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Genetic Algorithms

Nature-Inspired Optimization Methods

Data&Code Quiz&Feedback

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PhD in Computer Science

Outline

1. Introduction to Anchor

- What is an anchor?
- Anchor in XAI

2. Advanced Anchor-based Method

- Introduction to advanced anchor-based method

2. Traditional Anchor-based Method

- Introduction to standard anchor-based method

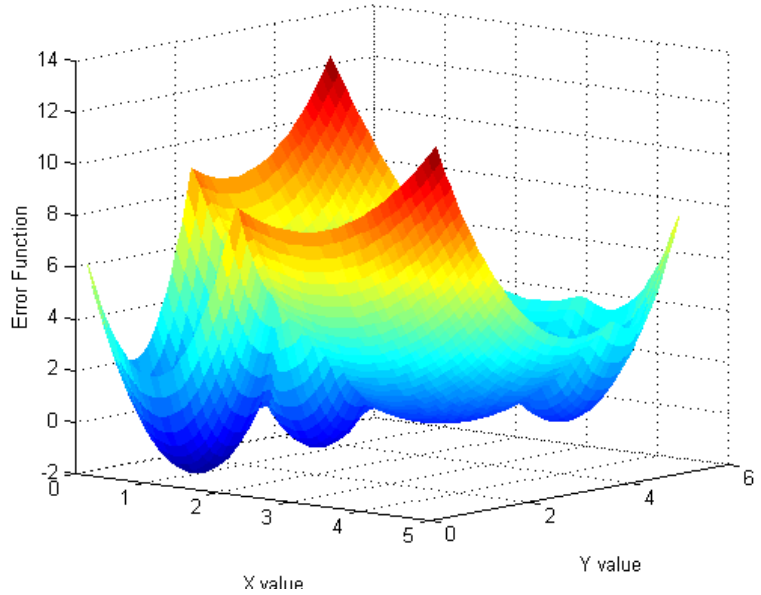
4. Anchor: Example

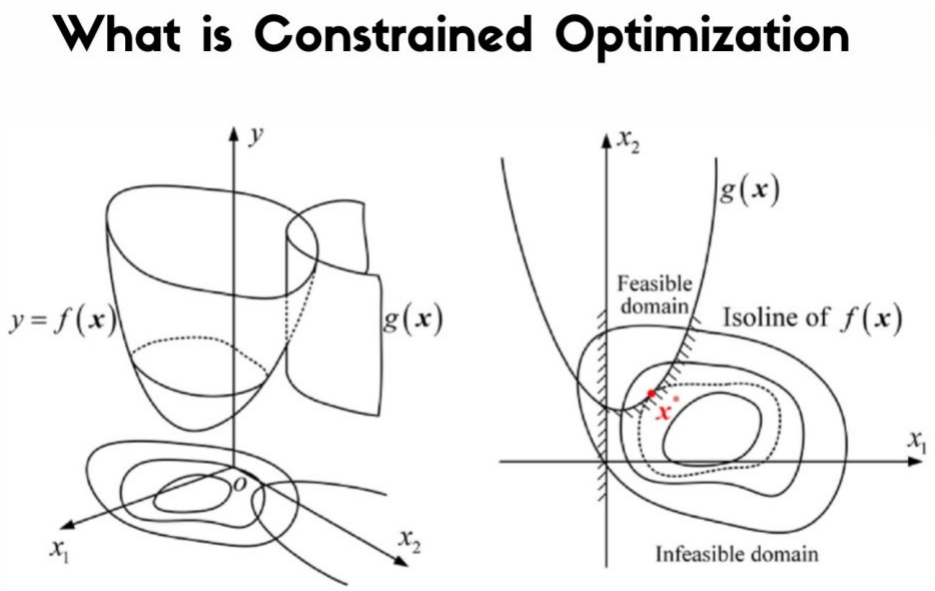
- Example in Image data

Outline

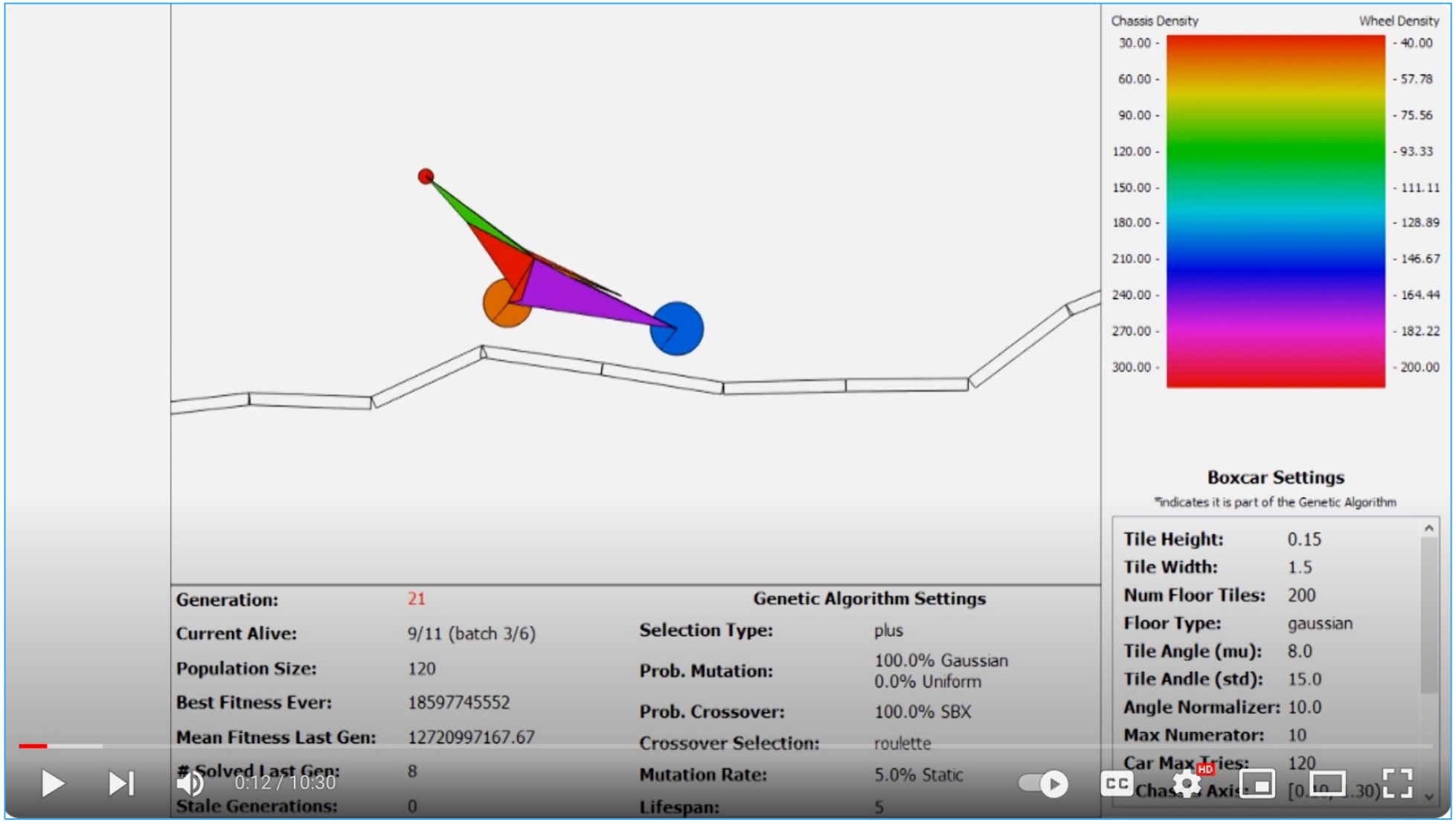
- Introduction to Evolutionary Algorithms
- Introduction to Genetic Algorithms
- One-Max Problem
- Sphere Function
- Regression Problem
- GA Applications

Genetic Algorithms are **heuristic search** algorithms that solve **constrained and unconstrained optimization** problems using the concepts of natural selection — a famous discipline in biological evolution.





AI Learns to be a Car using a Genetic Algorithm



https://www.youtube.com/watch?v=Ei2g8XoCkdg

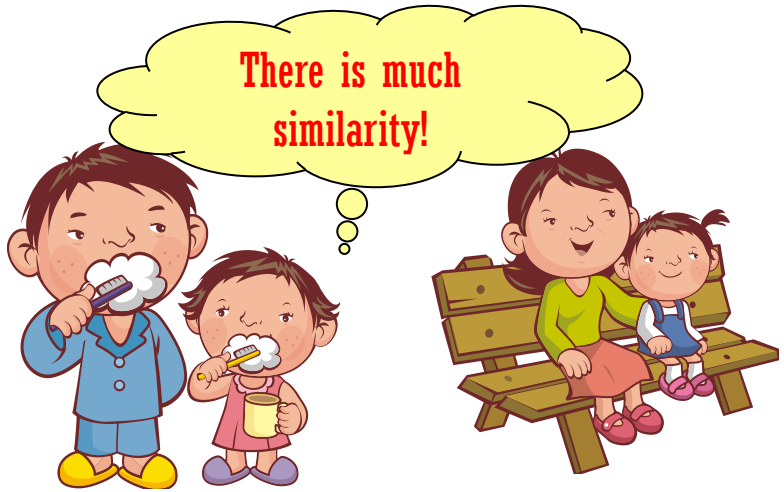
Principle of Evolutionary Algorithms

From Prof. Ahn

Evolutionary Algorithms: Principles

Evolutionary Algorithms (EAs)

- Any problem-solving method inspired from the theory of biological evolution, usually implemented on computers, which is employed for resolving problems

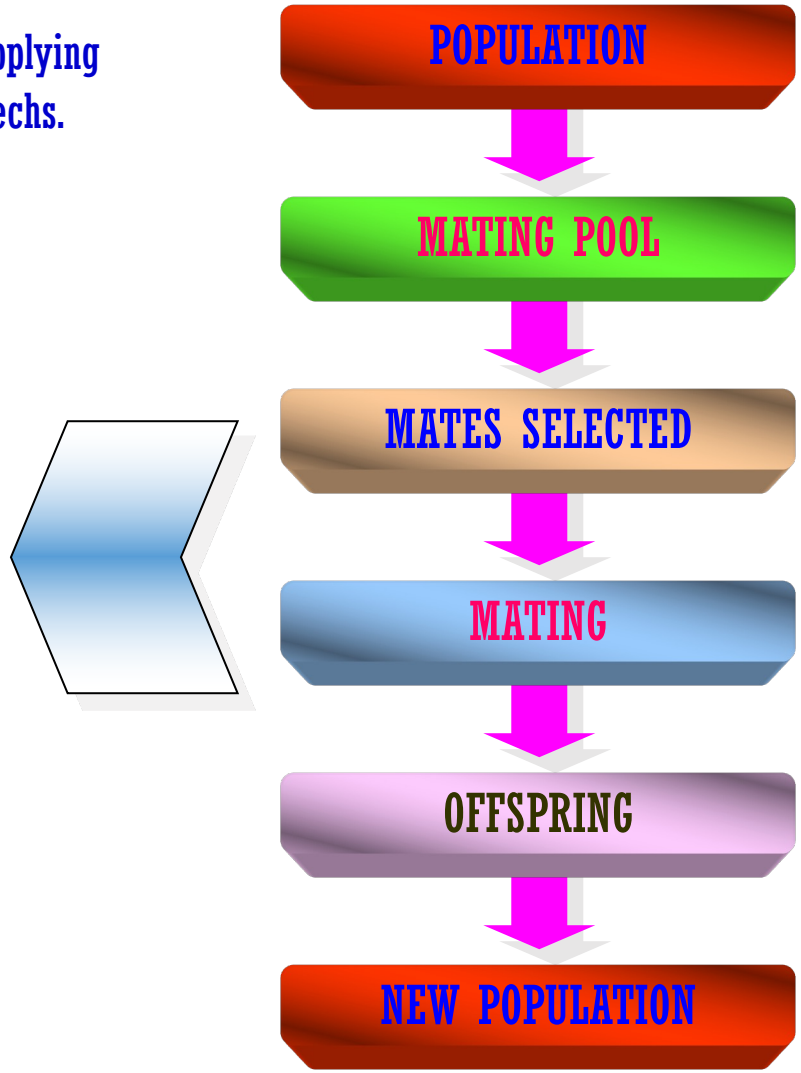


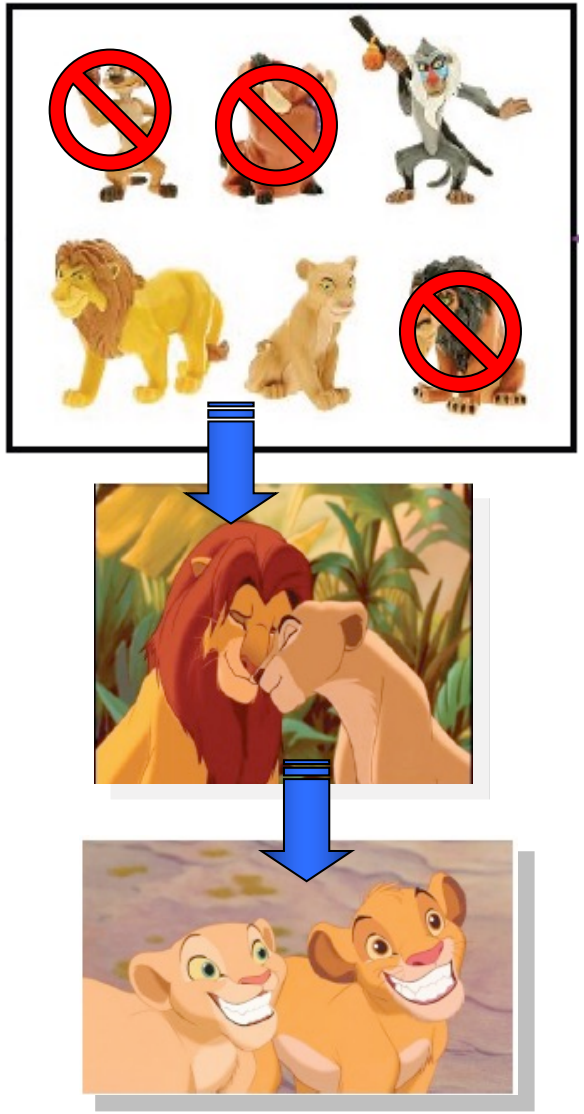
Evolutionary Algorithms: Principles

Lessons from Biological Evolution

Implications for applying to computing techs.

- Multiple
- Surviving
- Mixing
- Generation

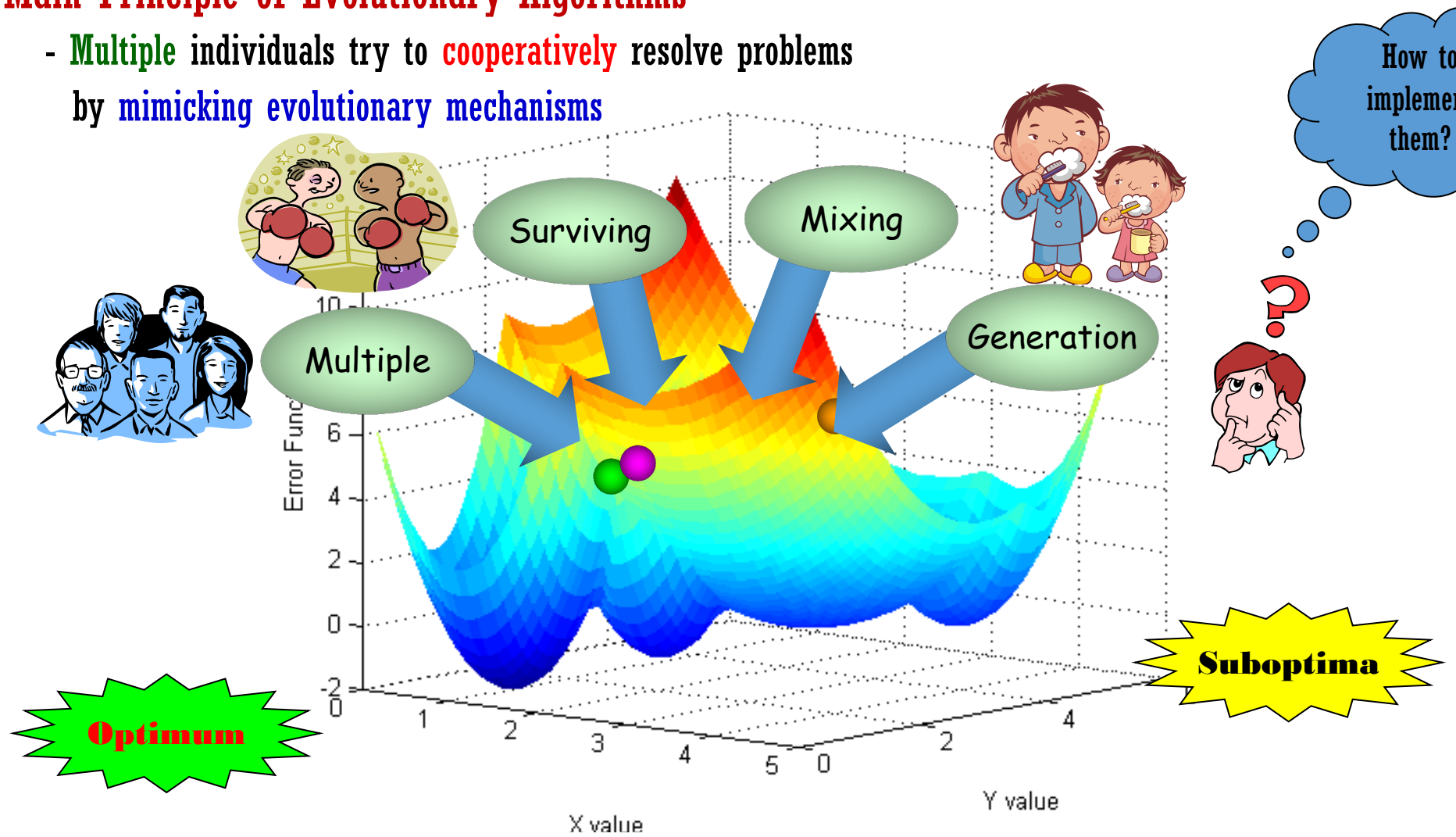




Evolutionary Algorithms: Principles

Main Principle of Evolutionary Algorithms

- Multiple individuals try to cooperatively resolve problems by mimicking evolutionary mechanisms



