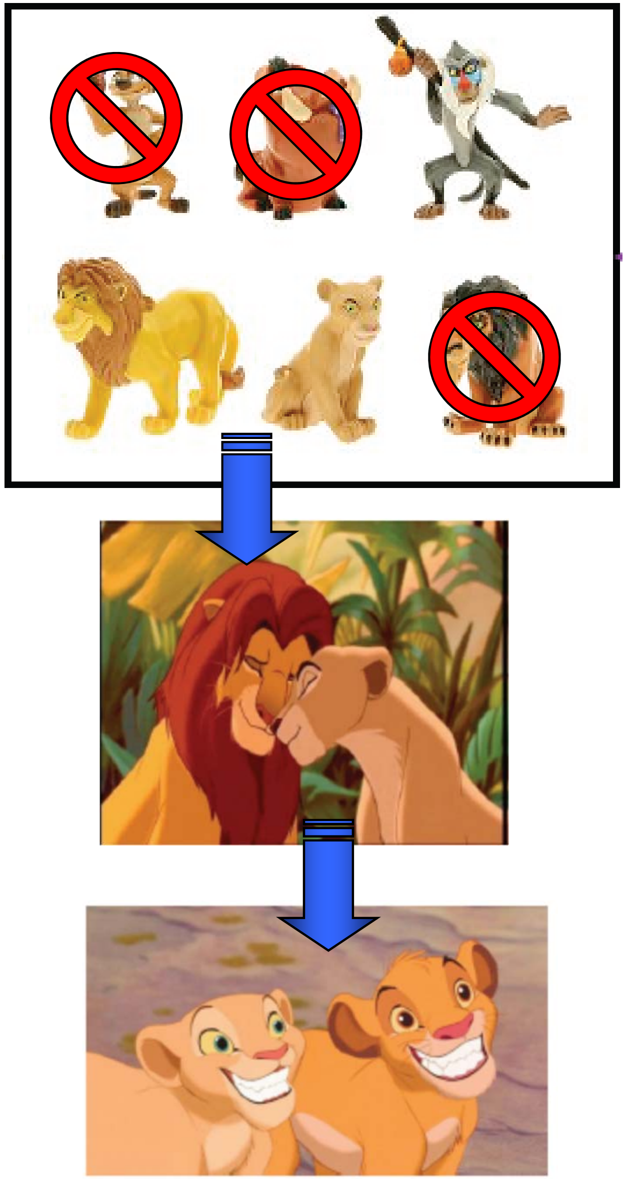
Principle (2)

● Lessons from Biological Evolution

Implications for applying to computing techs.

- Multiple
- Surviving
- Mixing
- Generation

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



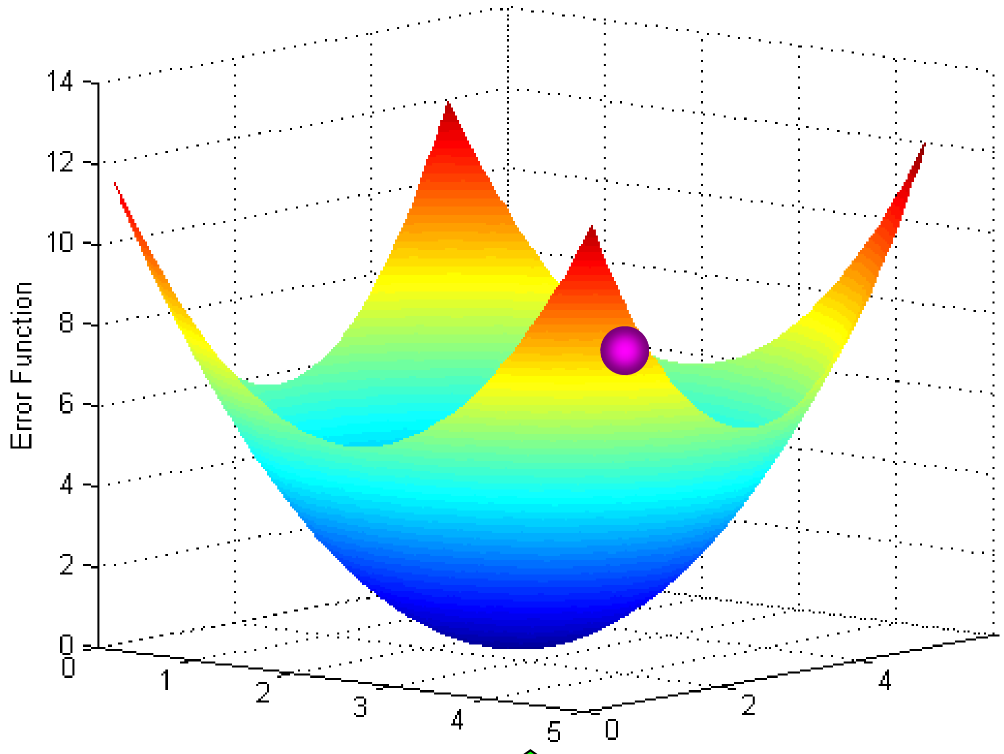
Conventional Approach

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

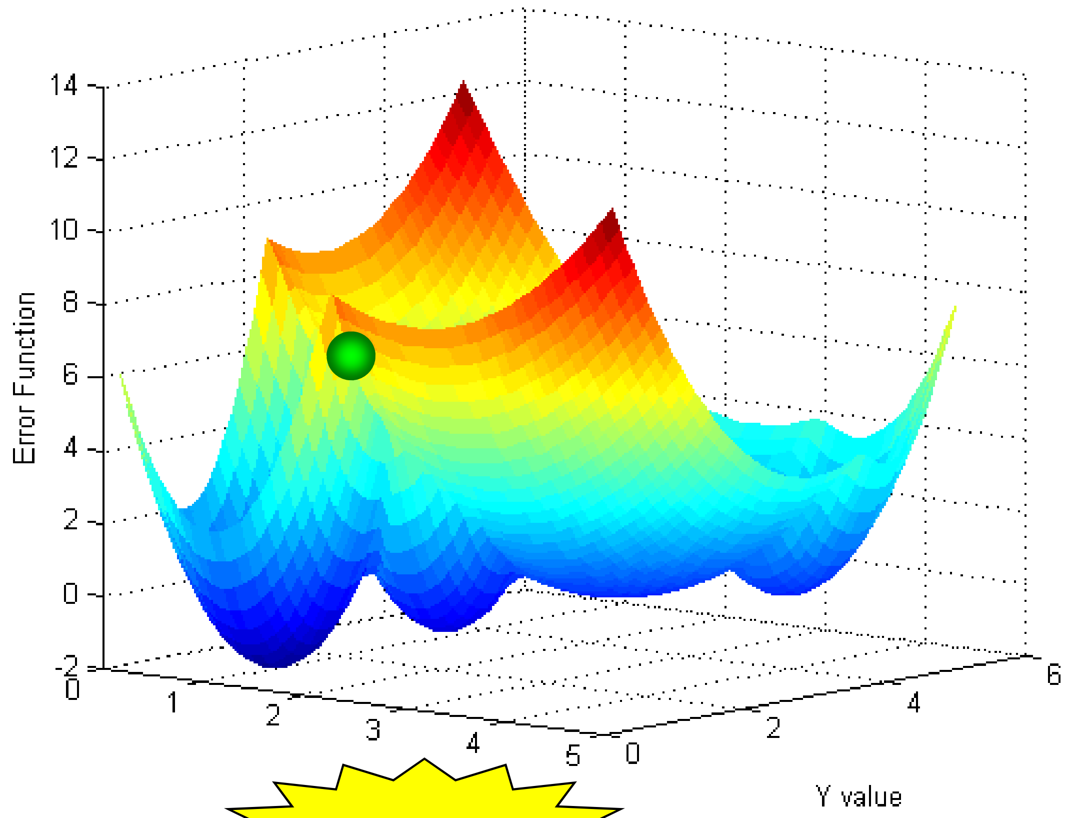
Gradient descent, Neural networks, etc.

Single nodal case

Multiple nodal case



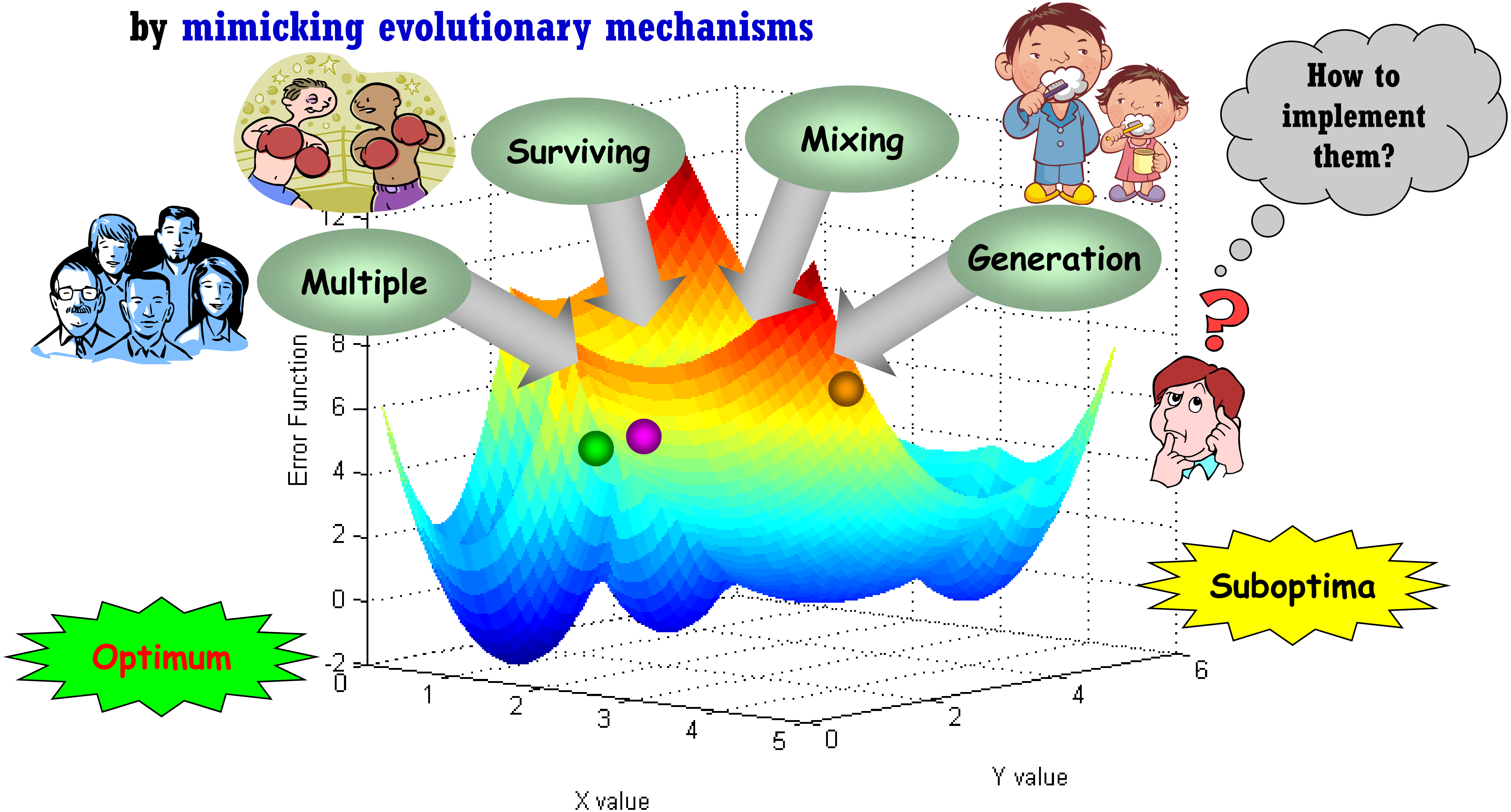
Optimum



Suboptimum

Operational Concept

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



Genetic Algorithms

Genetic Algorithms (1)

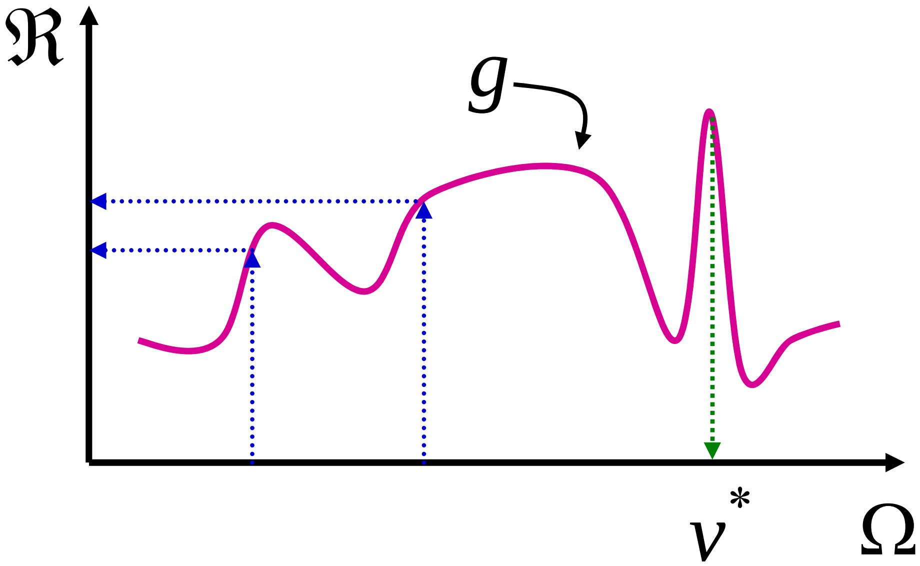
- **What's the Target of Interest?**
  - **Optimization Problems**
    - ✓ Can be defined by specifying the set of all feasible candidates
    - ✓ The goal is to find the best solution(s)