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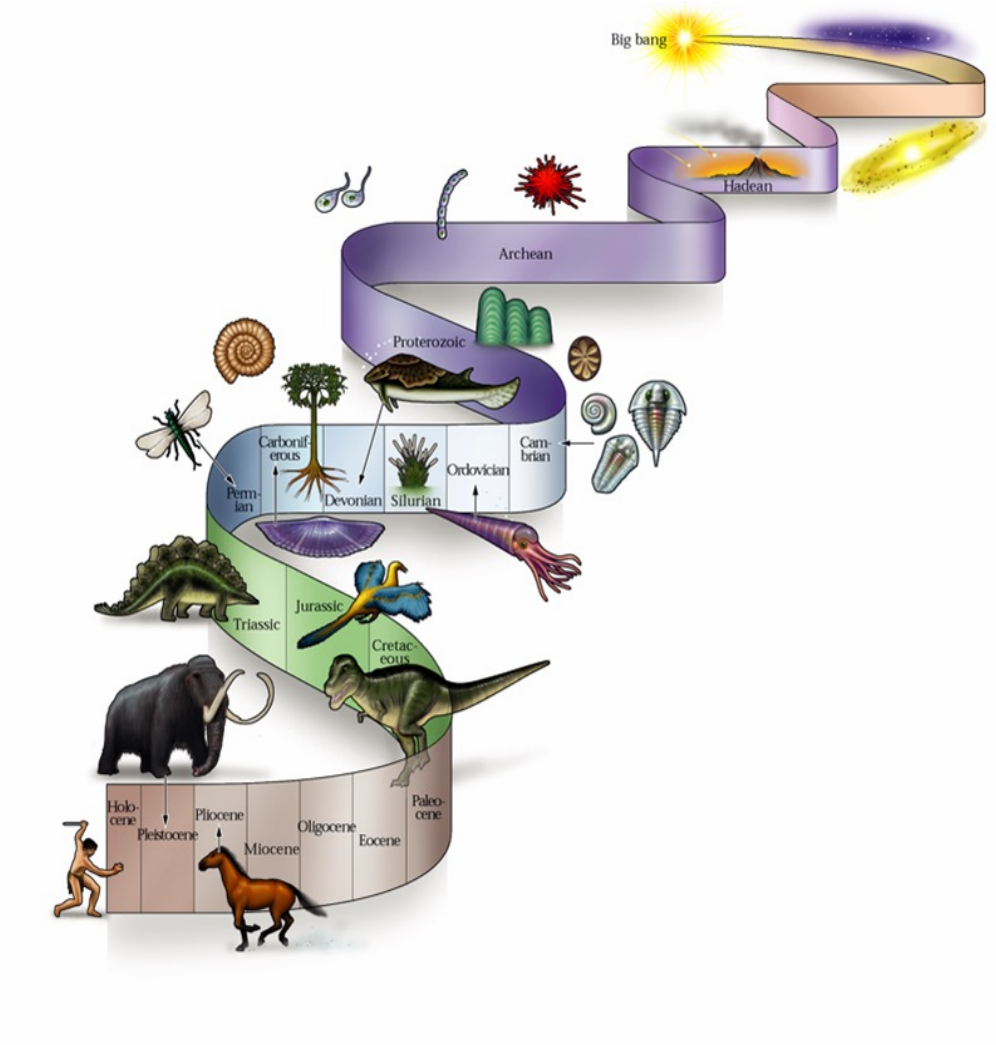
Genetic Algorithms



Genetic Algorithms

- **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)

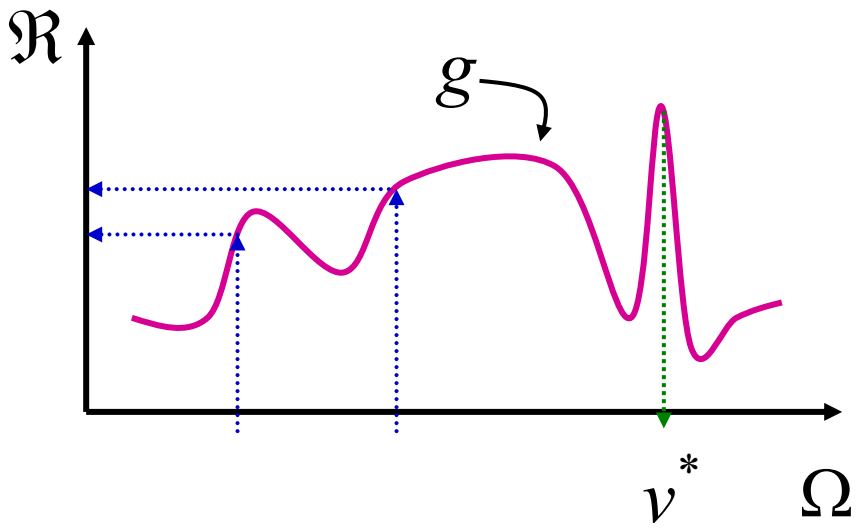
Formal Definition

For a search space Ω

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

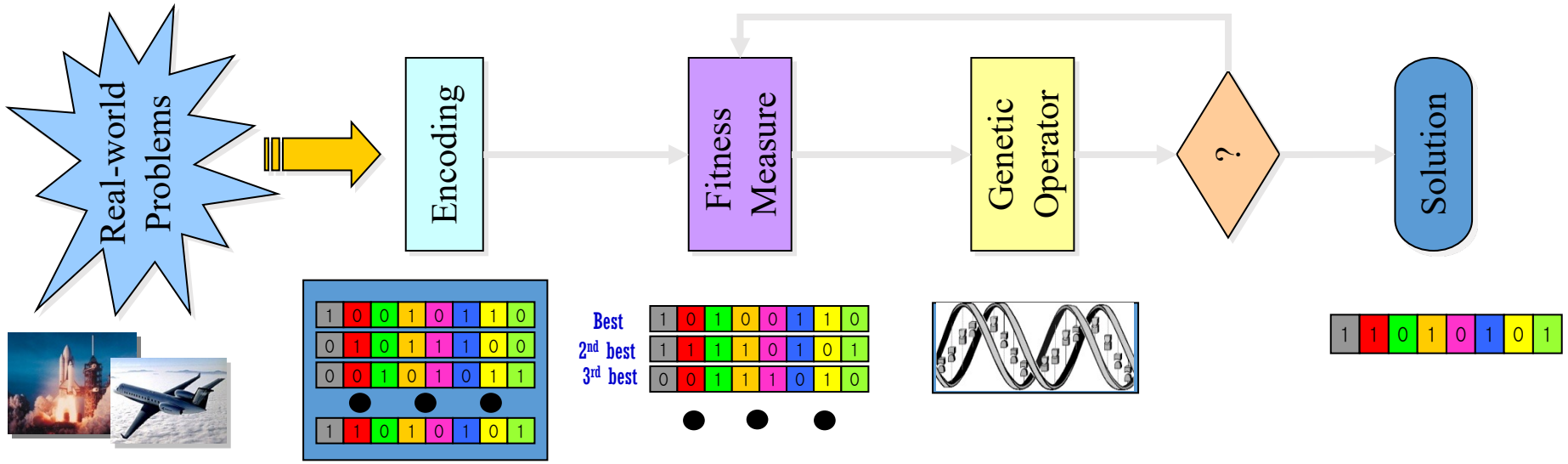
The task is to find $v^* = \arg\max_{v \in \Omega} g$

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

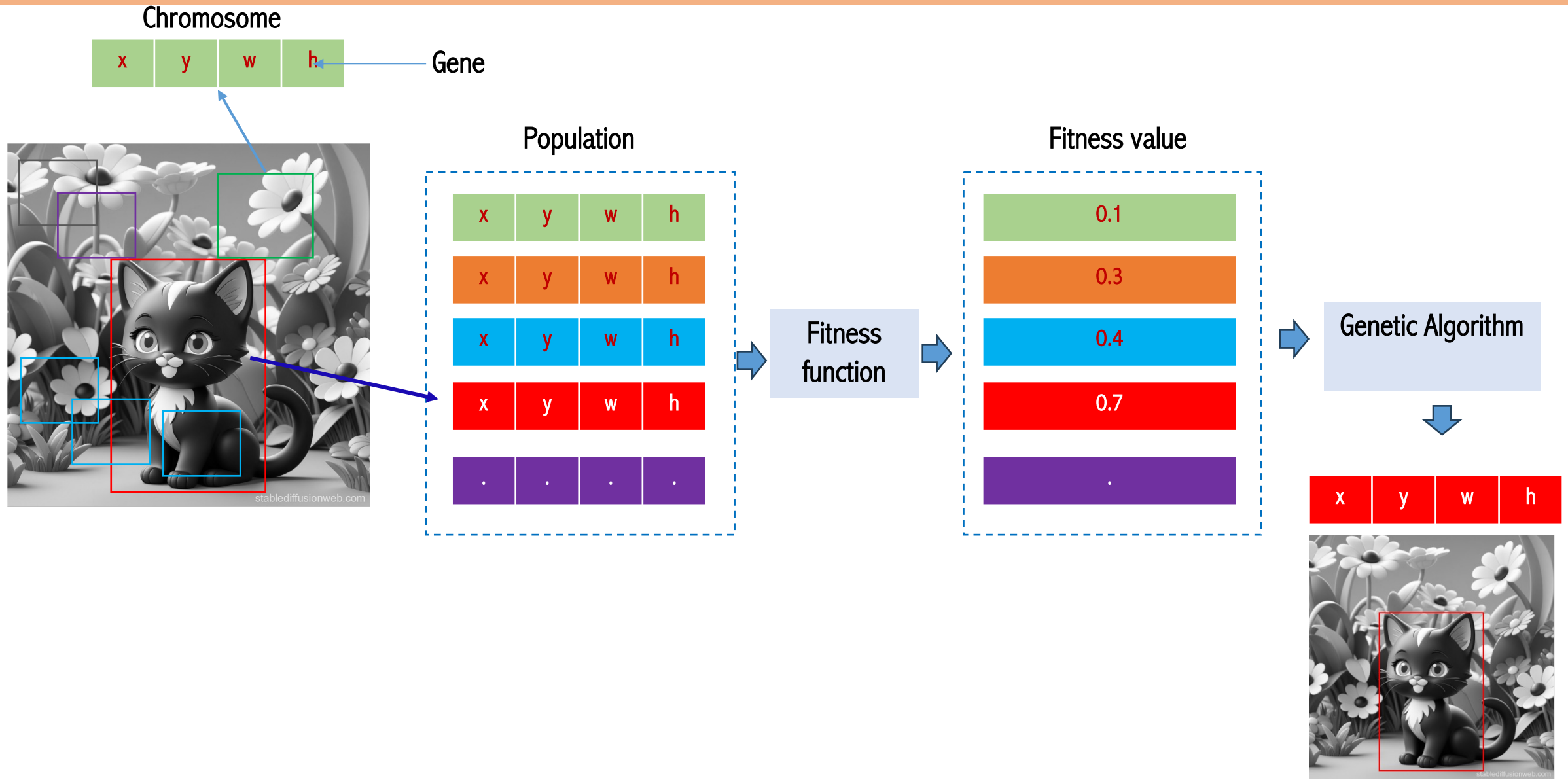


Genetic Algorithms

- **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

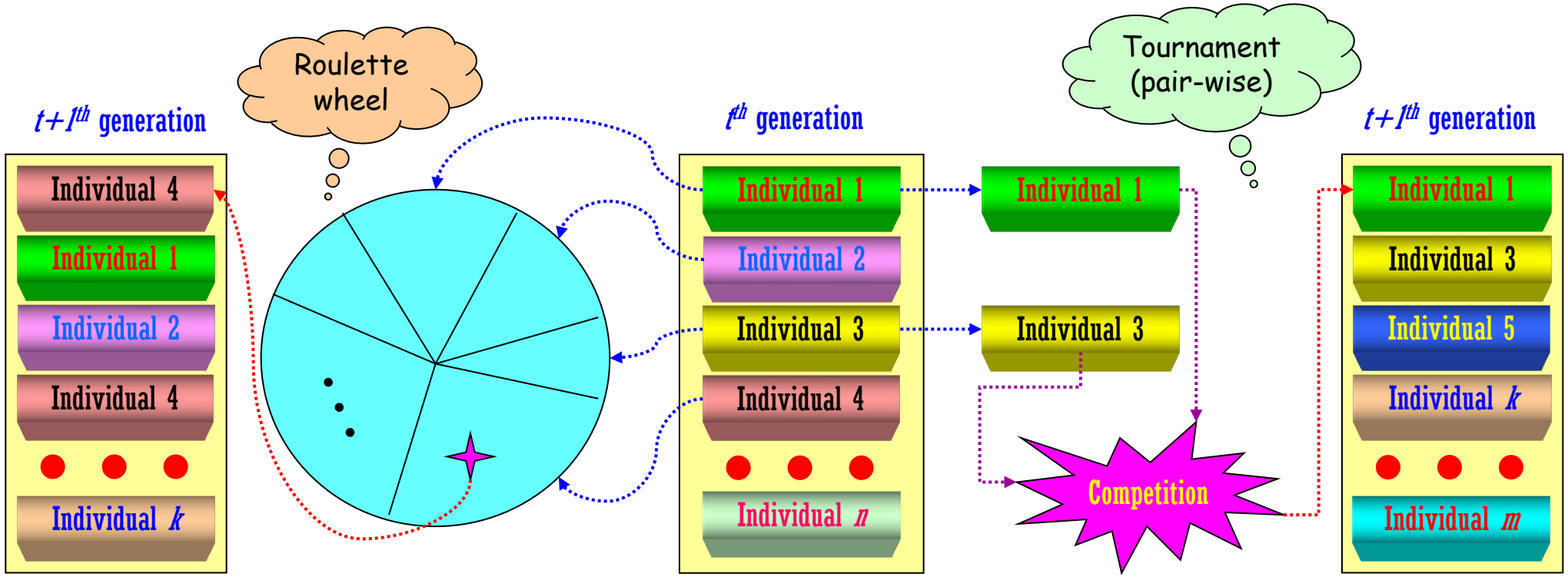


Genetic Algorithms



Genetic Algorithms

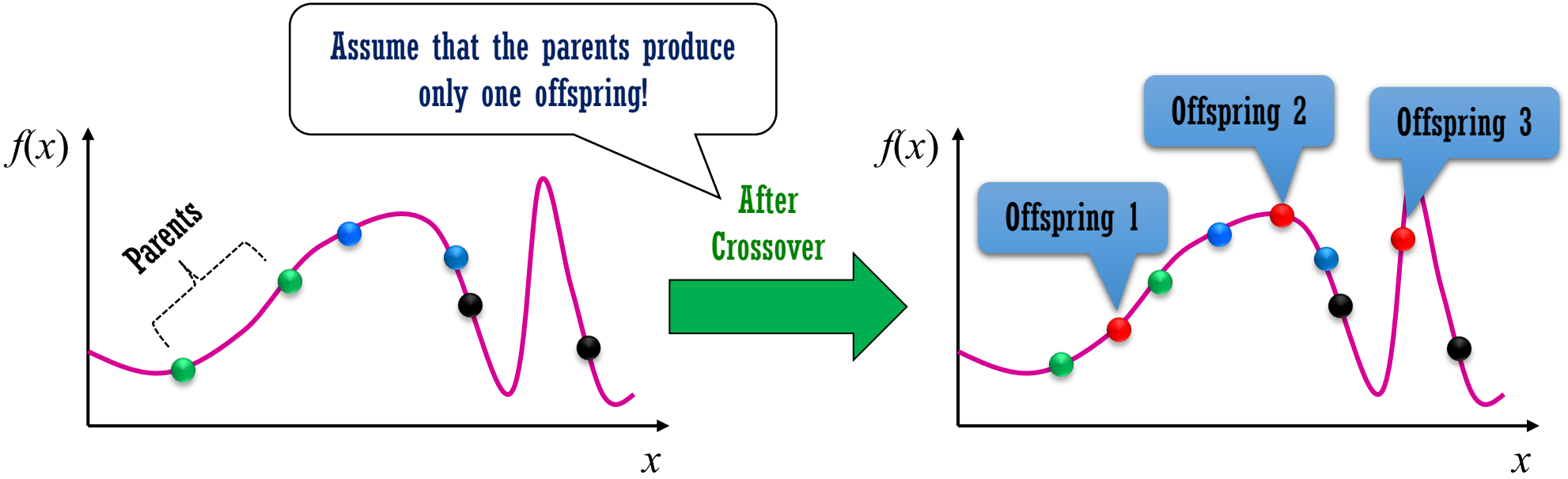
- **Roulette Wheel Selection**
  - The probability of selecting a given chromosome is proportional to its fitness
- **Tournament Selection**
  - Combine the fitness proportional concept with the random selection



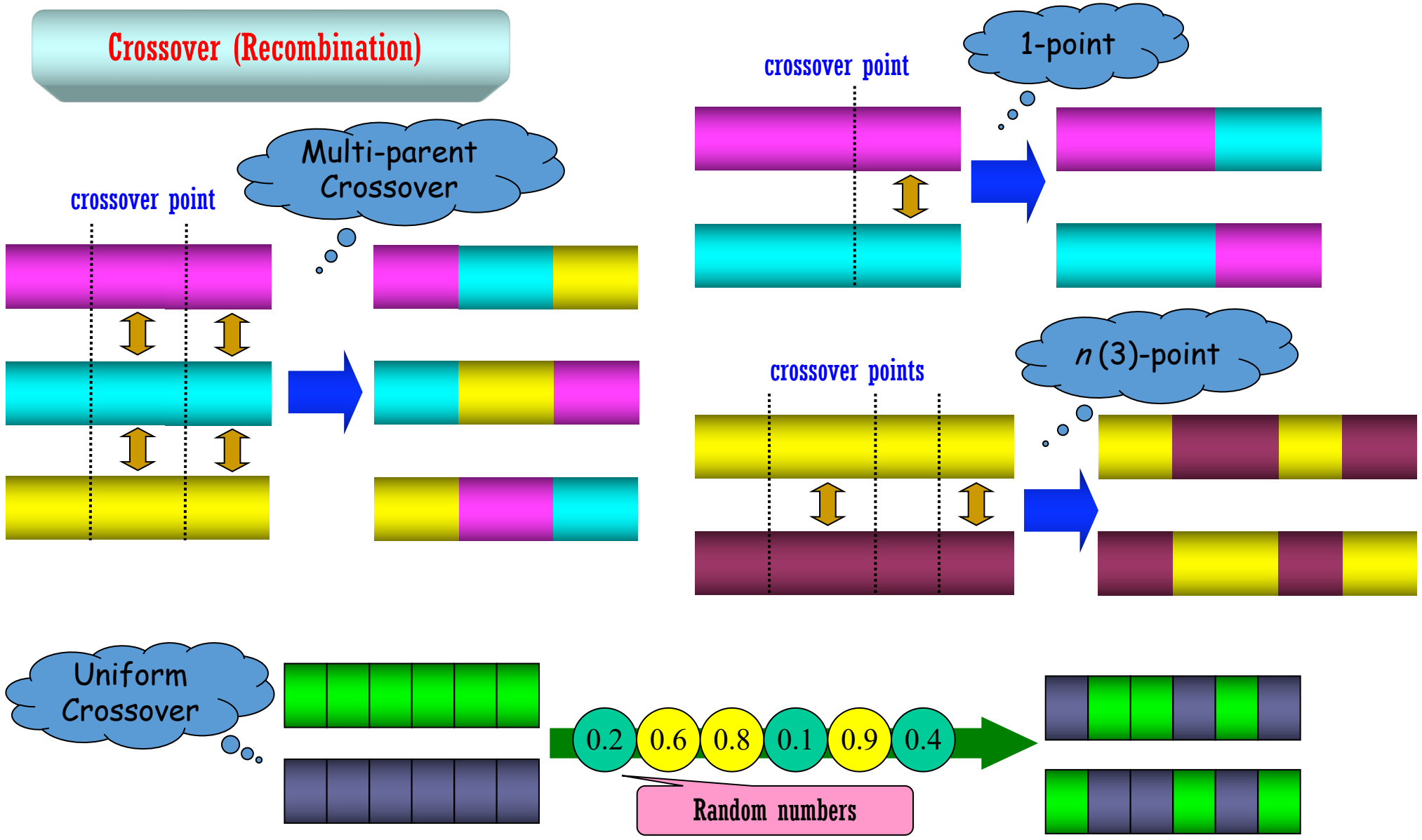
Genetic Algorithms

Crossover (Recombination)

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



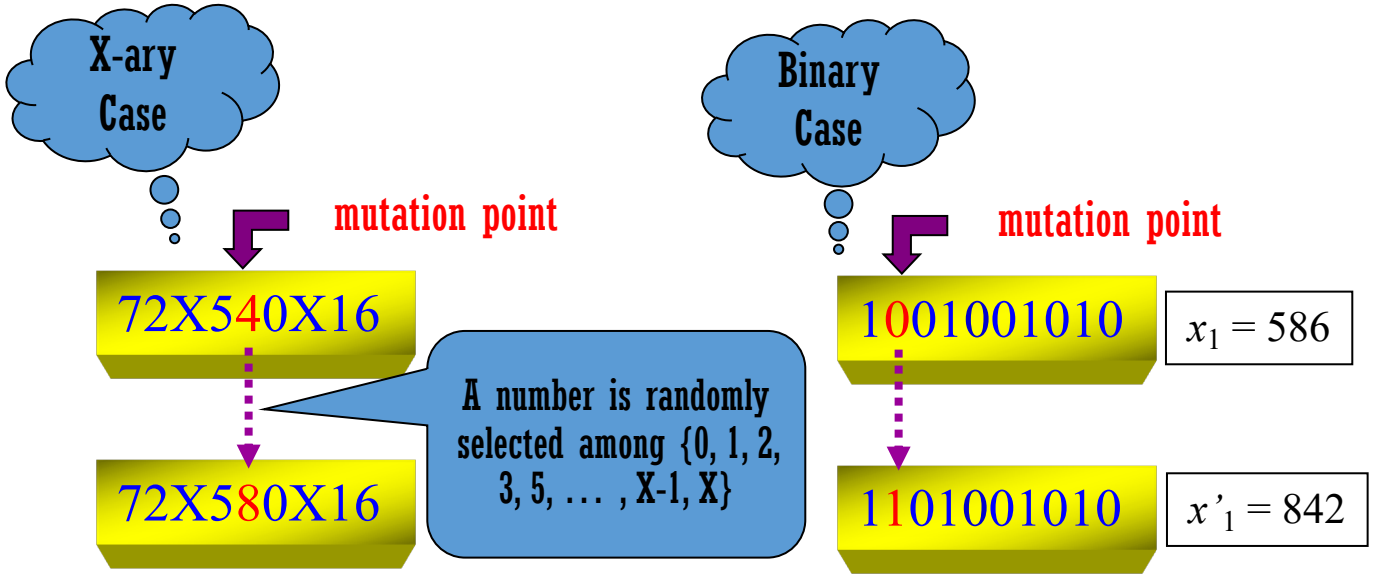
Genetic Algorithms

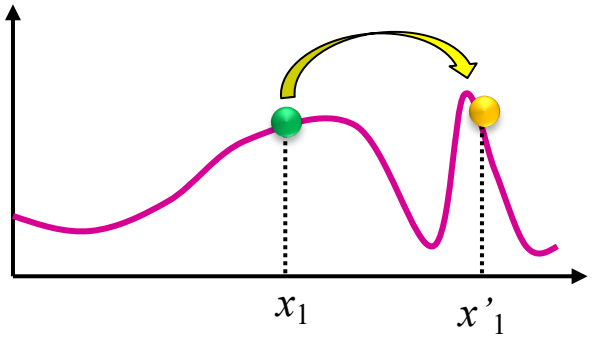


Genetic Algorithms

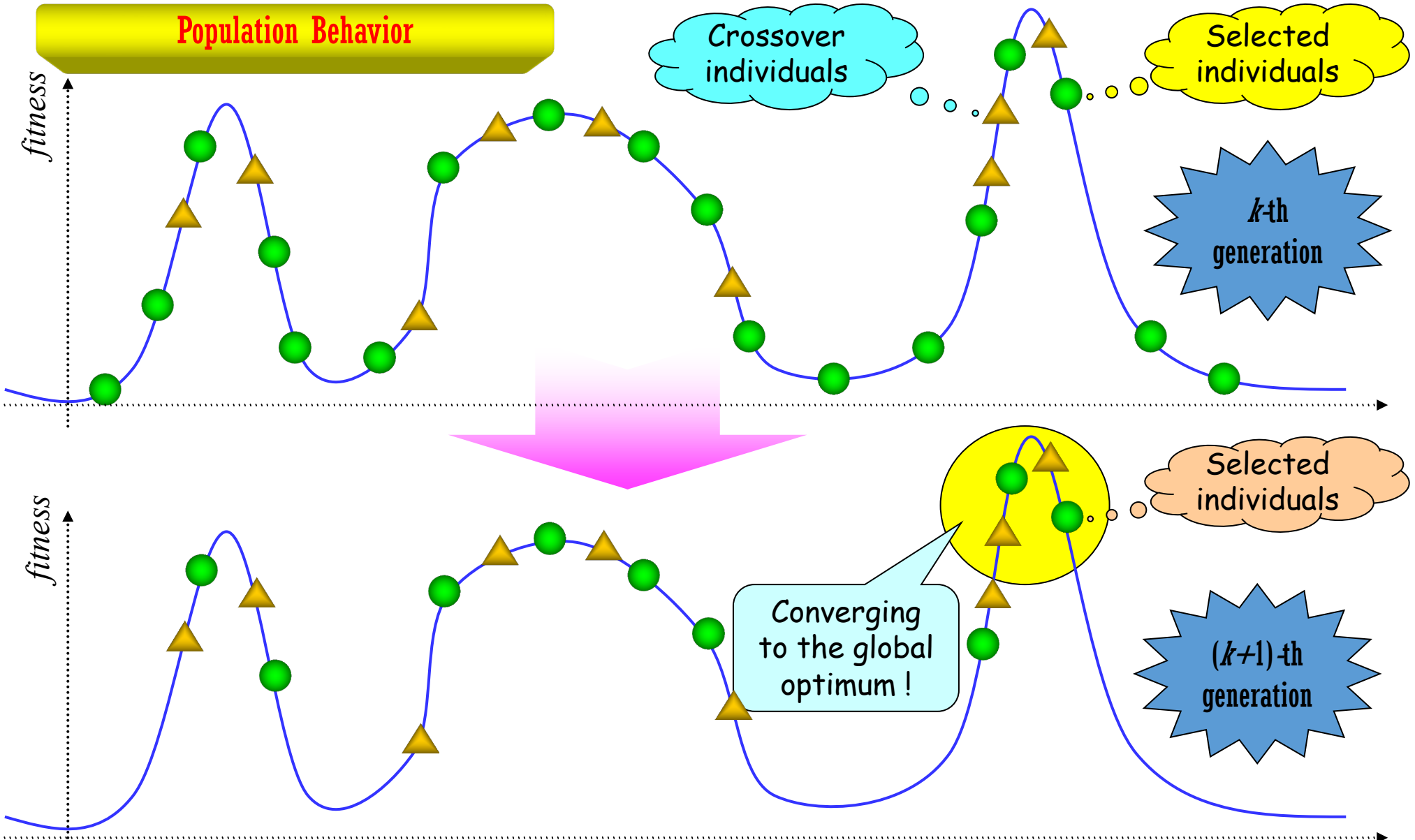
Mutation

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



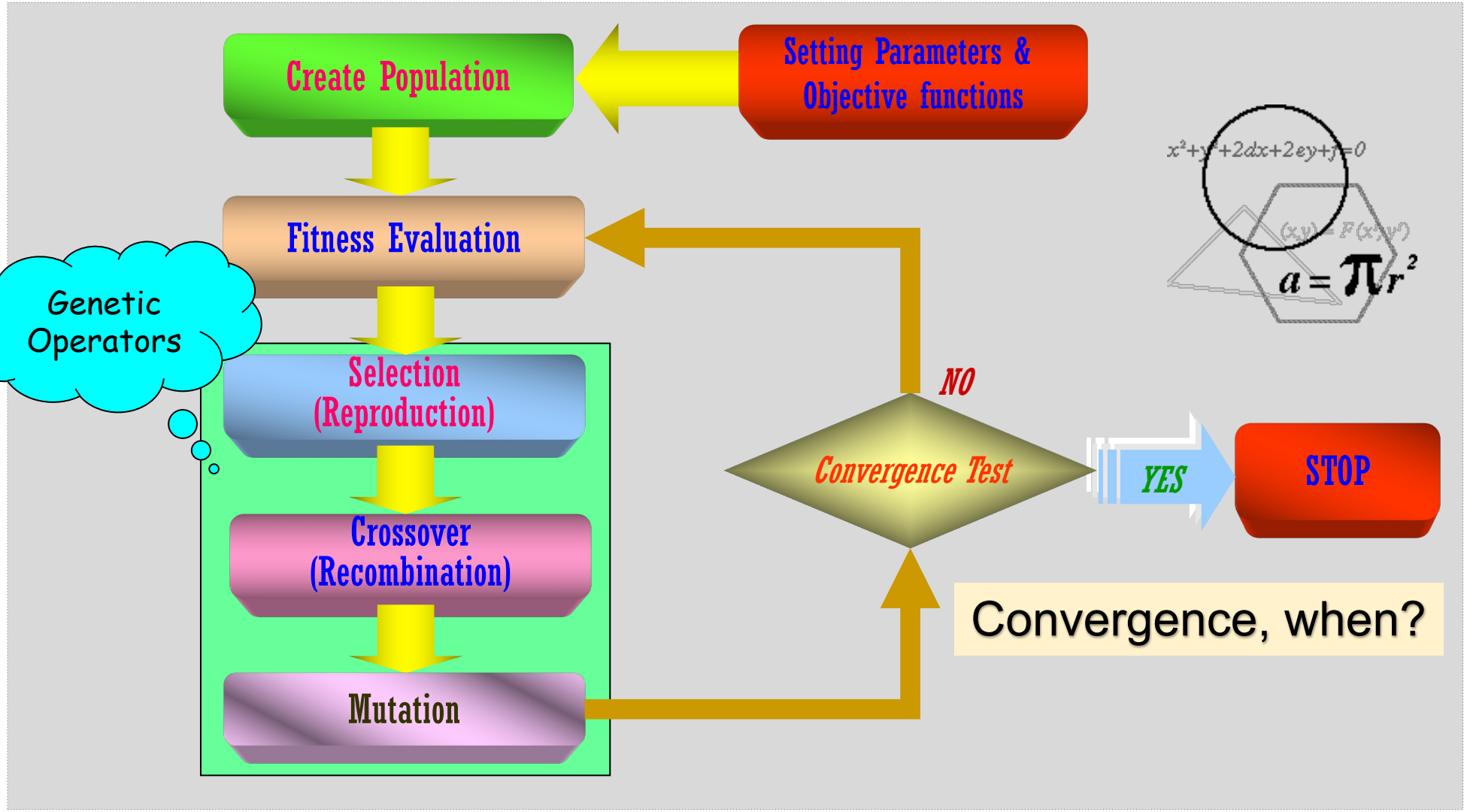


Genetic Algorithms



Genetic Algorithms

- Overall Procedures of GAs




QUIZ!

Genetic Algorithm

❖ Introduction to one-max problem

What is the maximum sum of a bitstring (a string consisting of only 1s and 0s) of length N?

Very simple, the maximum sum of a bitstring of length N is N.

However, if you wanted to prove this using a brute-force search, you'd end up needing to search through …?

Outline

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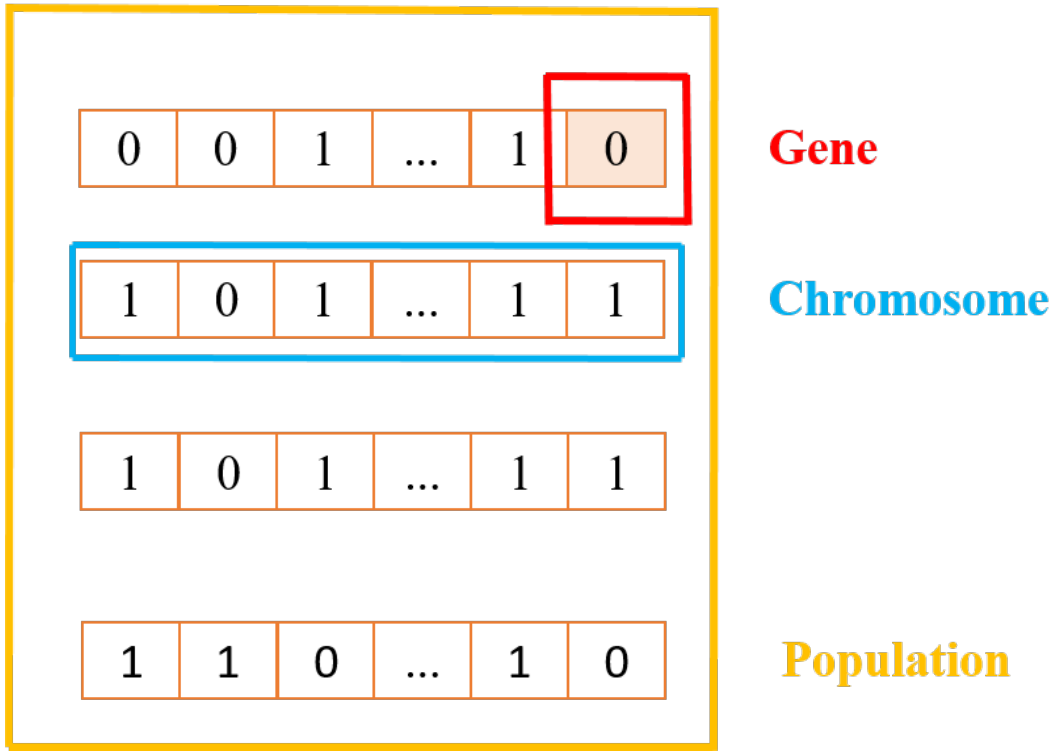
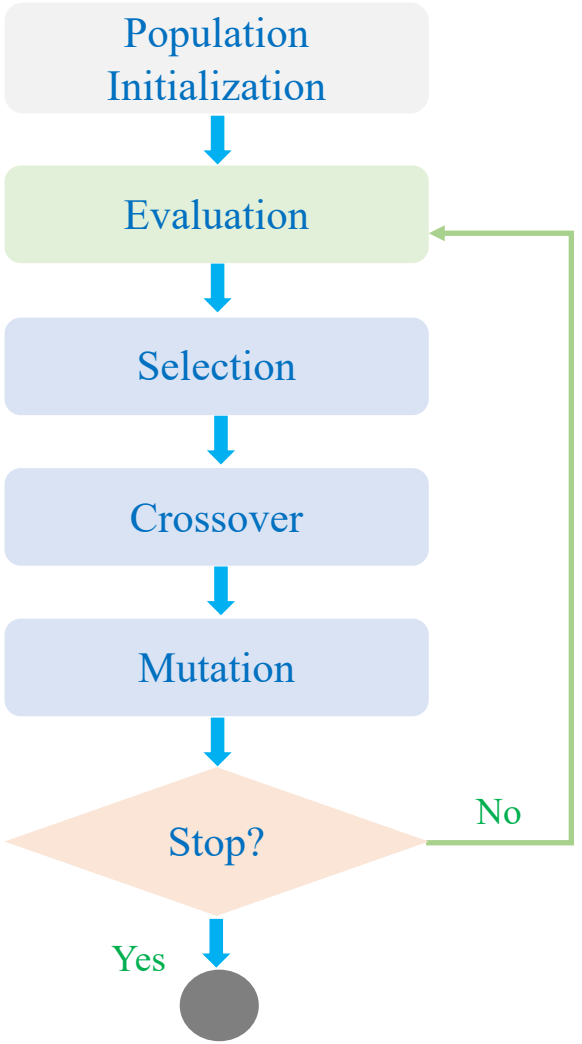
Genetic Algorithm

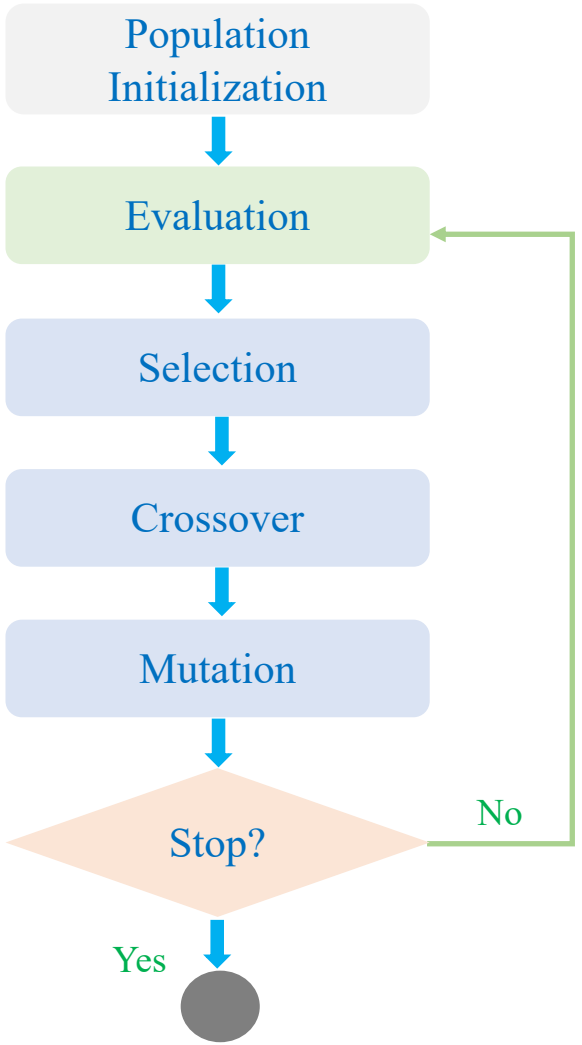
❖ **To solve the one-max problem**





Genetic Algorithm

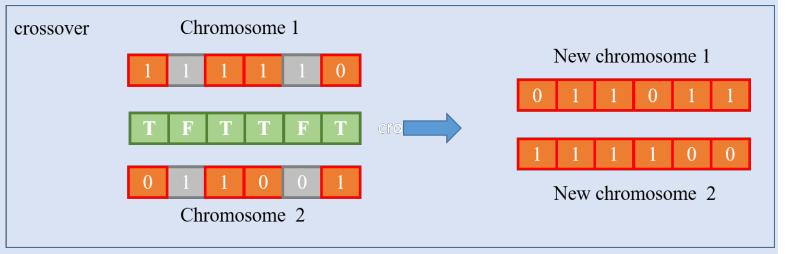
❖ Steps in Genetic Algorithm



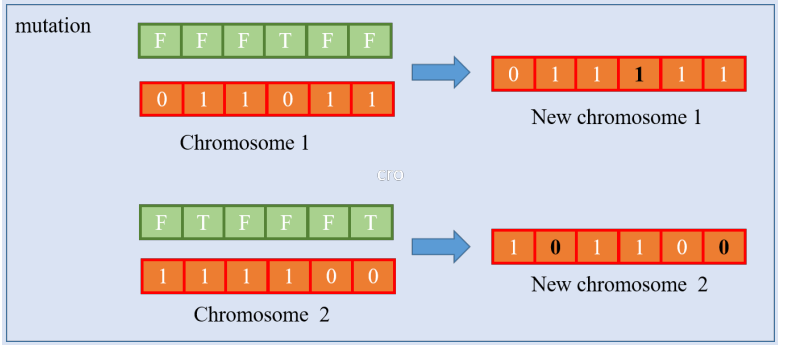
Khởi tạo quần thể: Gán giá trị ngẫu nhiên cho các gen của các cá thể

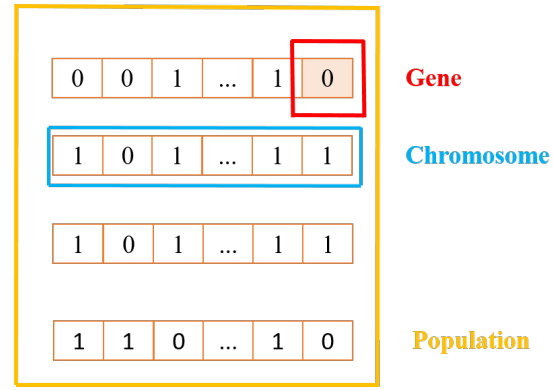
Cá thể 1	0	0	1	1	1	0
Cá thể 2	1	0	1	0	1	0
Cá thể 3	0	0	1	0	0	1
Cá thể 4	0	1	1	0	0	1
Cá thể 5	0	1	1	1	1	0
Cá thể 6	1	0	0	0	1	1
Cá thể 7	0	0	0	0	0	1
Cá thể 8	1	0	0	0	0	0
Cá thể 9	0	1	0	0	0	1
Cá thể 10	1	1	1	1	1	0