Formal Definition

For a search space Ω

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

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

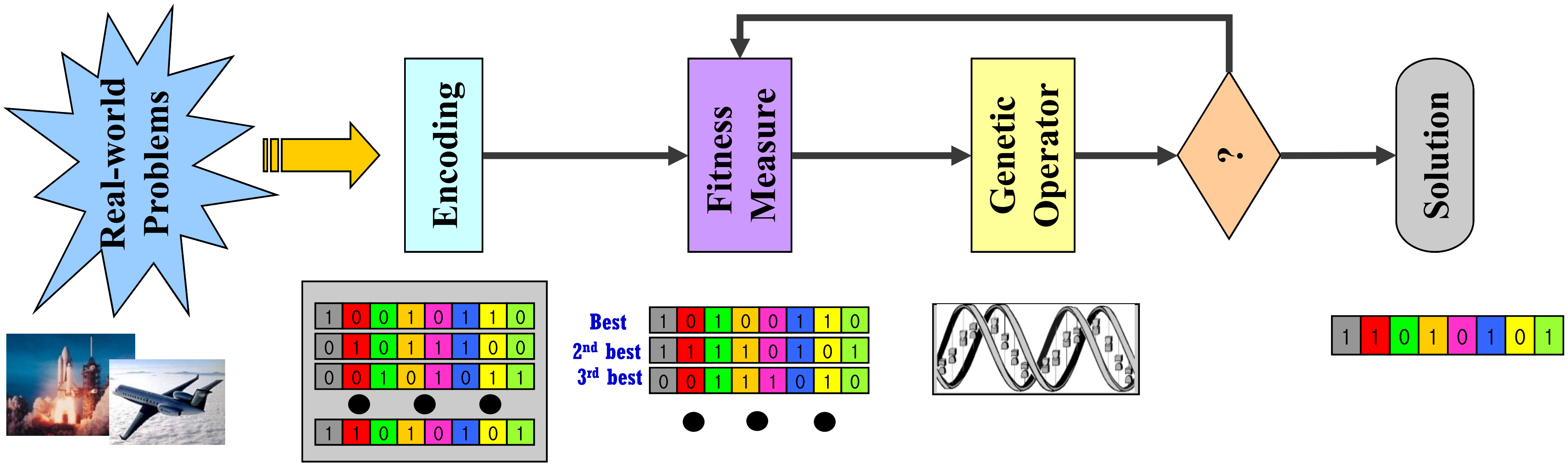


Here, v is a vector of decision variables,
and g is the objective function

Genetic Algorithms (2)

● Key Components & Terminology

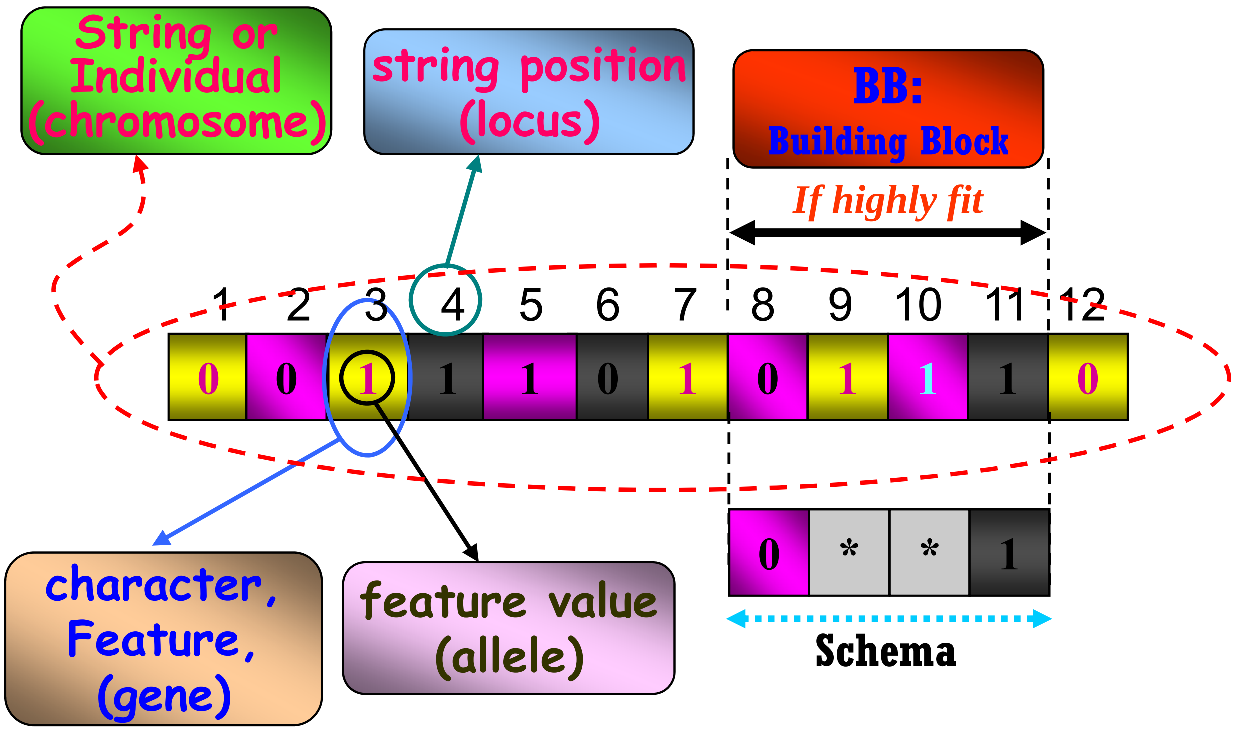
- **Encoding:** variables (phenotype) are encoded into a chromosome (genotype)
- **Population:** a set of chromosomes (i.e., individuals or candidate solutions)
- **Fitness function:** measure the goodness of each candidate solution: it can be mathematical terms, computer simulation, human evaluation
- **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

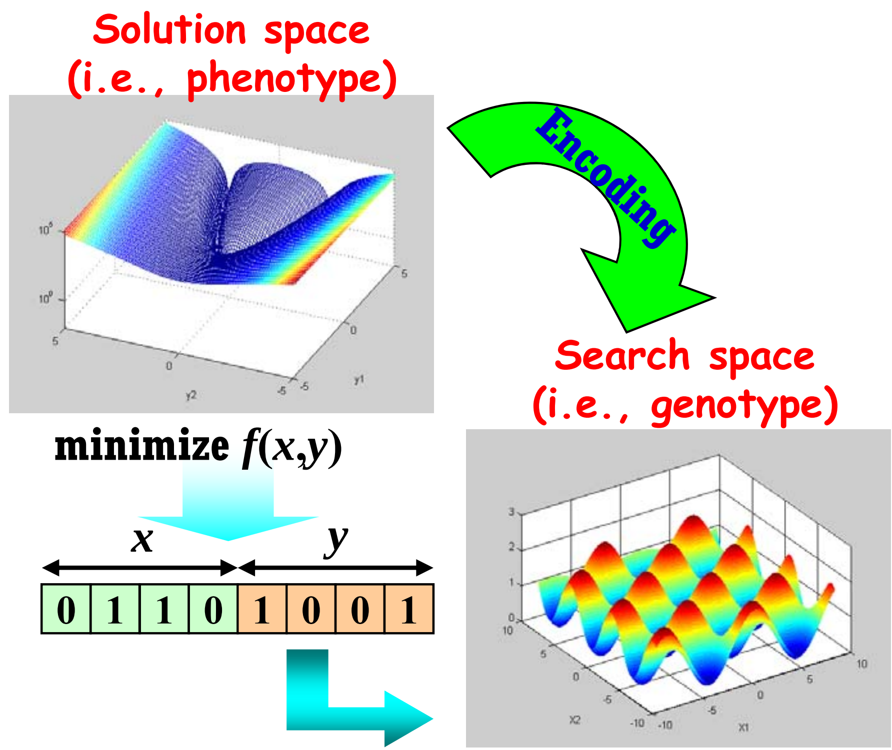


Genetic Algorithms (3)