Trao đổi gen (giá trị) giữa các cá thể với nhau



Đột biến gen cho từng cá thể





Tính fitness cho các cá thể

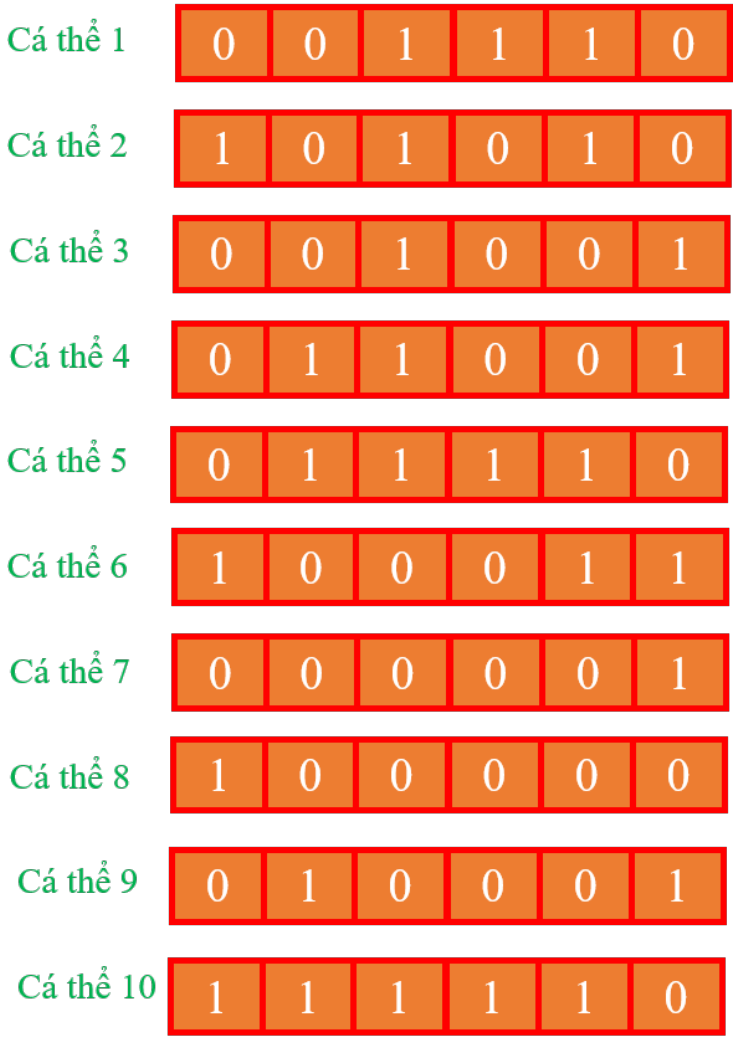
							Fitness
Cá thể 1	0	0	1	1	1	0	3
Cá thể 2	1	0	1	0	1	0	3
Cá thể 3	0	0	1	0	0	1	2
Cá thể 4	0	1	1	0	0	1	3
Cá thể 5	0	1	1	1	1	0	4
Cá thể 6	1	0	0	0	1	1	3
Cá thể 7	0	0	0	0	0	1	1
Cá thể 8	1	0	0	0	0	0	1
Cá thể 9	0	1	0	0	0	1	2
Cá thể 10	1	1	1	1	1	0	5

Genetic Algorithm

❖ Population initialization

Population size m = 10

Vector length is with n =6




```python
# aivietnam.ai
import random

n = 6   # size of individual (chromosome)
m = 10  # size of population

def generate_random_value():
    return random.randint(0, 1)

def create_individual():
    return [generate_random_value() for _ in range(n)]

population = [create_individual() for _ in range(m)]

# print population
for ind in population:
    print(ind)
```

```
[0, 0, 0, 1, 0, 1]
[0, 0, 0, 0, 1, 1]
[0, 1, 0, 1, 0, 1]
[1, 0, 1, 1, 0, 1]
[1, 0, 0, 1, 0, 1]
[1, 1, 0, 1, 0, 0]
[0, 0, 1, 1, 0, 0]
[1, 1, 1, 1, 1, 1]
[1, 0, 0, 0, 0, 1]
[0, 0, 1, 1, 0, 1]
```

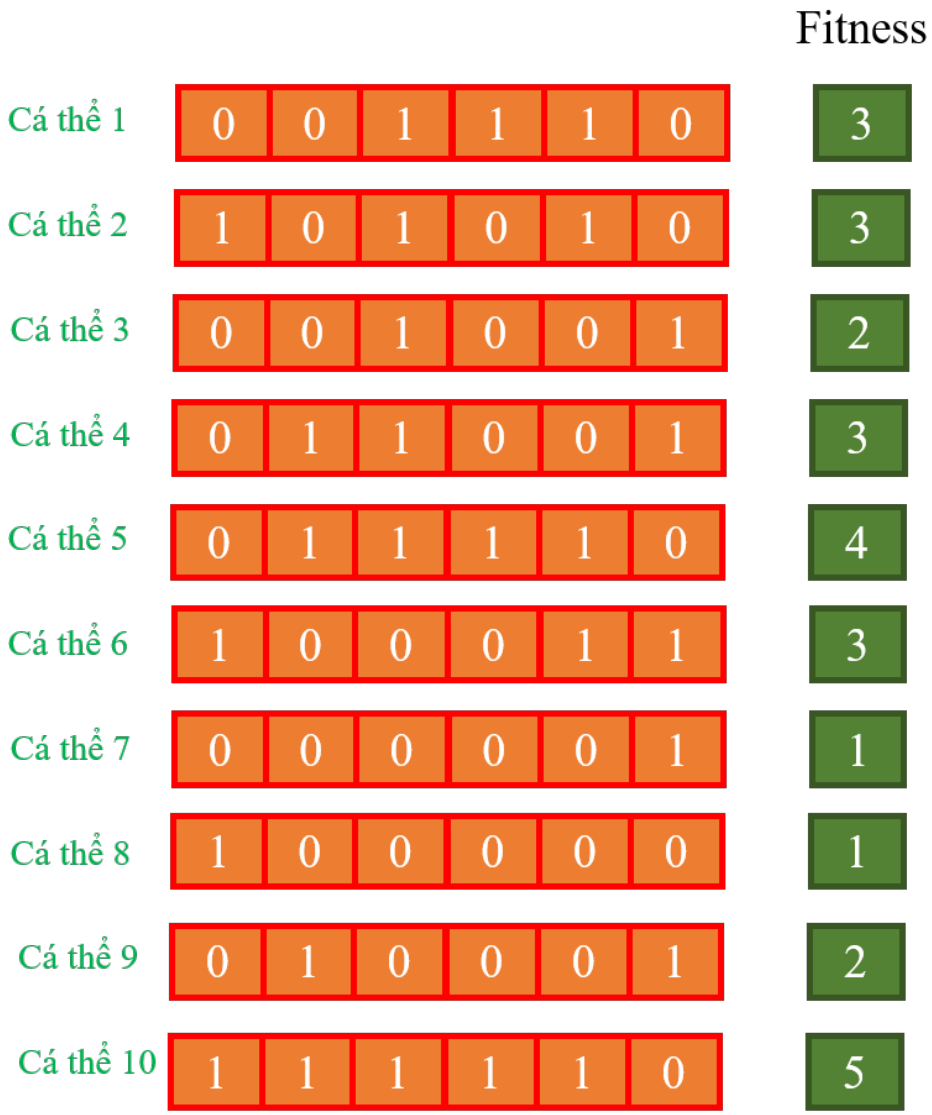
Genetic Algorithm

❖ Evaluation

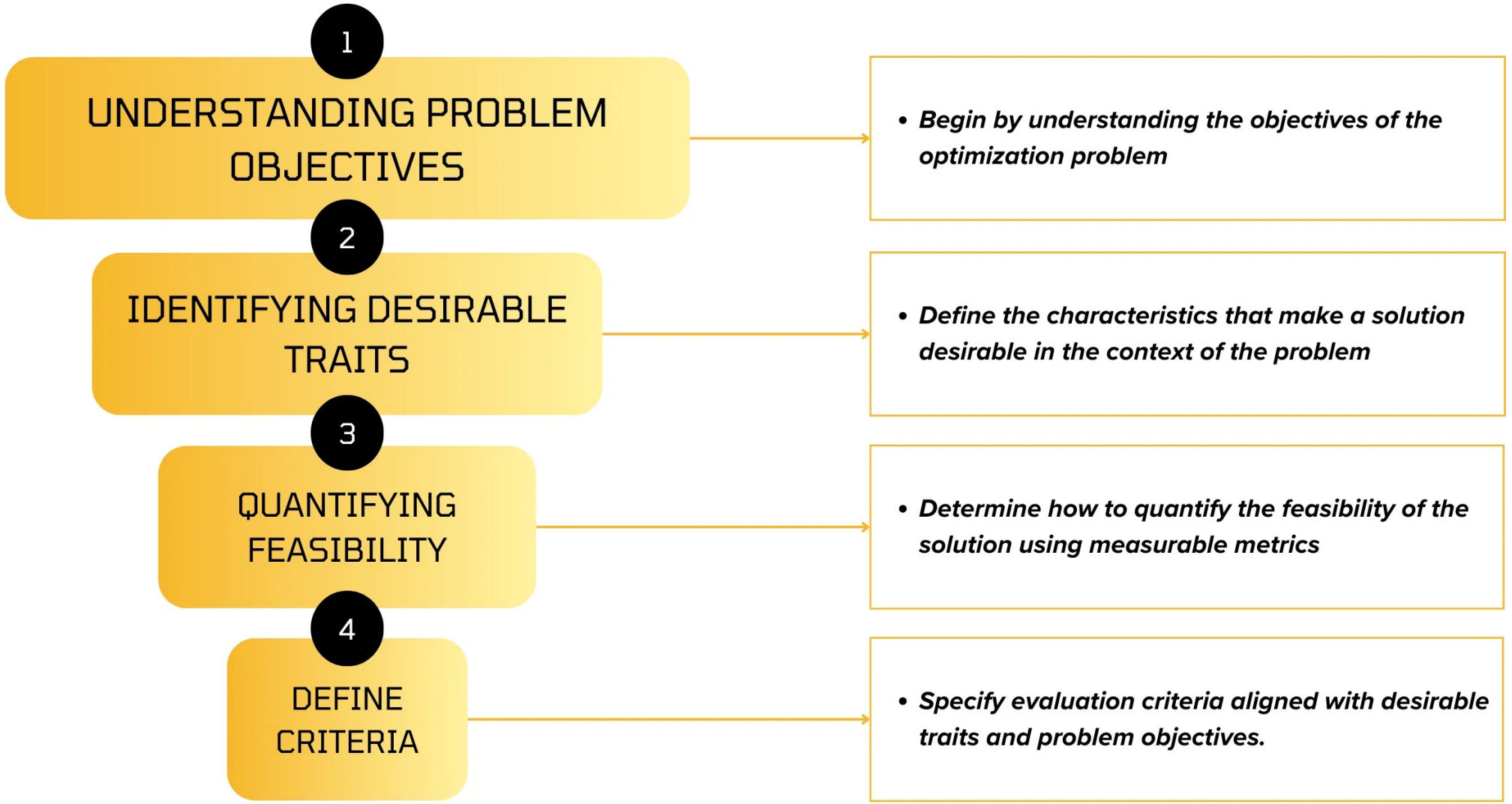
- ❖ This function is given

Secret information

$$\text{secret}(v) = \sum_i v_i$$

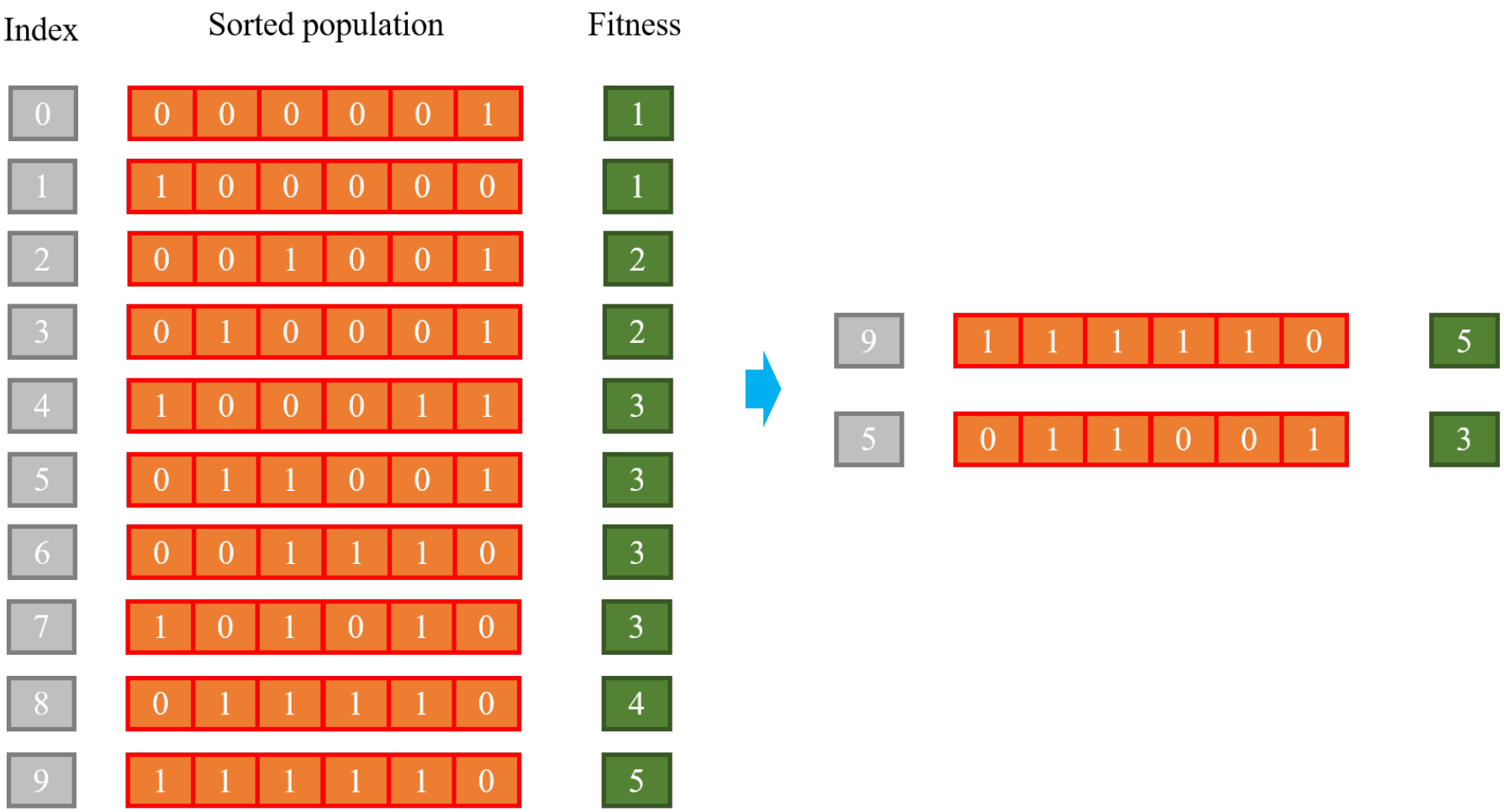


How to design Fitness Function



Genetic Algorithm

❖ Selection



Genetic Algorithm

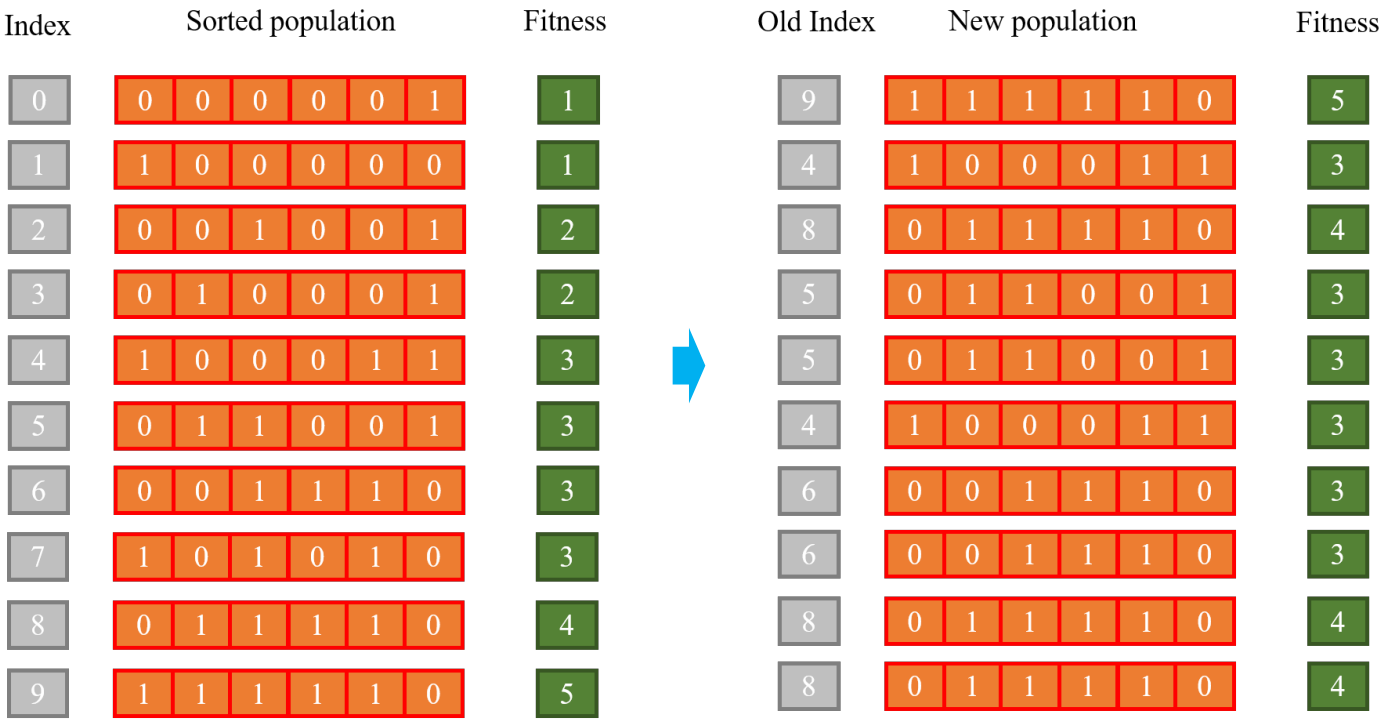
❖ Selection

Index	Sorted population	Fitness
0	0 0 0 0 0 1	1
1	1 0 0 0 0 0	1
2	0 0 1 0 0 1	2
3	0 1 0 0 0 1	2
4	1 0 0 0 1 1	3
5	0 1 1 0 0 1	3
6	0 0 1 1 1 0	3
7	1 0 1 0 1 0	3
8	0 1 1 1 1 0	4
9	1 1 1 1 1 0	5

Old Index	New population	Fitness
9	1 1 1 1 1 0	5
4	1 0 0 0 1 1	3
8	0 1 1 1 1 0	4
5	0 1 1 0 0 1	3
5	0 1 1 0 0 1	3
4	1 0 0 0 1 1	3
6	0 0 1 1 1 0	3
6	0 0 1 1 1 0	3
8	0 1 1 1 1 0	4
8	0 1 1 1 1 0	4

Genetic Algorithm

❖ Selection




```python
def selection(sorted_old_population):
    index1 = random.randint(0, m-1)
    while True:
        index2 = random.randint(0, m-1)
        if (index2 != index1):
            break

    individual_s = sorted_old_population[index1]
    if index2 > index1:
        individual_s = sorted_old_population[index2]

    return individual_s
```

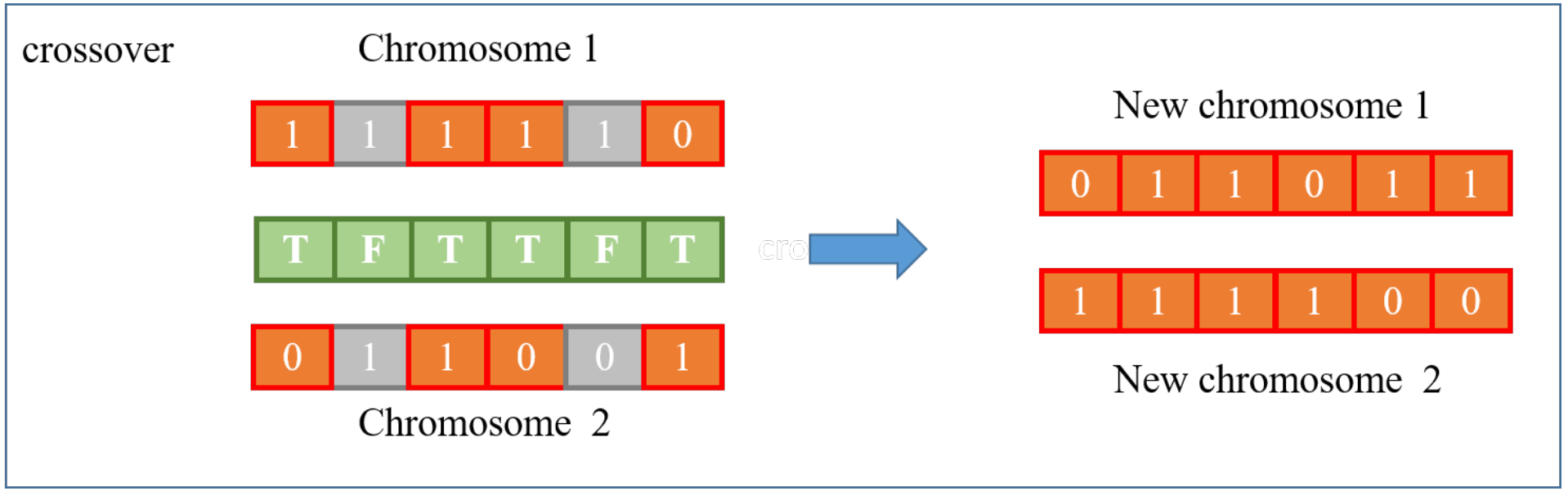
Genetic Algorithm

- Crossover
  - Binary crossover

```python
def crossover(individual1, individual2, crossover_rate = 0.9):
    individual1_new = individual1.copy()
    individual2_new = individual2.copy()

    for i in range(n):
        if random.random() < crossover_rate:
            individual1_new[i] = individual2[i]
            individual2_new[i] = individual1[i]

    return individual1_new, individual2_new
```



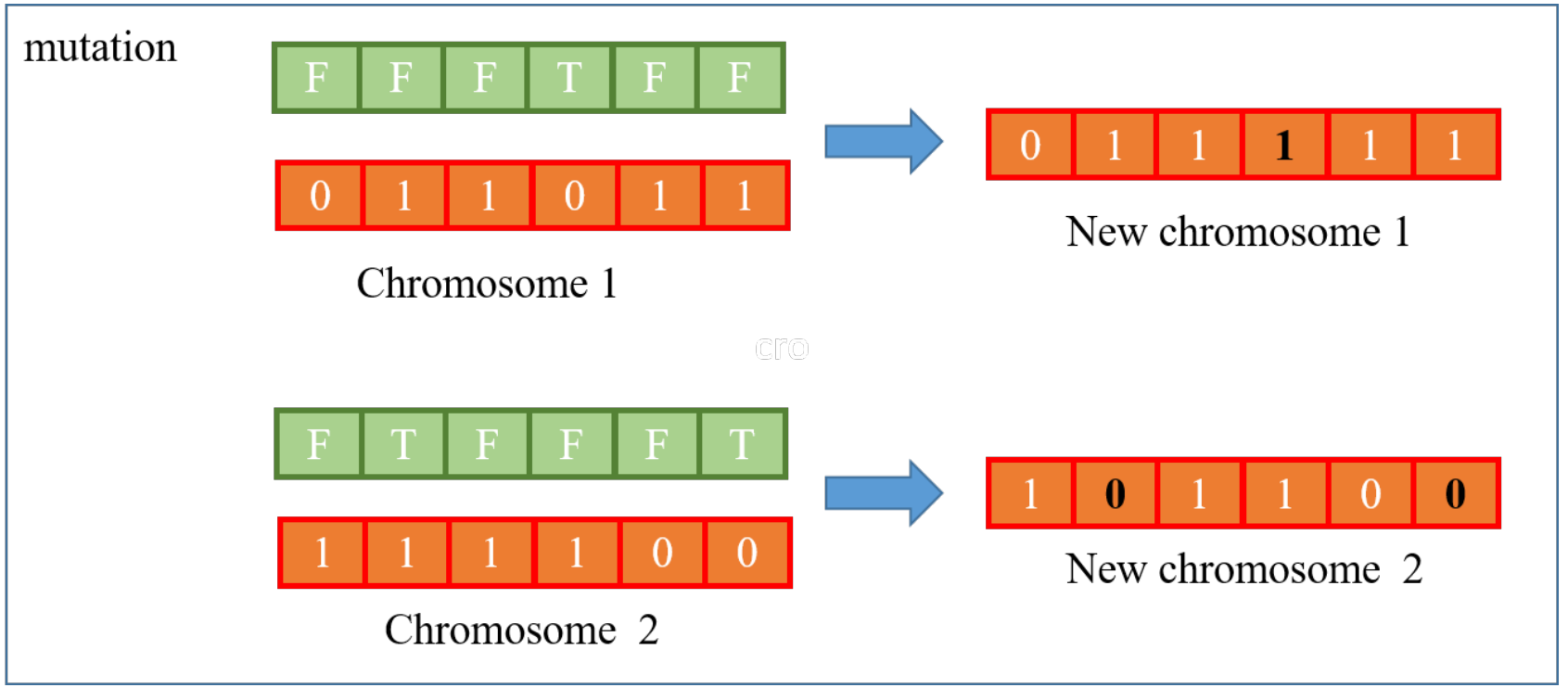
Genetic Algorithm

❖ Mutation

```python
def mutate(individual, mutation_rate = 0.05):
    individual_m = individual.copy()

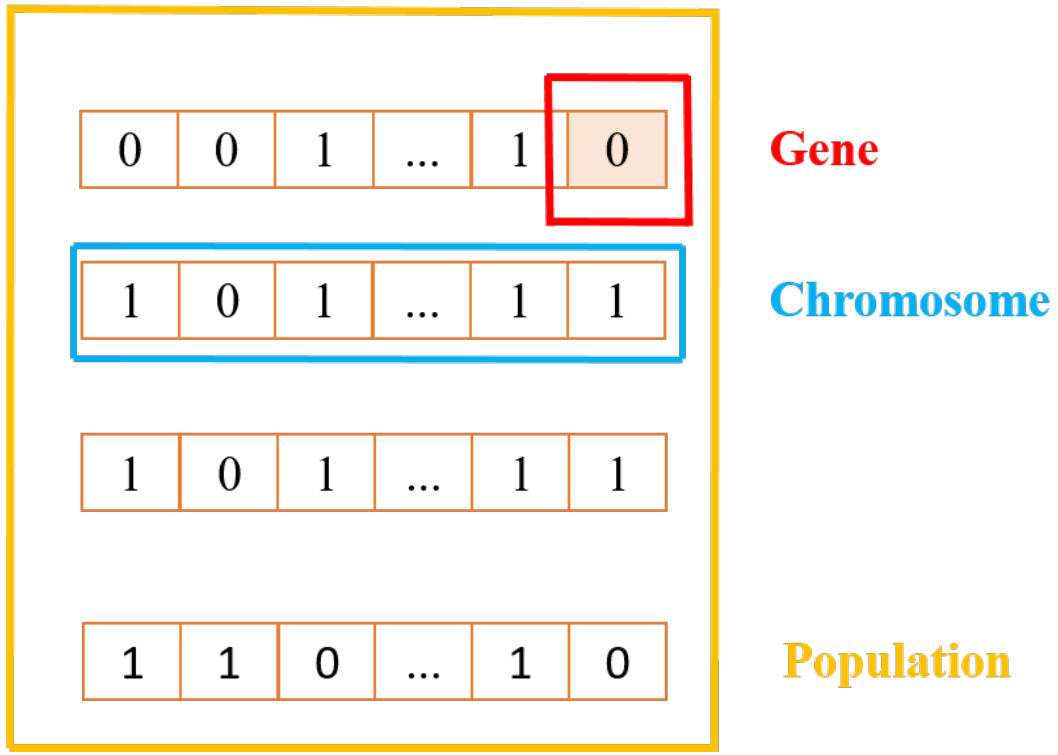
    for i in range(n):
        if random.random() < mutation_rate:
            individual_m[i] = generate_random_value()

    return individual_m
```

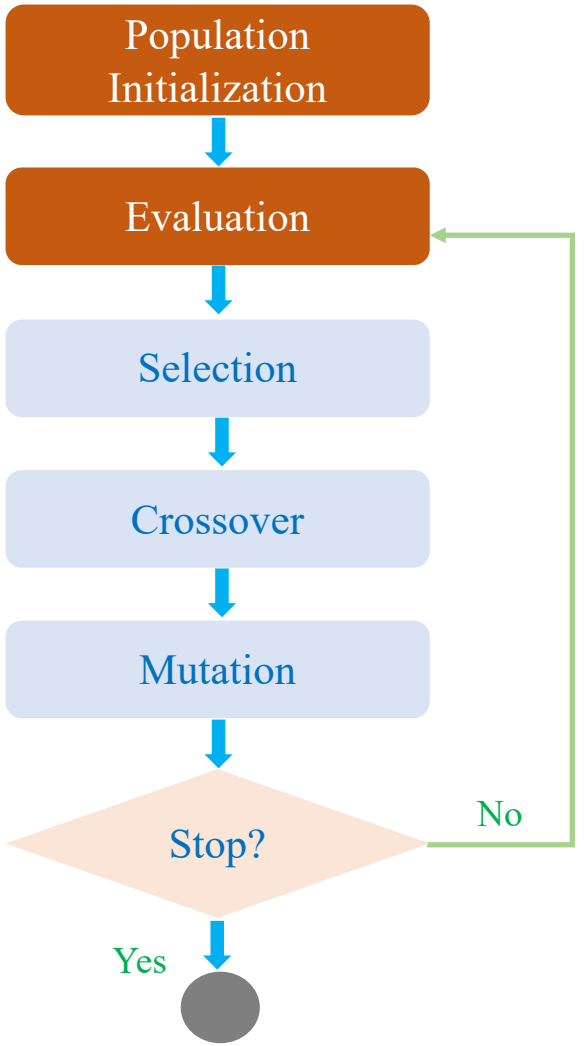


Genetic Algorithm

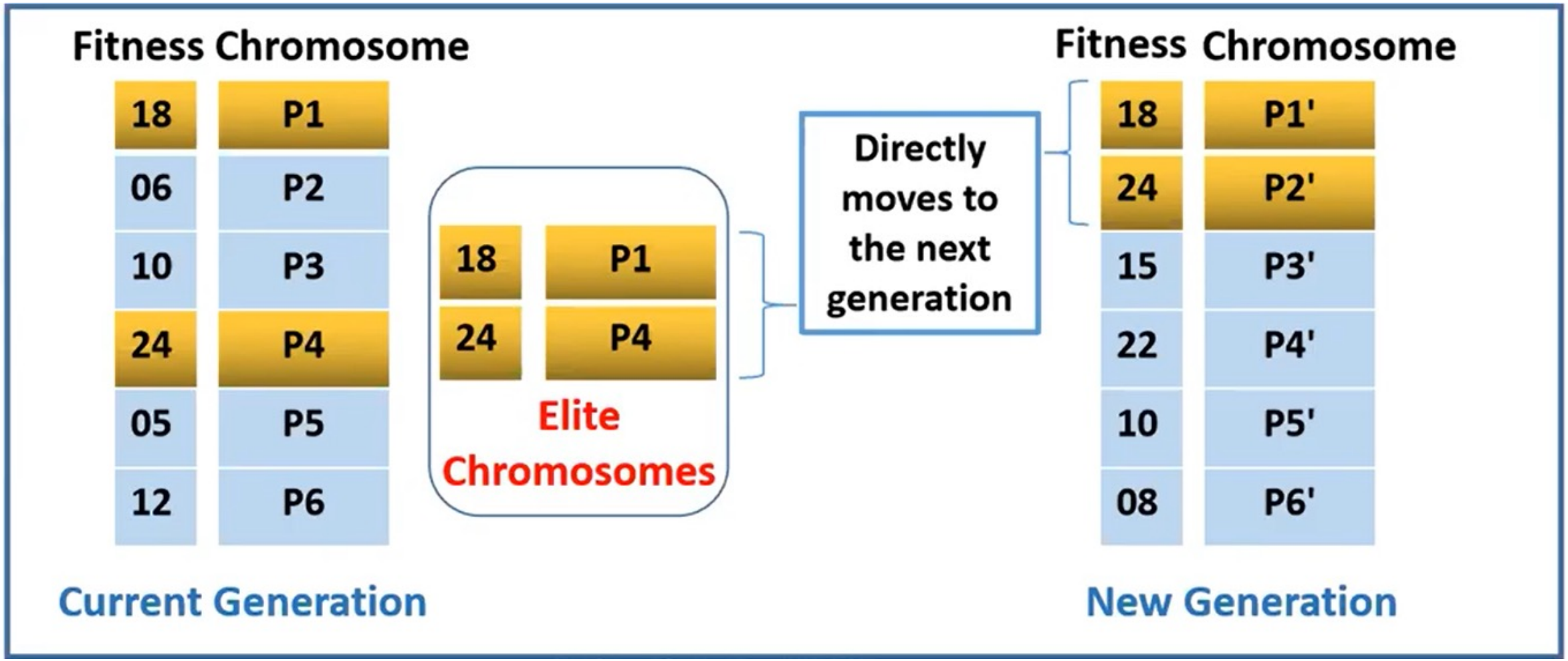
❖ **To solve the one-max problem**



Can you find any limitation?



Example of Elitism



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Genetic Algorithm

❖ Sphere function

$$f(x) = x_1^2 + x_2^2$$

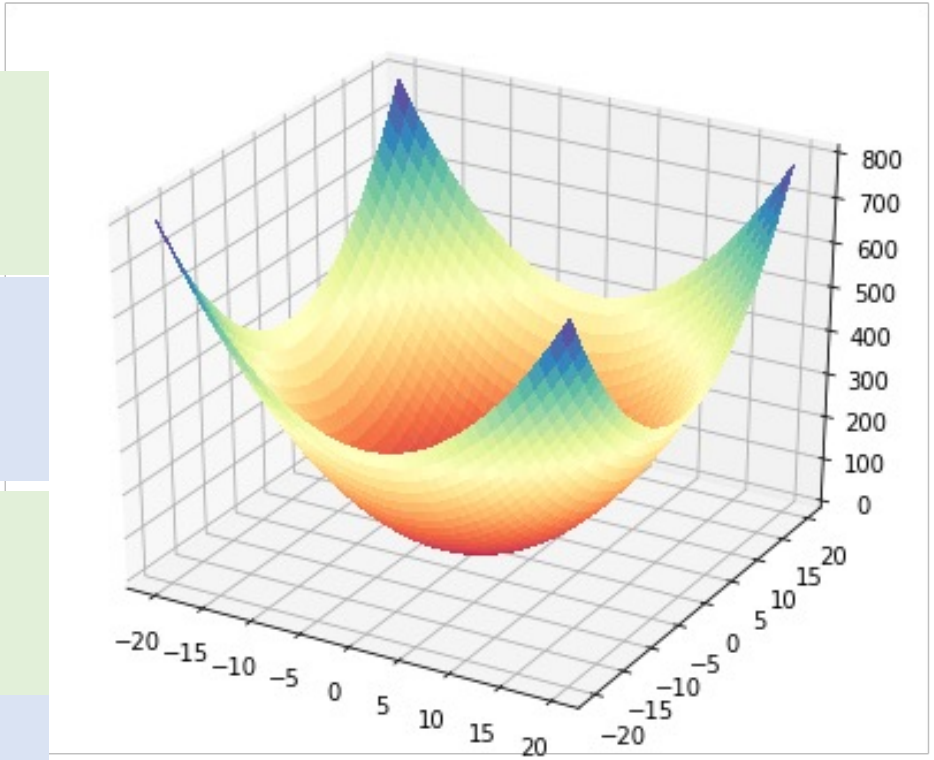
Các biến x_i có kiểu số tự nhiên và $x_i \in \mathbb{N}$.

Gen của chromosome được biểu diễn bằng kiểu integer.

Hàm f(x) có 2 biến. Do đó, độ dài của chromosome là 2 (n = 2).

fitness và accuracy

loss, error, và cost



Genetic Algorithm

			Cost
Cá thể 1	5	-2	29
Cá thể 2	-6	4	50
Cá thể 3	1	6	37
Cá thể 4	-3	-1	10
Cá thể 5	8	6	100
Cá thể 6	7	-2	53
Cá thể 7	0	5	25
Cá thể 8	9	-1	82
Cá thể 9	2	3	13
Cá thể 10	1	-3	10

			Cost
Cá thể 10	1	-3	10
Cá thể 4	-3	-1	10
Cá thể 9	2	3	13
Cá thể 7	0	5	25
Cá thể 1	5	-2	29
Cá thể 3	1	6	37
Cá thể 2	-6	4	50
Cá thể 6	7	-2	53
Cá thể 8	9	-1	82
Cá thể 5	8	6	100

			Cost
Cá thể 1	5	-2	29
Cá thể 2	-3	-1	10
Cá thể 3	1	6	37
Cá thể 4	-3	-1	10
Cá thể 5	1	-3	10
Cá thể 6	-6	4	50
Cá thể 7	0	5	25
Cá thể 8	0	5	25
Cá thể 9	2	3	13
Cá thể 10	1	-3	10