Encoding (Representation)

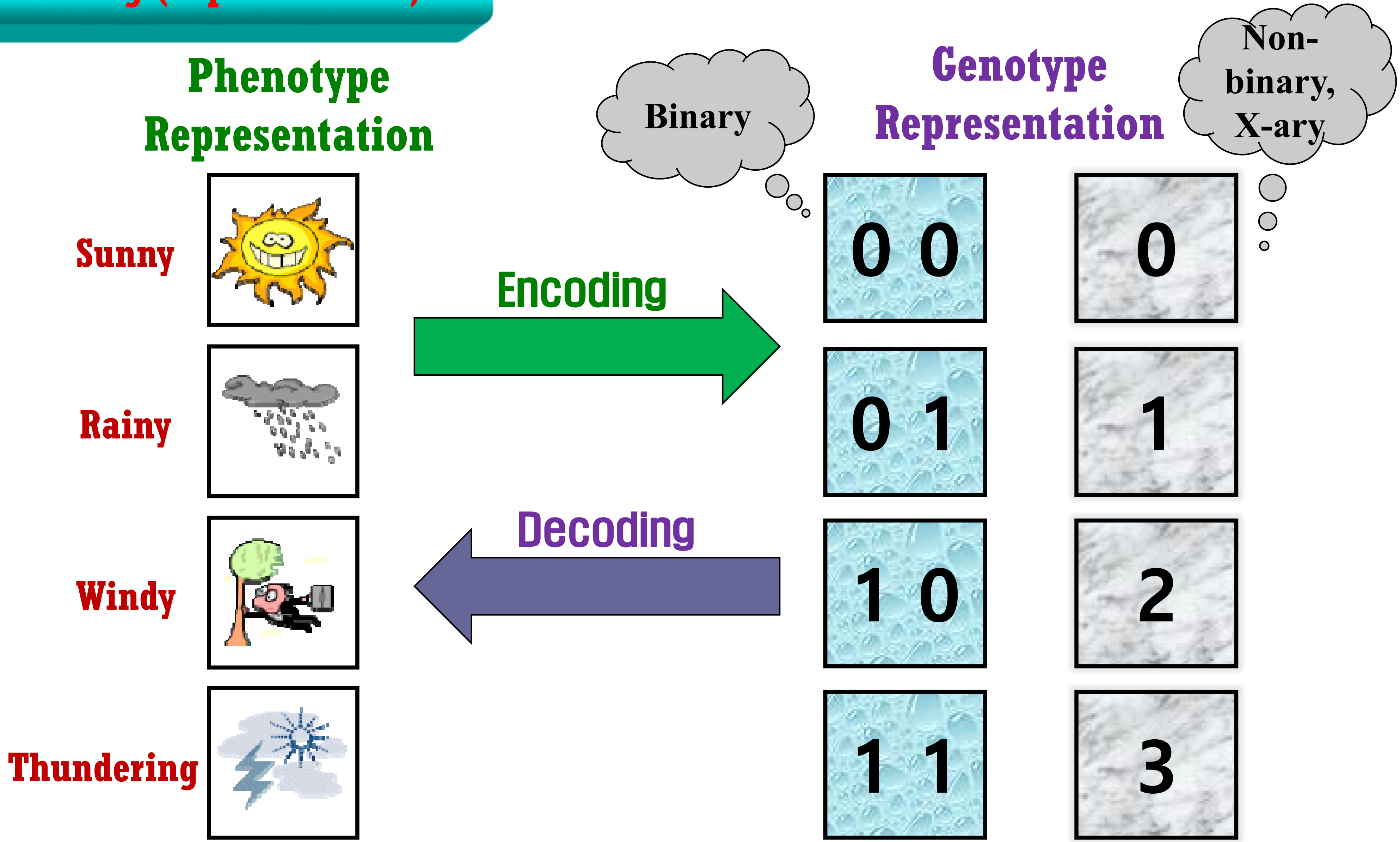
- It transforms the phenotypic problem into genotypic form
  - ✓ It determines the difficulty of problem
- Decision variables (in phenotype) are encoded into a chromosome (in genotype)
  - ✓ **Binary:** {0, 1} , **X-ary:** {0, 1, … , X-1} ,
    Real-coded: {floating point numbers itself}





Genetic Algorithms (4)

Encoding (Representation)

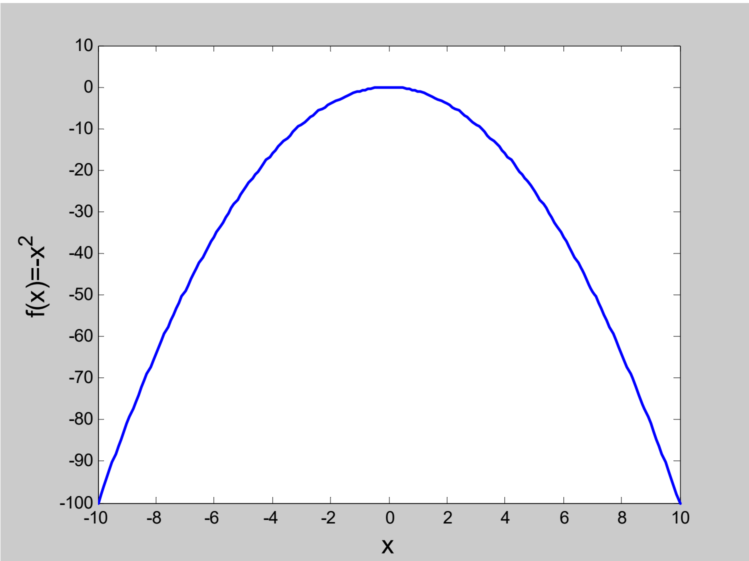


Genetic Algorithms (5)

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.