Genetic Algorithm

			Cost
Cá thể 1	5	-2	29
Cá thể 2	-3	-1	10
Cá thể 3	1	6	37
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Cá thể 5	1	-3	10
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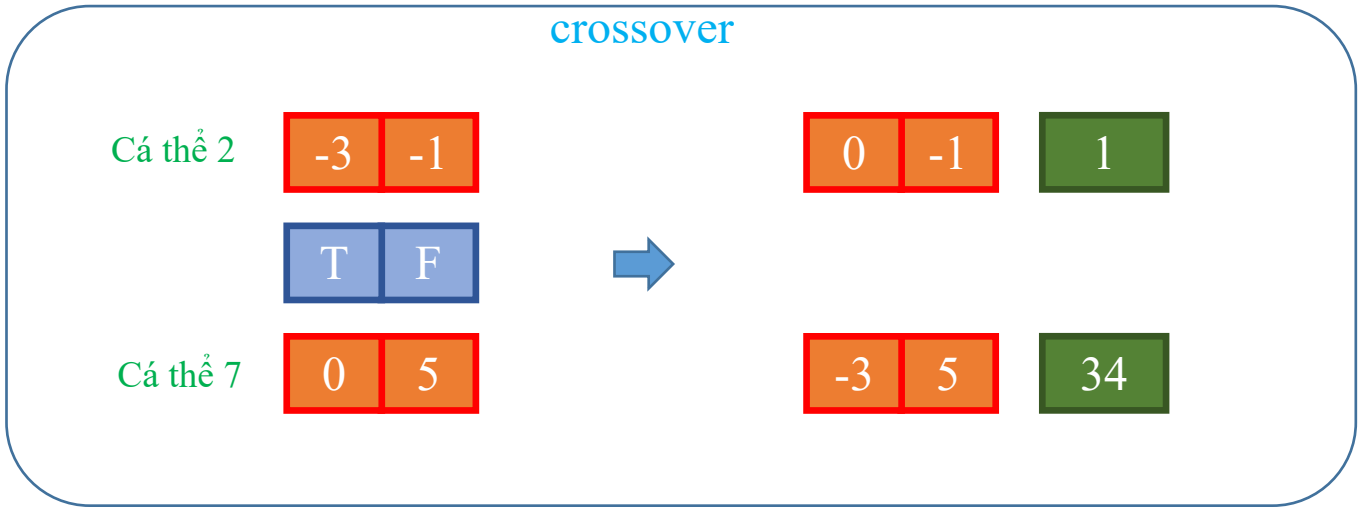
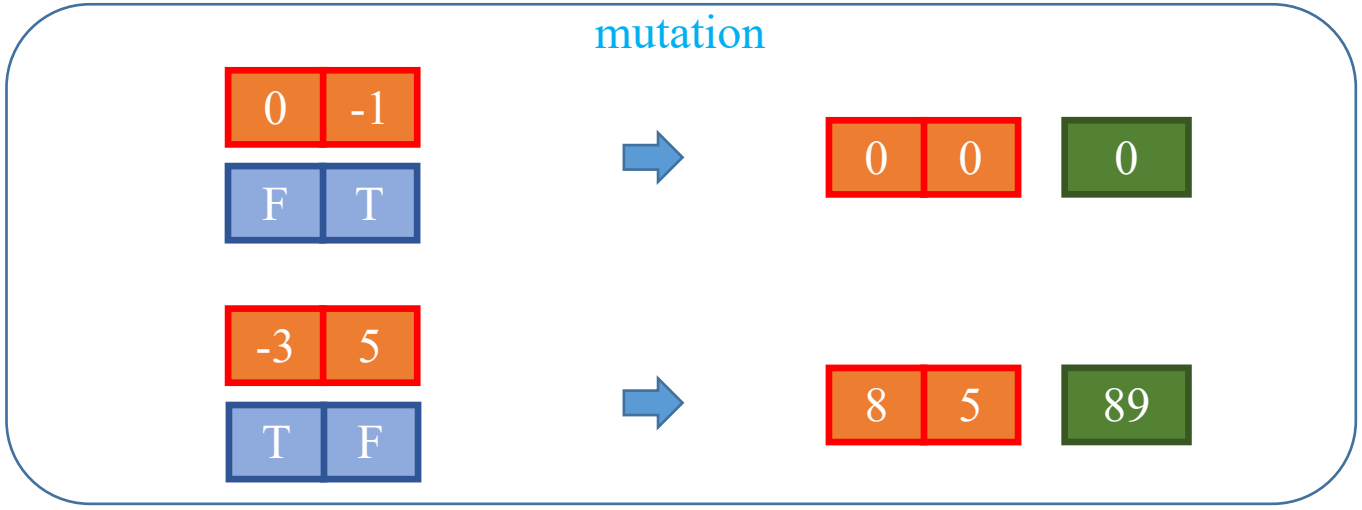
Cá thể 7	0	5	25
Cá thể 8	0	5	25
Cá thể 9	2	3	13
Cá thể 10	1	-3	10





Genetic Algorithm

❖ Sphere function

$$f(x) = x_1^2 + x_2^2 + x_3^2 + x_4^2 + x_5^2 + x_6^2$$

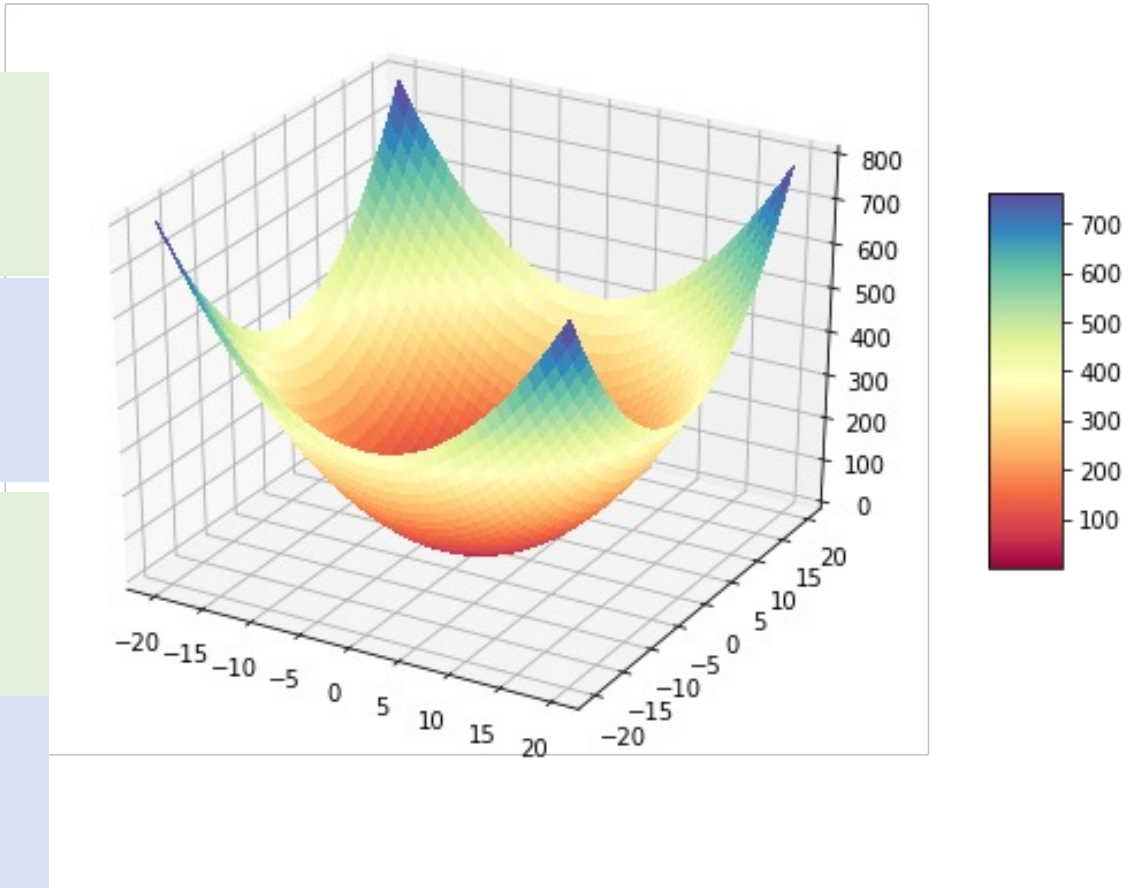
Do các biến x_i có kiểu số thực, nên số điểm trong không gian tìm kiếm là vô hạn.

Gen của chromosome được biểu diễn bằng kiểu floating-point.

Hàm f(x) có 6 biến. Do đó, độ dài của chromosome là 6 (n = 6).

fitness và accuracy

loss, error, và cost



Genetic Algorithm

❖ Sphere function

generate_random_value()

feasible values in [-20, 20]

```
def generate_random_value(bound = 20):
    return (random.random()*2 - 1)*bound
```

compute_fitness()

```
def compute_loss(individual):
    return sum(gen*gen for gen in individual)

def compute_fitness(individual):
    loss =  compute_loss(individual)
    fitness = 1 / (loss + 1)
    return fitness
```

```
def compute_loss(individual):
    return sum(gen*gen for gen in individual)

def compute_fitness(individual):
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    fitness = 1 / (loss + 1)
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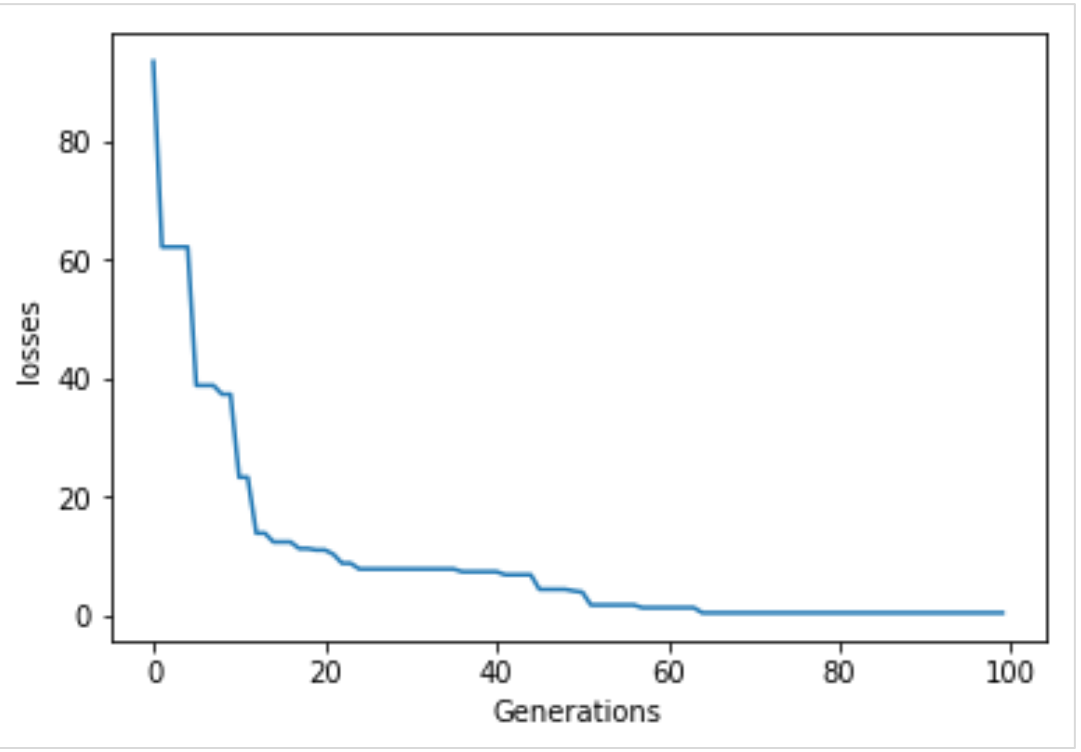


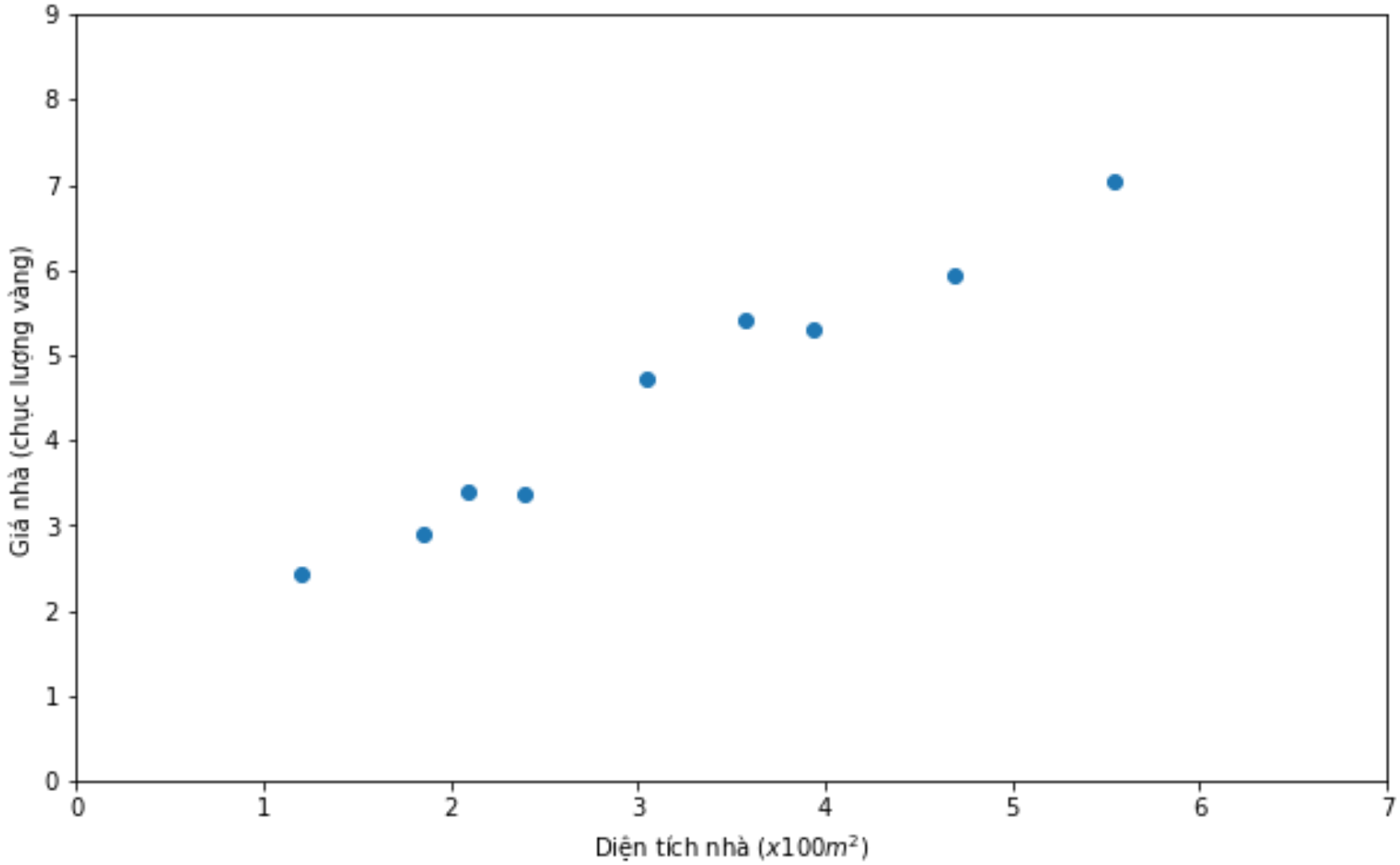
Outline

- Introduction to Evolutionary Algorithms
- Introduction to Genetic Algorithms
- One-Max Problem
- Sphere Function
- Regression Problem
- GA Applications

Genetic Algorithm

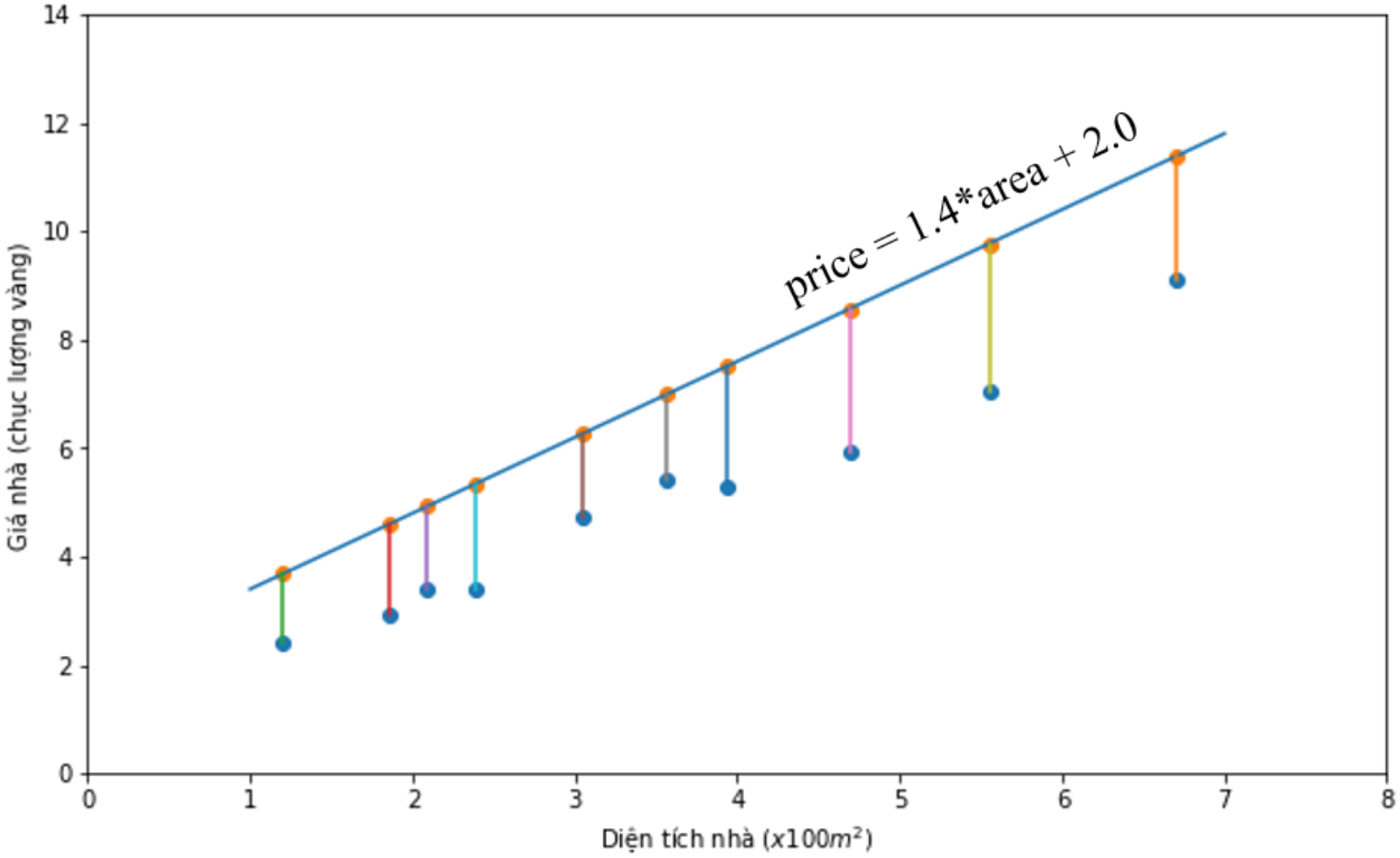
❖ House price prediction

area	price
6.71	9.12
1.2	2.43
1.86	2.91
2.09	3.41
3.05	4.71
4.69	5.94
3.57	5.4
5.55	7.04
2.39	3.38
3.94	5.29



Genetic Algorithm

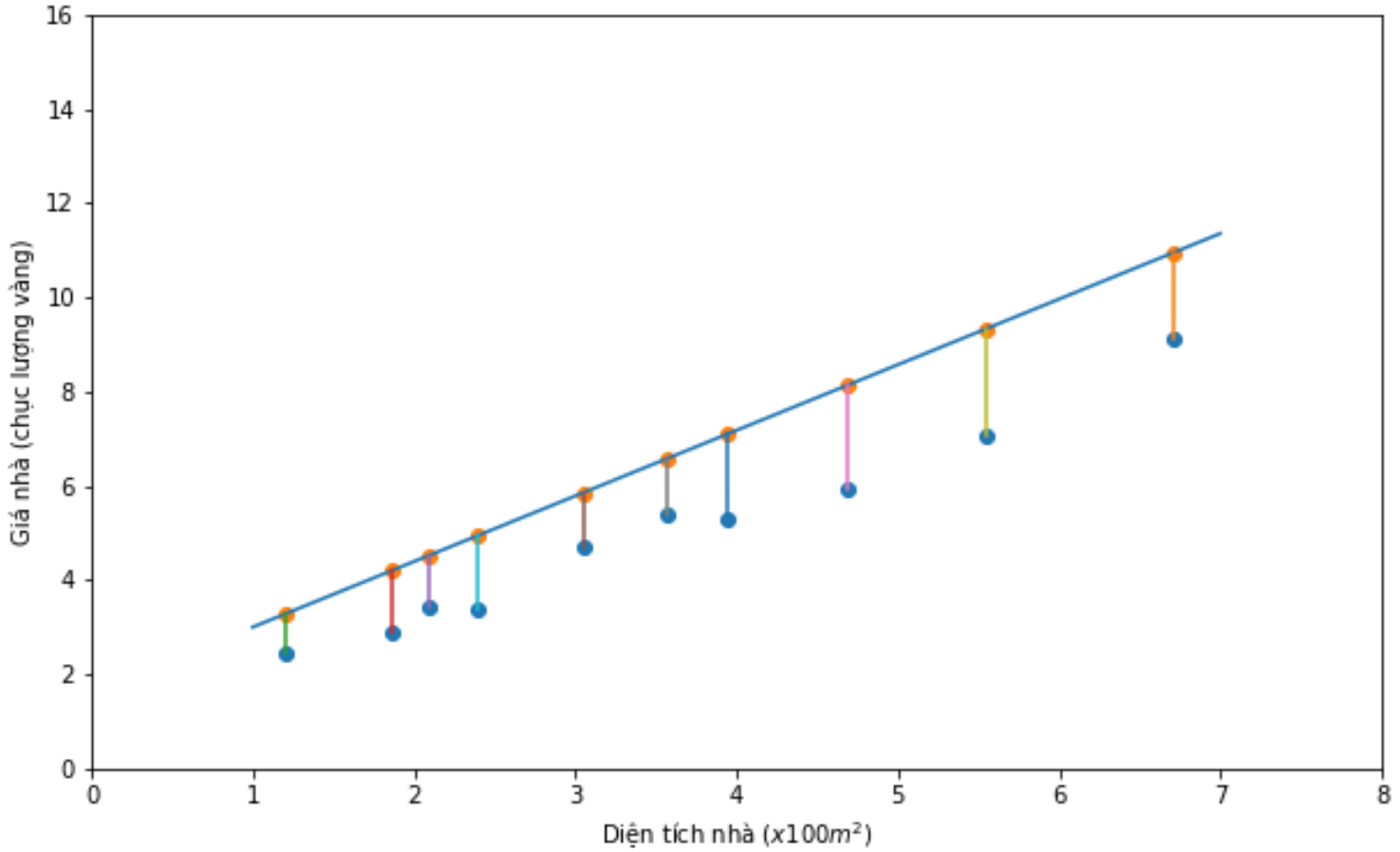
❖ House price prediction



Genetic Algorithm

❖ House price prediction

$$price = a * area + b$$



Genetic Algorithm

❖ House price prediction

area	price
6.71	9.12
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3.05	4.71
4.69	5.94
3.57	5.4
5.55	7.04
2.39	3.38
3.94	5.29

```
# Hàm load data
def load_data():
    # kết nối với file
    file = open('data.csv','r')

    # readlines giúp việc đọc file theo từng dòng , mỗi dòng là 1 chuỗi
    lines = file.readlines()

    areas  = []
    prices = []
    for i in range(10):
        string = lines[i].split(',')
        areas.append(float(string[0]))
        prices.append(float(string[1]))

    # Đóng kết nối với file
    file.close()

    return areas, prices
```

Genetic Algorithm

❖ House price prediction

```
def compute_loss(individual):
    result = 65534

    a = individual[0]
    b = individual[1]
    estimated_prices = [a*x + b for x in areas]

    # all prices should be positive numbers
    num_negetive_prices = sum(p < 0 for p in estimated_prices)
    if num_negetive_prices == 0:
        losses = [abs(y_est-y_gt) for y_est, y_gt in zip(estimated_prices, prices)]
        result = sum(losses)

    return result
```

Discussion

- Mutation
- Crossover
- Gene

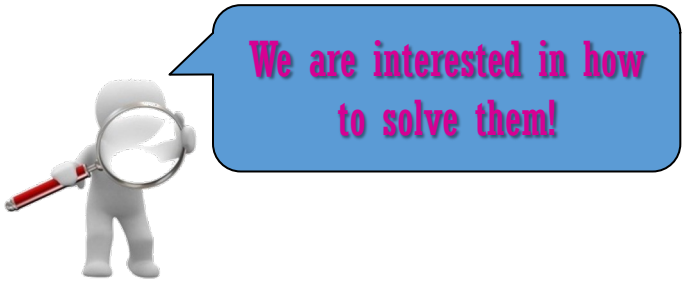
Outline

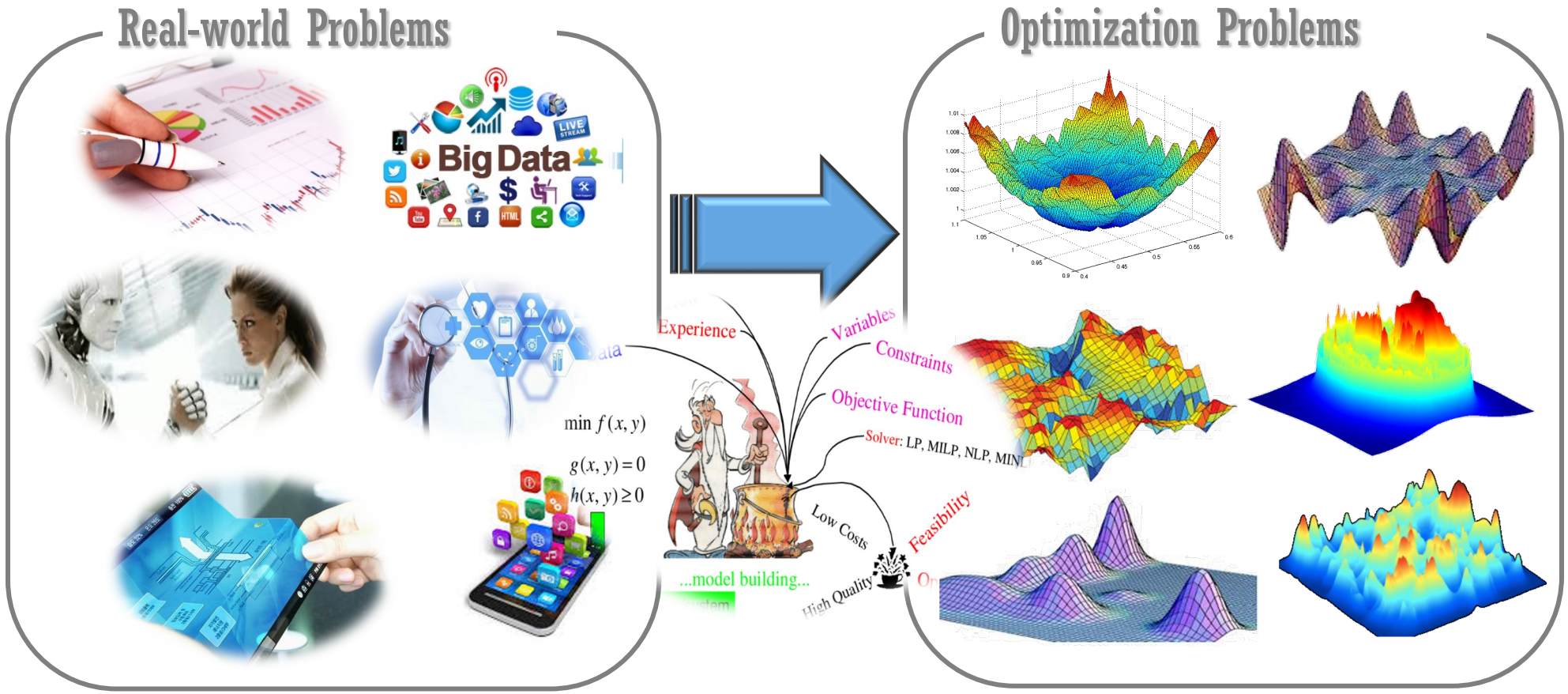
- Introduction to Evolutionary Algorithms
- Introduction to Genetic Algorithms
- One-Max Problem
- Sphere Function
- Regression Problem
- GA Applications

Applications

What is the Target of Interest?

- All the Problems in Any Field!
- That is, a sort of Optimization Problem!

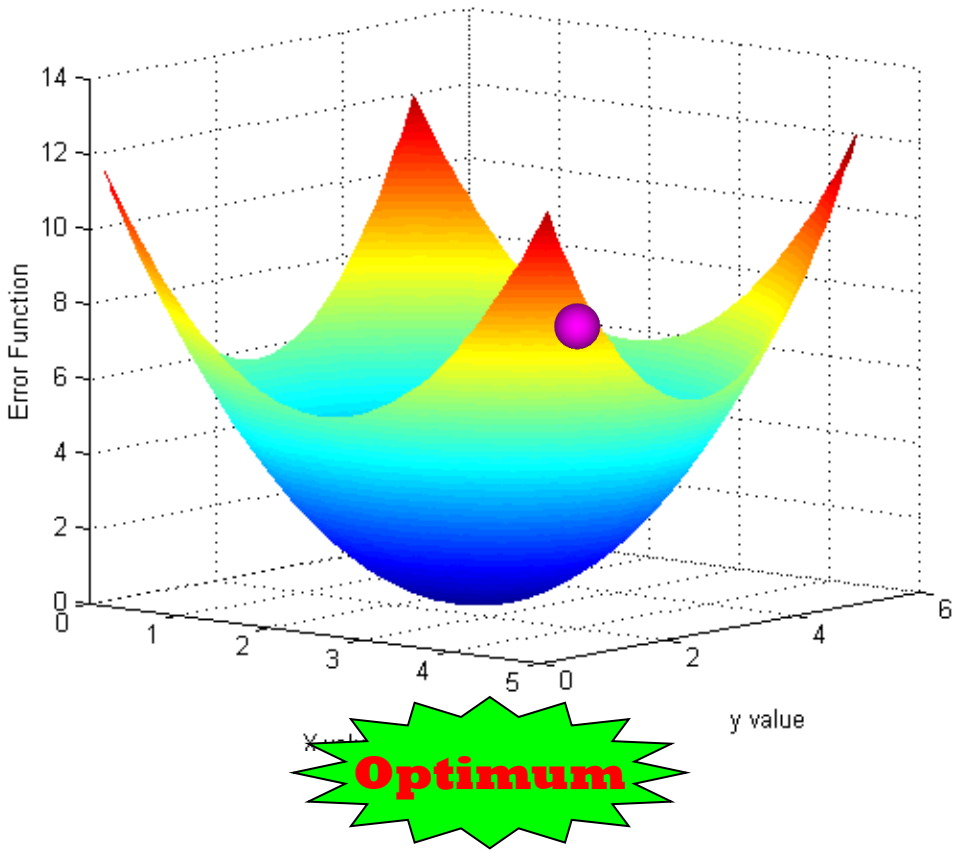




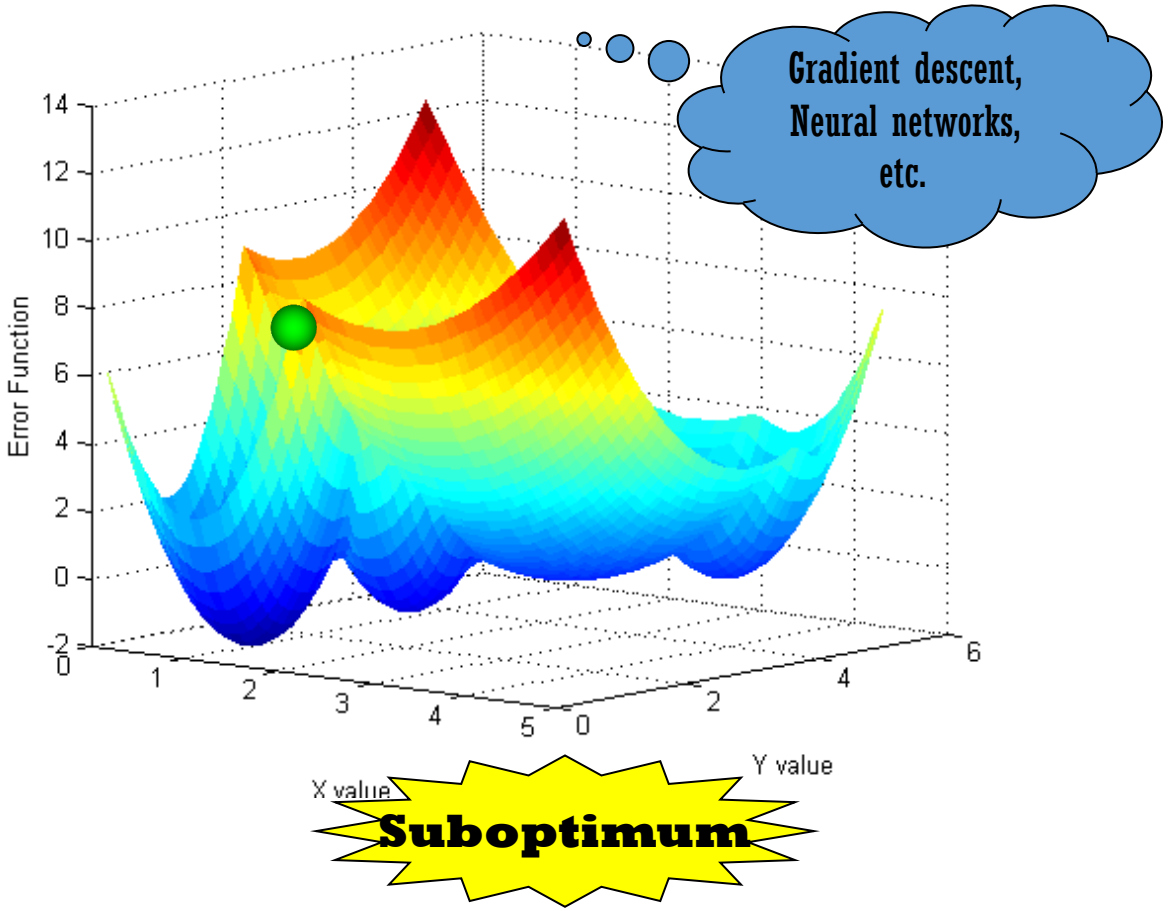
Applications

What's the Problem of Existing (Deterministic) Methods?

Single modal case

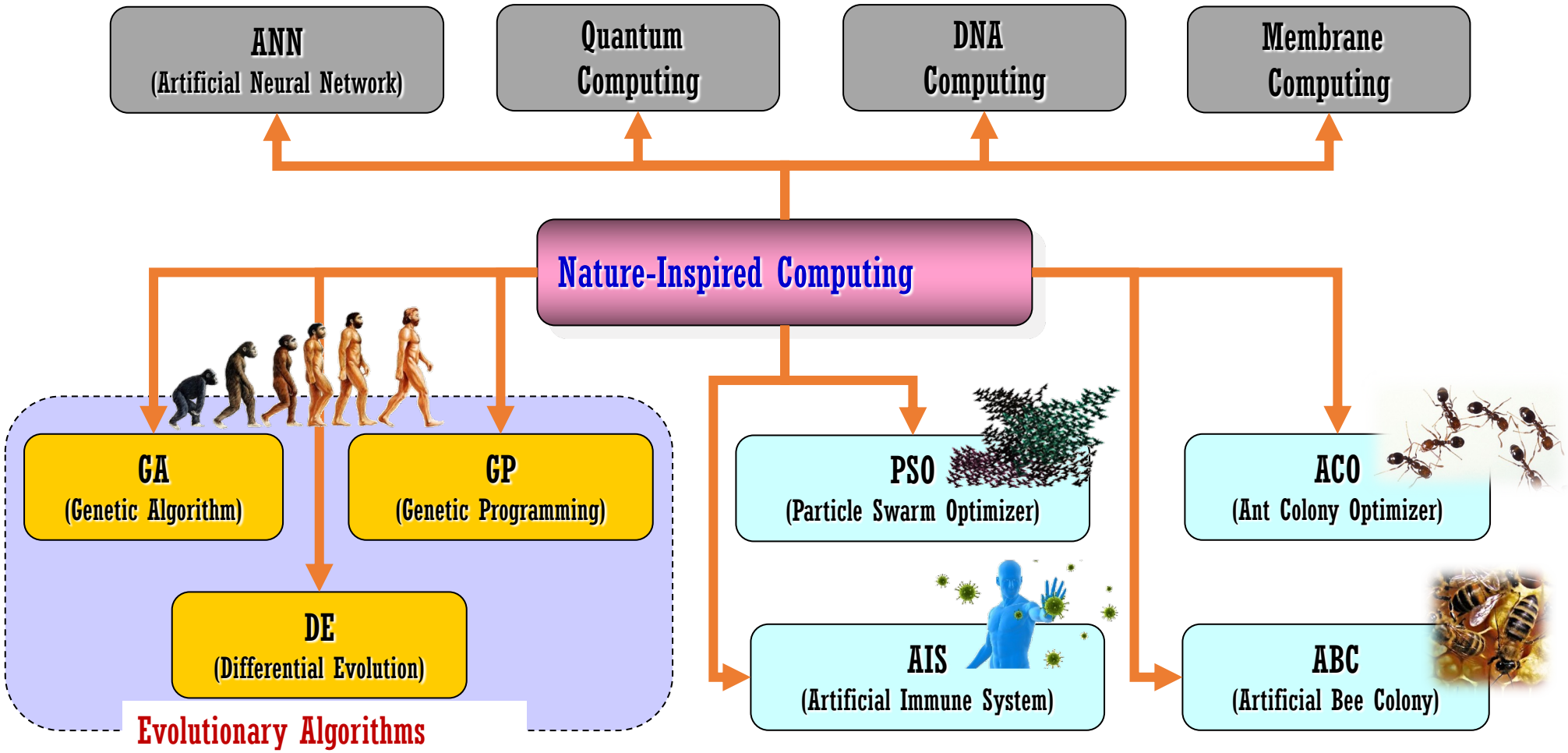


Multiple modal case



Applications

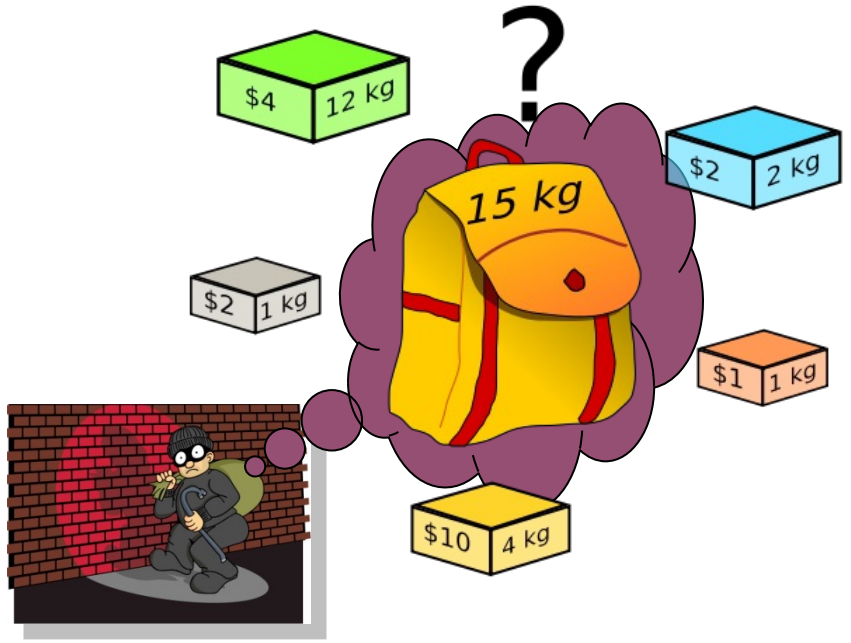
Nature-Inspired Computing (Algorithms): Examples



Applications

Traveling Salesman Problem

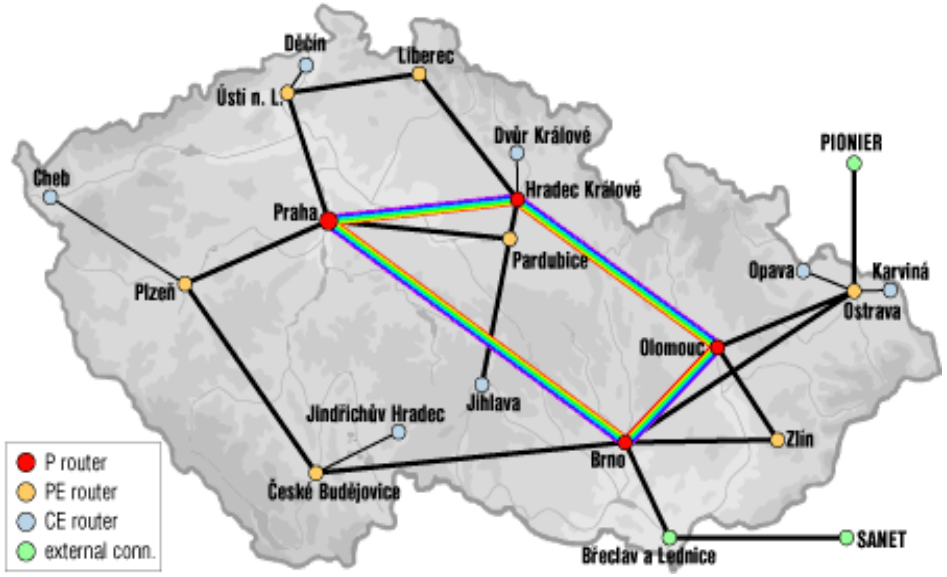
Knapsack Problem



- Maximize the amount of profits (e.g., money) while still keeping the overall weight under or equal to a given limit!

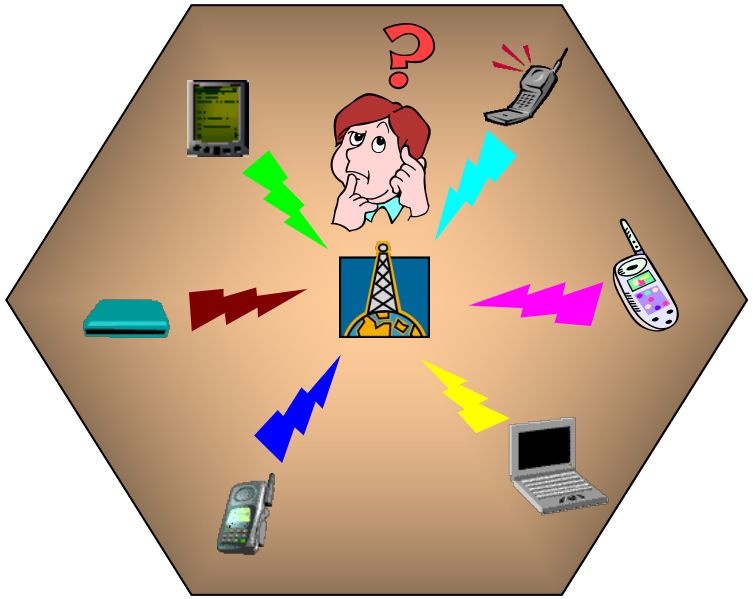
Applications

Multicast Routing



- Minimize the cost of multicast tree while satisfying delay and bandwidth constraints

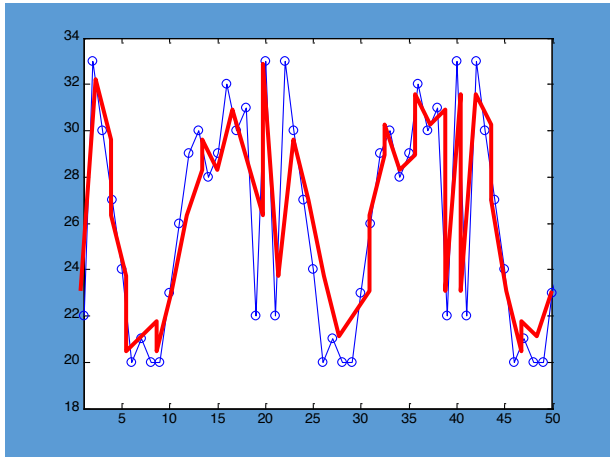
Resource Allocation



- Maximize resource utilization by fairly distributing wireless resources among the connections

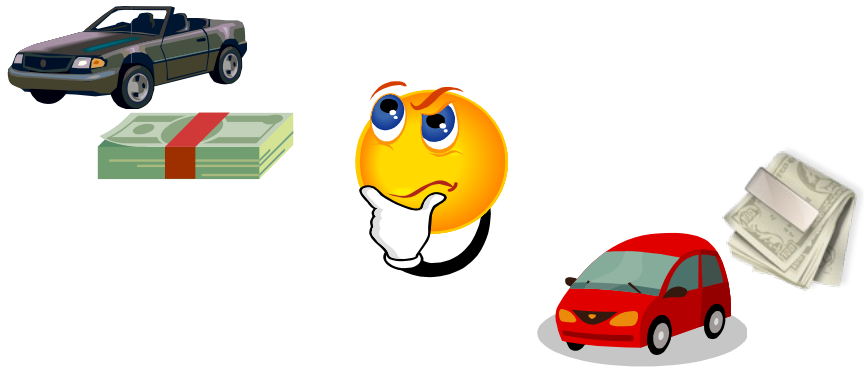
Applications

Time-Series Forecasting



- Predicting some future outcomes from a set of historical events
- Stock prediction, Weather forecasting, etc.

Decision in Dilemma

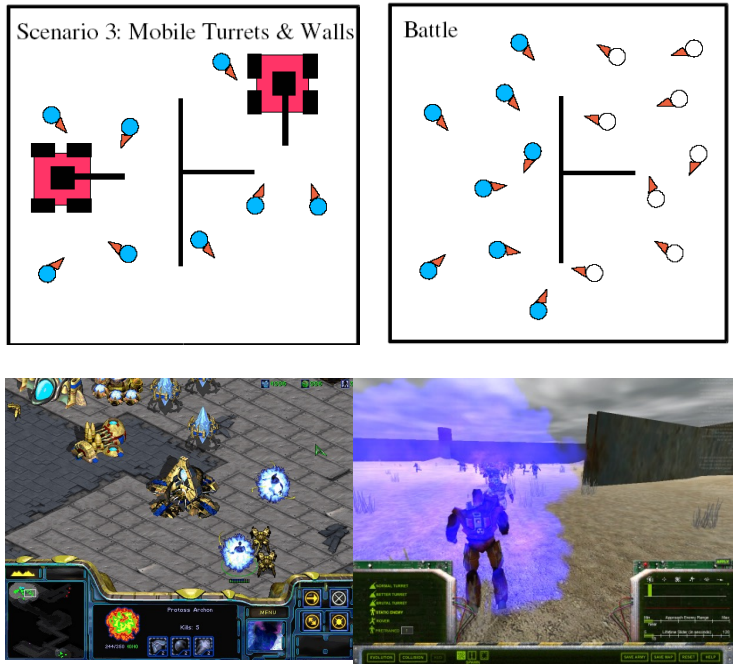


- Choosing a decision in conflict objectives
- Prisoner's dilemma, Game theory, etc.

Applications

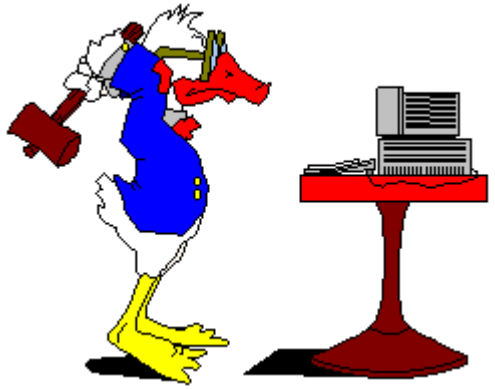
- **Evolutionary Checker**
  - 8X8 board, 12 checkers for each player
    - Diagonal moves, Jumps are forced, etc.
  - Neural Networks + Evolutionary Prog.
    - Checkerboards are evaluated by NNs
    - NNs and King value are evolved with EP
  - Almost the expert level without knowledge