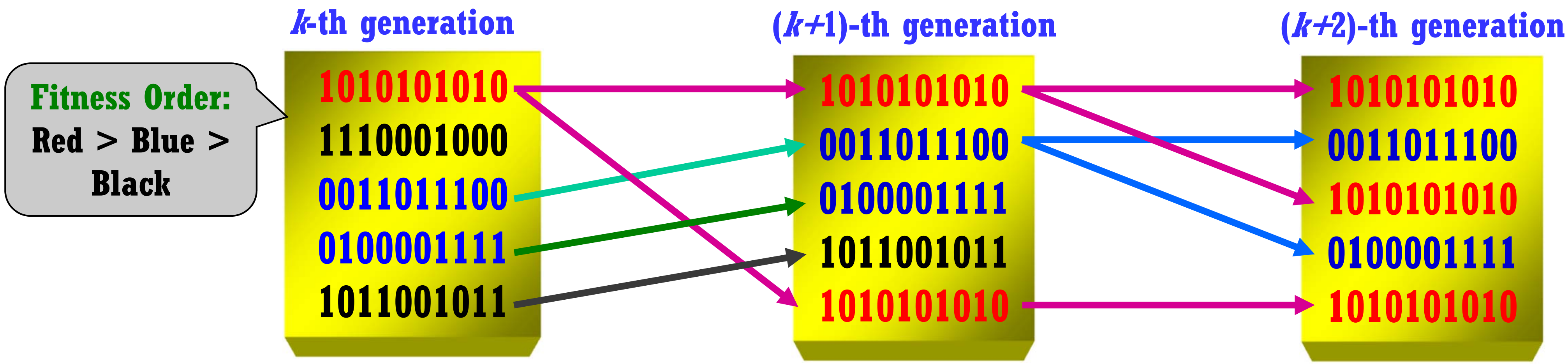
$$\operatorname{argmax} f(x) = -x^2$$

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)

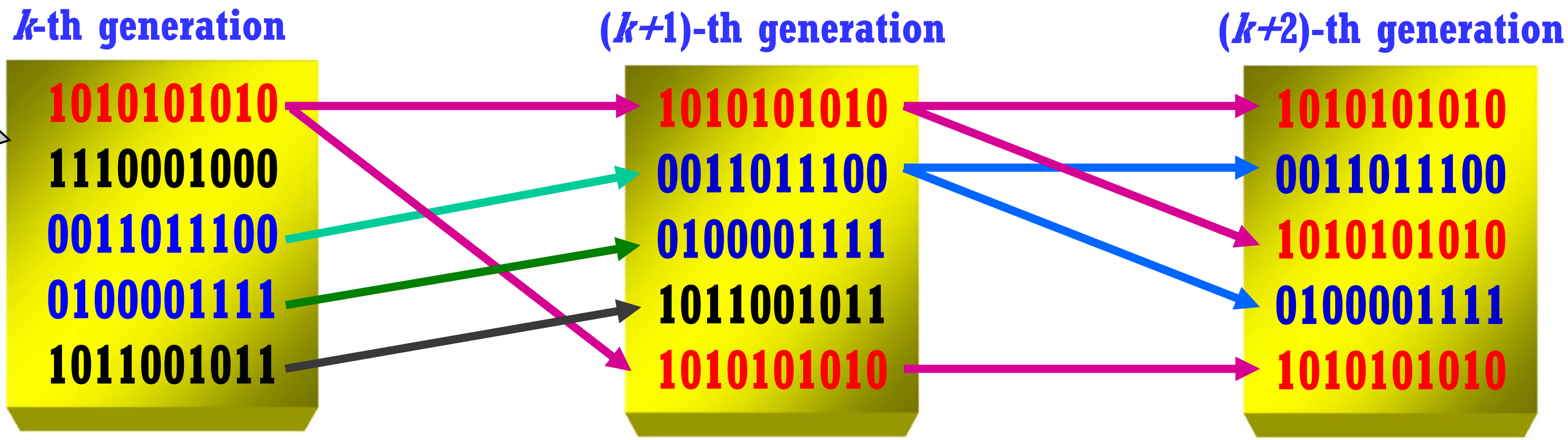
1. Mimicking the survival of the fittest
2. Improving the average quality of population
   (by copying better individuals into the next generation)
3. There are two kinds of selection schemes
   - ❖ Proportional selection – e.g., Roulette wheel selection (RWS)
   - ❖ Ordinal selection – e.g., Tournament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

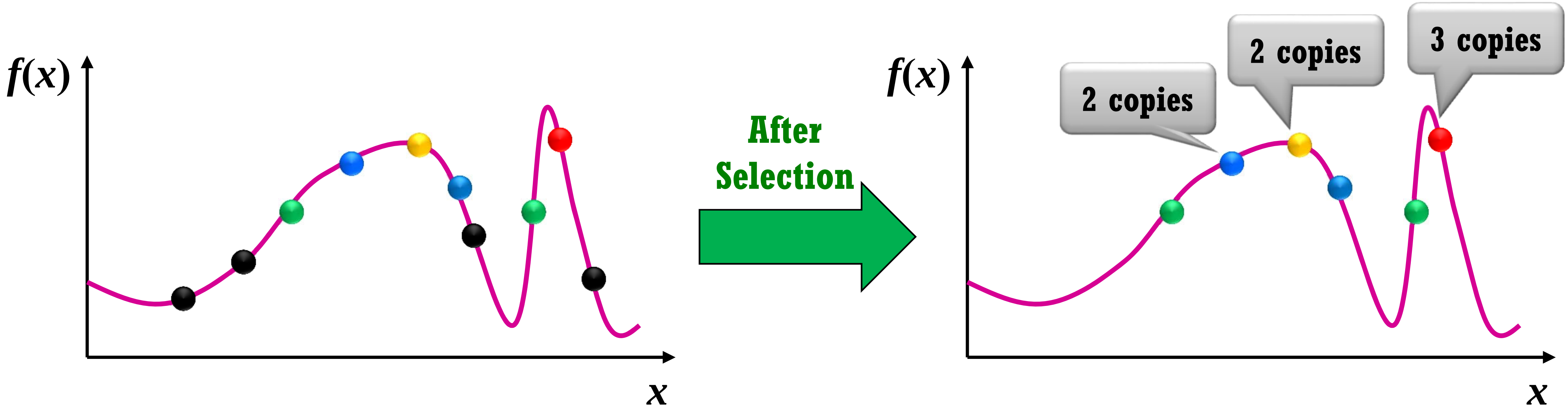


Genetic Algorithms (7)

Selection (Reproduction)

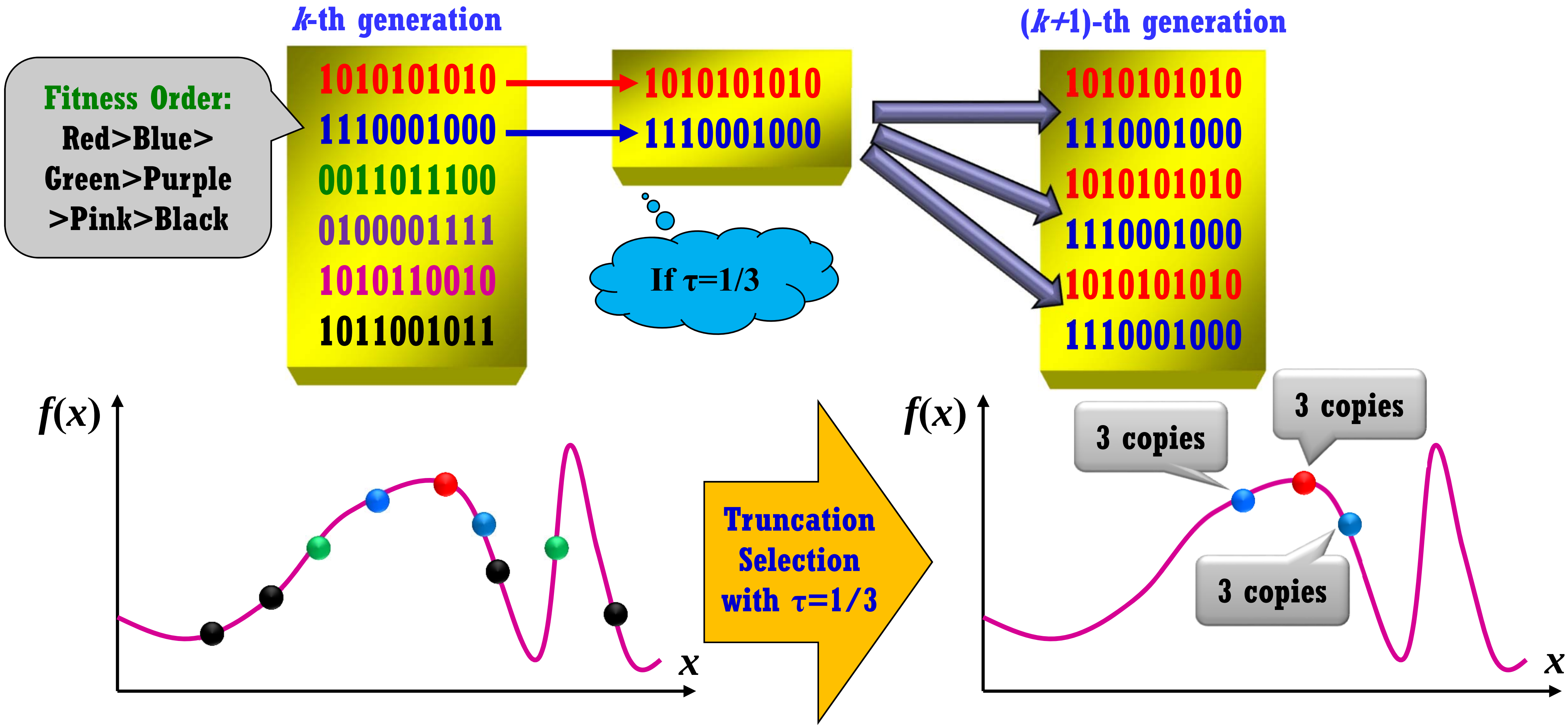
Fitness Order:
Red > Blue > Black





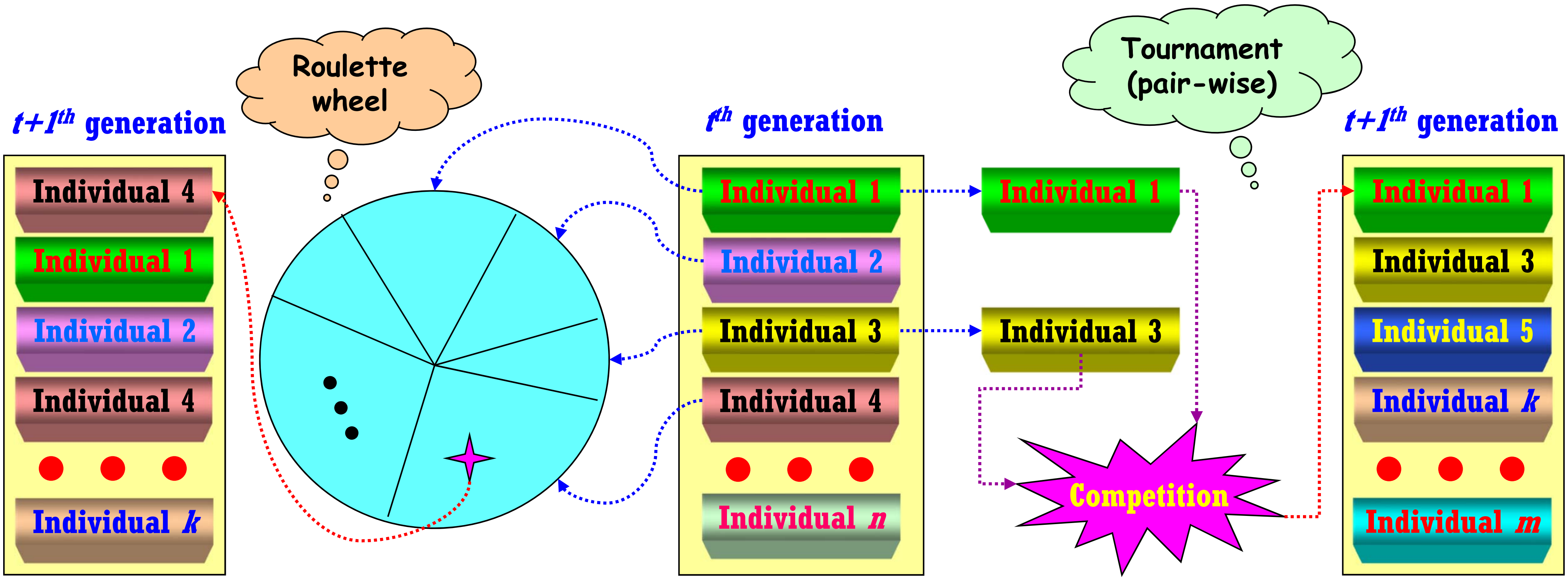
Genetic Algorithms (8)

- **Truncation Selection**
  - ❖ It is the simplest but least useful selection method.
    - ✓ It simply retains the fittest τ% (top τ-portion) of the population
    - ✓ These individuals are duplicated up to the population size



Genetic Algorithms (9)