- **Video Game: NERO**
  - Univ. of Texas at Austin
  - Player's role
    - Train agents for competition
  - No prepackaged or scripted agents
  - Evolve in real-time

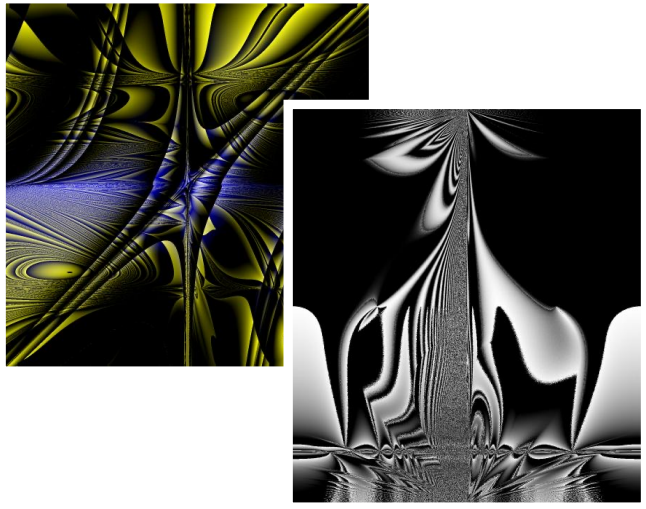


Applications

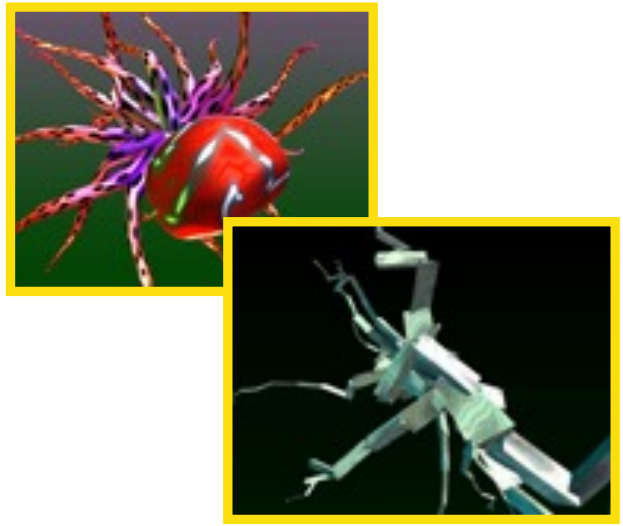
- **What's Evolutionary Art?**
  - Technically, it is creating pieces of art through human-computer interaction
  - Computer runs evolutionary algorithms and human applies subjective selection
    - Role of computers: offer choices and create diversity
    - Role of human: make (subjective) choices and reduce diversity
  - Selection (aesthetic/subjective) steers towards implicit user preferences



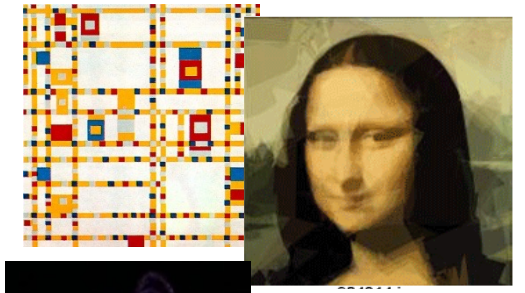
Evol. Art by Kleiweg

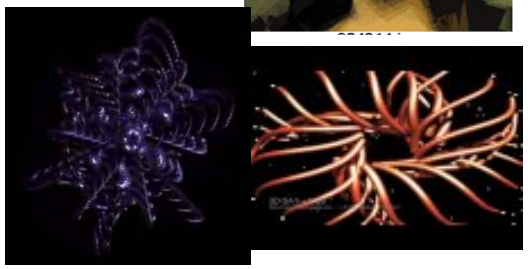


Galapagos by Karl Sims



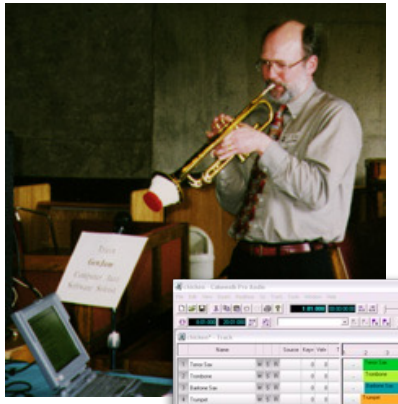
Other Examples





Applications

- **GenJam (Genetic Jammer)**
  - Developed in 1993~94 by Prof. John Al Biles
  - Interactive GA that learns to play jazz solos
  - GemJam's repertoire: Over 250 jazz-style tunes
  - Evolving by special fitness operators;
    e.g., rhythm conformity
  - What can it be done?
    - ✓ Playing full-chorus improvised solos
    - ✓ Listening to trumpet and responds interactively when we trade fours
    - ✓ Engaging in collective improvisation; we both solo simultaneously and GenJam performs a smart echo of improvisation
    - ✓ Listening to me and play the head of a tune and breeds my measures



Source:
http://www.it.rit.edu/~jab/GenJam.html

Source: http://phoenix.inf.upol.cz/~dostal/evm.html

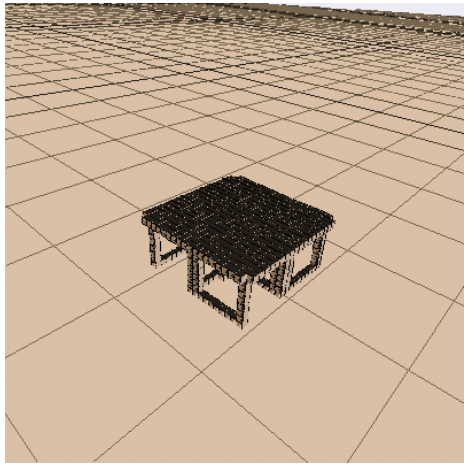
Virtual quintet

MusiGenesis

Applications

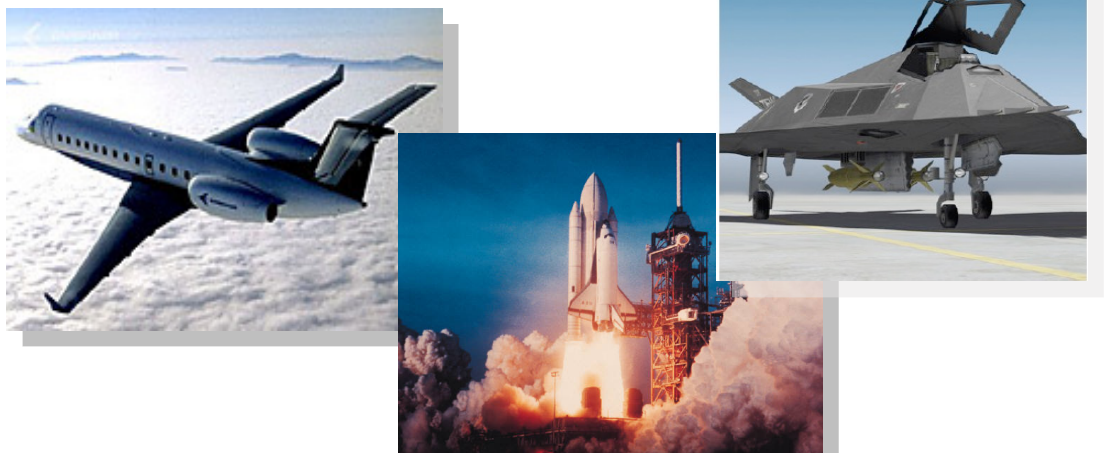
Structure Design

- Bridge structure optimization
- Building structure design



Aviation System Design

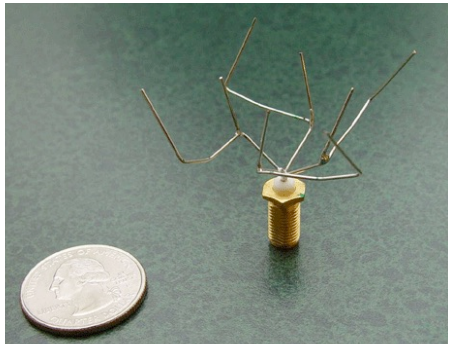
- Airfoil, wing, and antenna designs
- Space platform structure optimization
- Jet aircraft model optimization

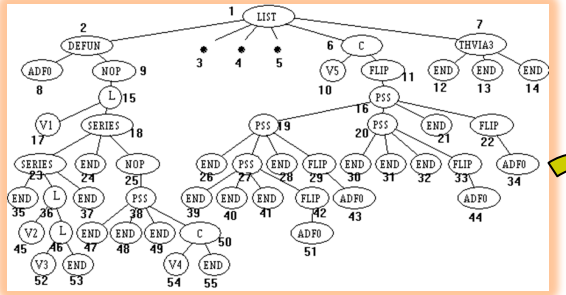


Circuit Design

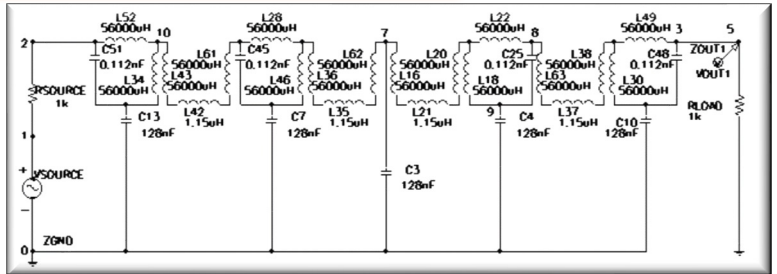
- Automatic synthesis of topology & sizing of analog electrical circuits

Evolved antenna (NASA, 2004)



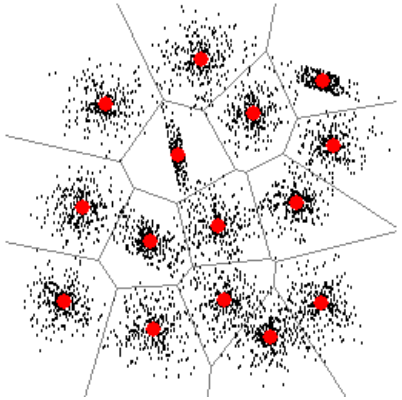


Lowpass filter

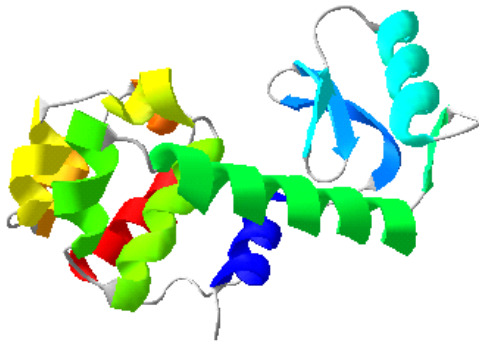


Applications

- **Clustering**
  - Data clustering
  - Text mining
  - Web search

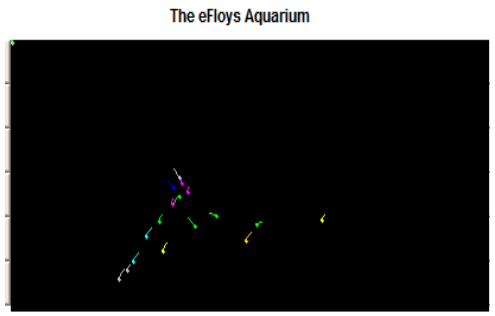


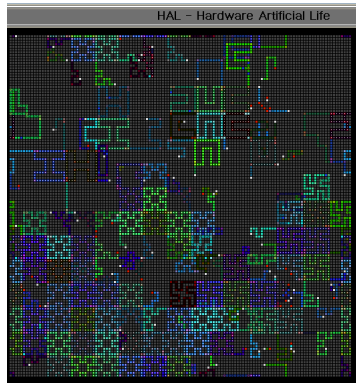
- **Bioinformatics**
  - Drug discovery
  - Protein folding
  - Cancer diagnosis

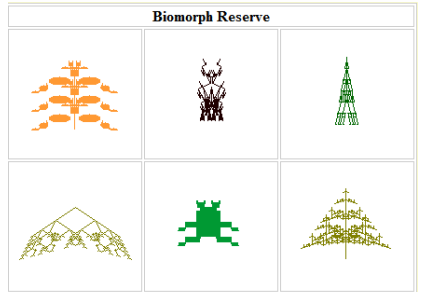


Applications

- **Artificial Creatures**
  - eFly, Biomorph, HAL,
  - Self-replicating Worms
  - Gozilla, Solitaire







- **Robotics**
  - Humanoid Robots; e.g., e.g., ASIMO
  - Genetic Robots; e.g., Gene
  - Others; e.g., Six-Legged Robot
    Robot Snake

Quiz and Feedback: https://forms.gle/HuuCo45NfQNuiW719