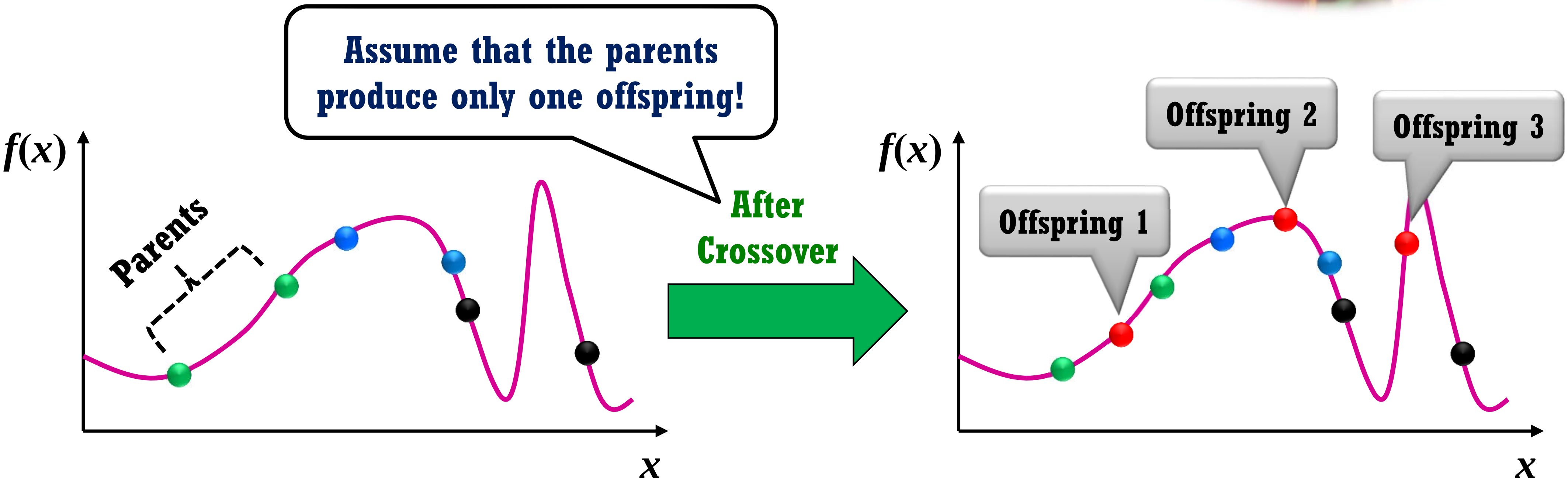
- **Roulette Wheel Selection**
  - The probability of selecting a given chromosome is proportional to its fitness
- **Tournament Selection**
  - Combine the fitness proportional concept with the random selection



Genetic Algorithms (10)

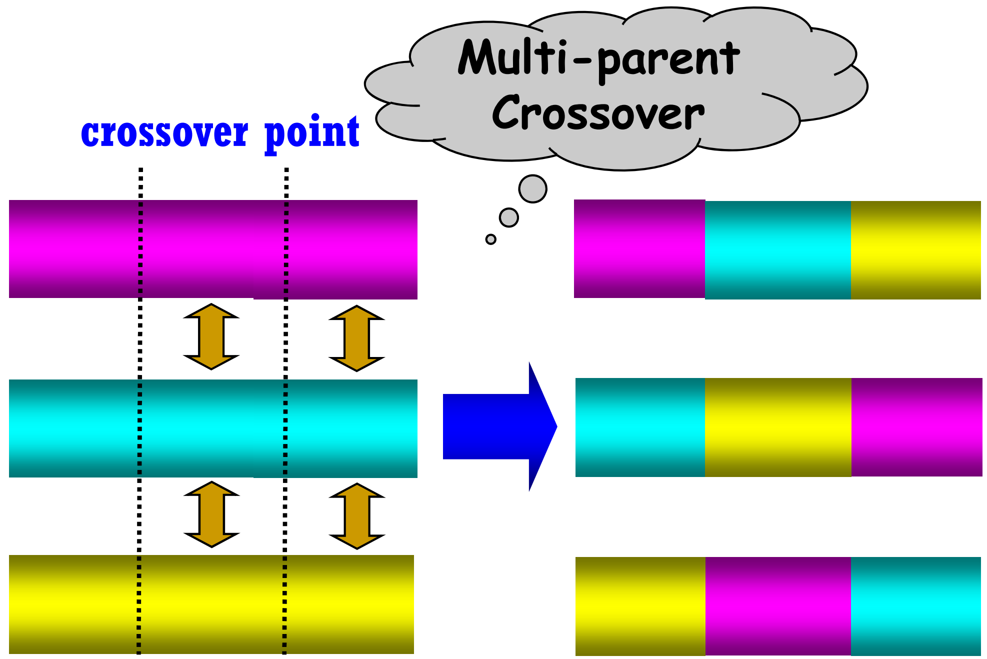
Crossover (Recombination)

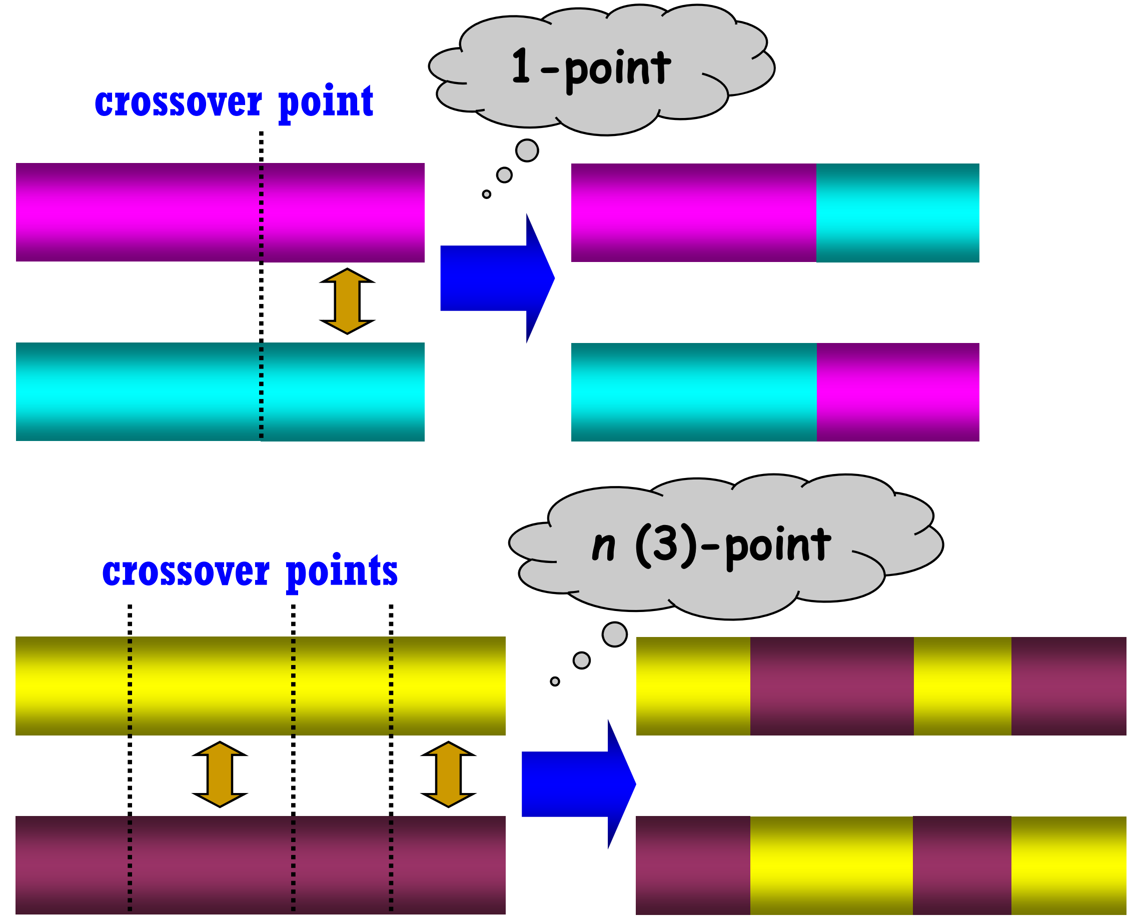
1. Imitating the genetic inheritance (by recombining segments belonging to the individuals corresponding to parents)
2. Ensuring the exploration of search space
3. One-point crossover, *n*-point crossover, Uniform crossover, etc.

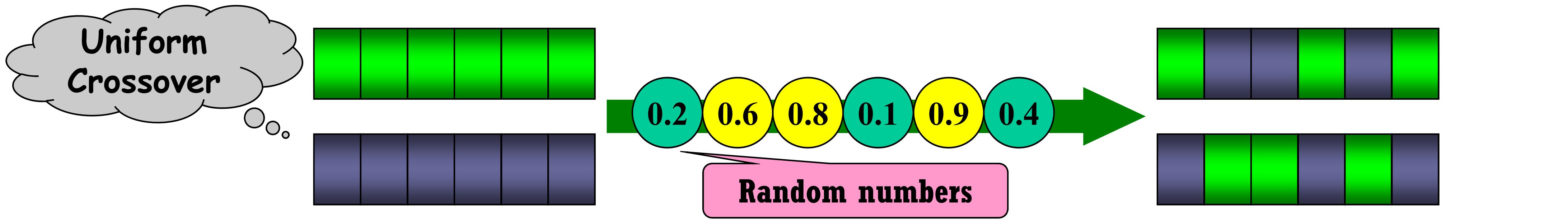


Genetic Algorithms (11)

Crossover (Recombination)







Genetic Algorithms (12)

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

72X5**4**0X16

72X5**8**0X16

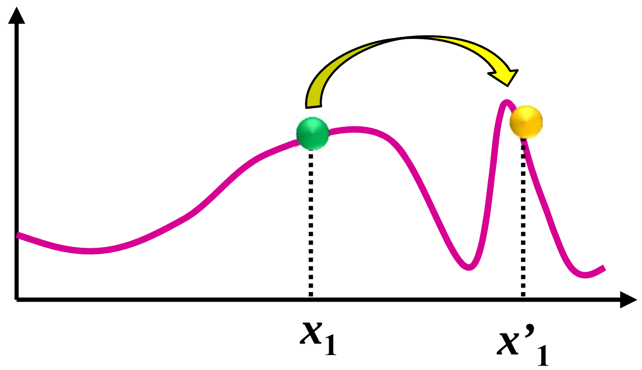
A number is randomly selected among {0, 1, 2, 3, 5, … , X-1, X}

Binary Case

mutation point

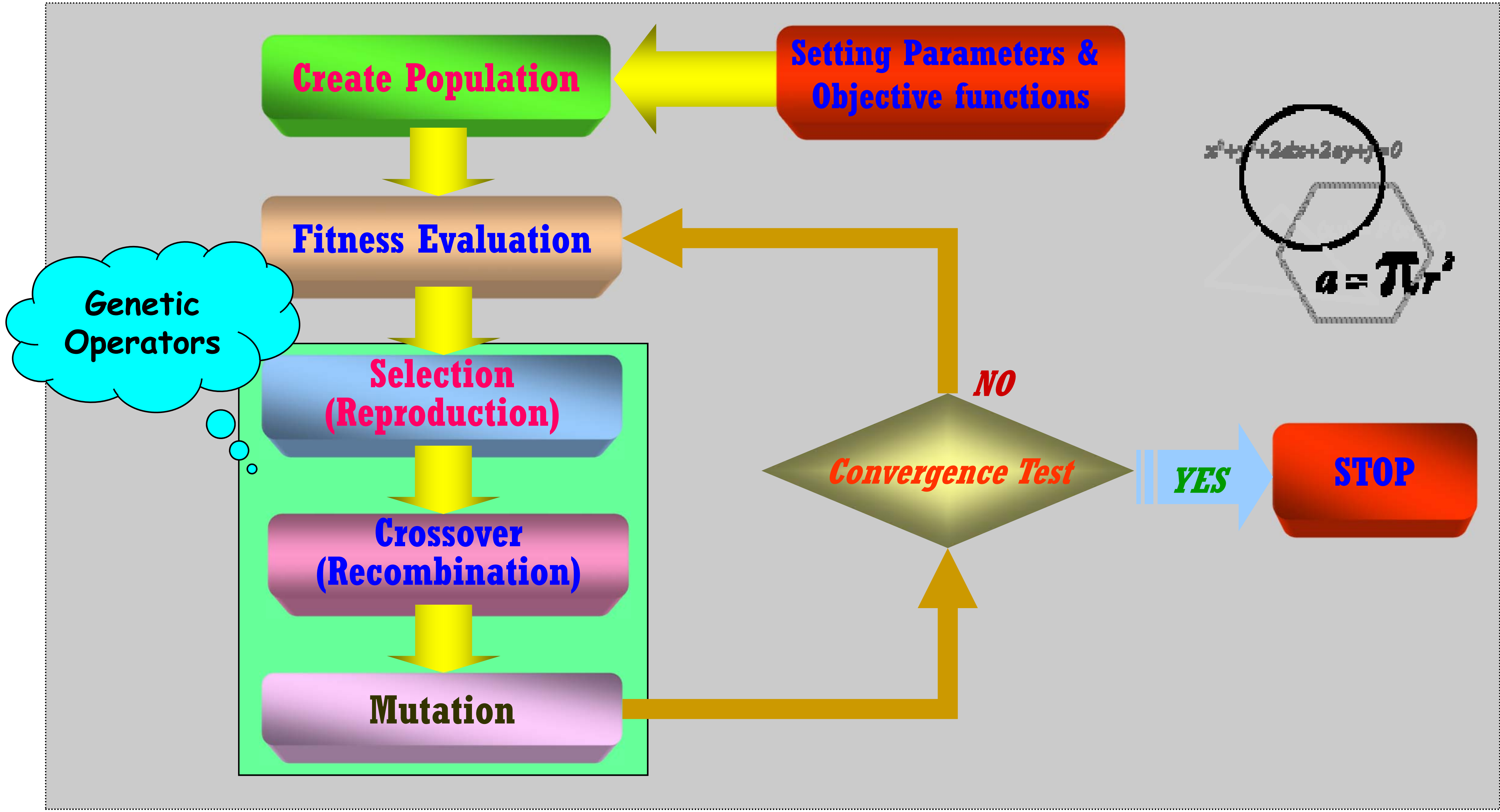
1**0**01001010 — $x_1 = 586$

1**1**01001010 — $x'_1 = 842$



Genetic Algorithms (13)

- **Overall Procedures of GAs**



Genetic Algorithms (14)