Computational Intelligence (CI)

Introduction to Genetic Algorithm

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Genetic Algorithm (GA)

- Genetic Algorithm is a population-based stochastic search and optimization technique.

- It is based on the principles of two fundamental biological processes:

    - **Genetics**
    - **Evolution/Natural Selection**

- It is also known as adaptive heuristic search.

- It was first introduced by prof. John Holland of Michigan University, USA (1965). But the first article on GA was published in 1975.

- Inspired by Darwin's theory about evolution

" Survival of the fittest"

Genetic Algorithm (GA)

- GA is a subset of much larger branch of computation known as Evolutionary Computing.

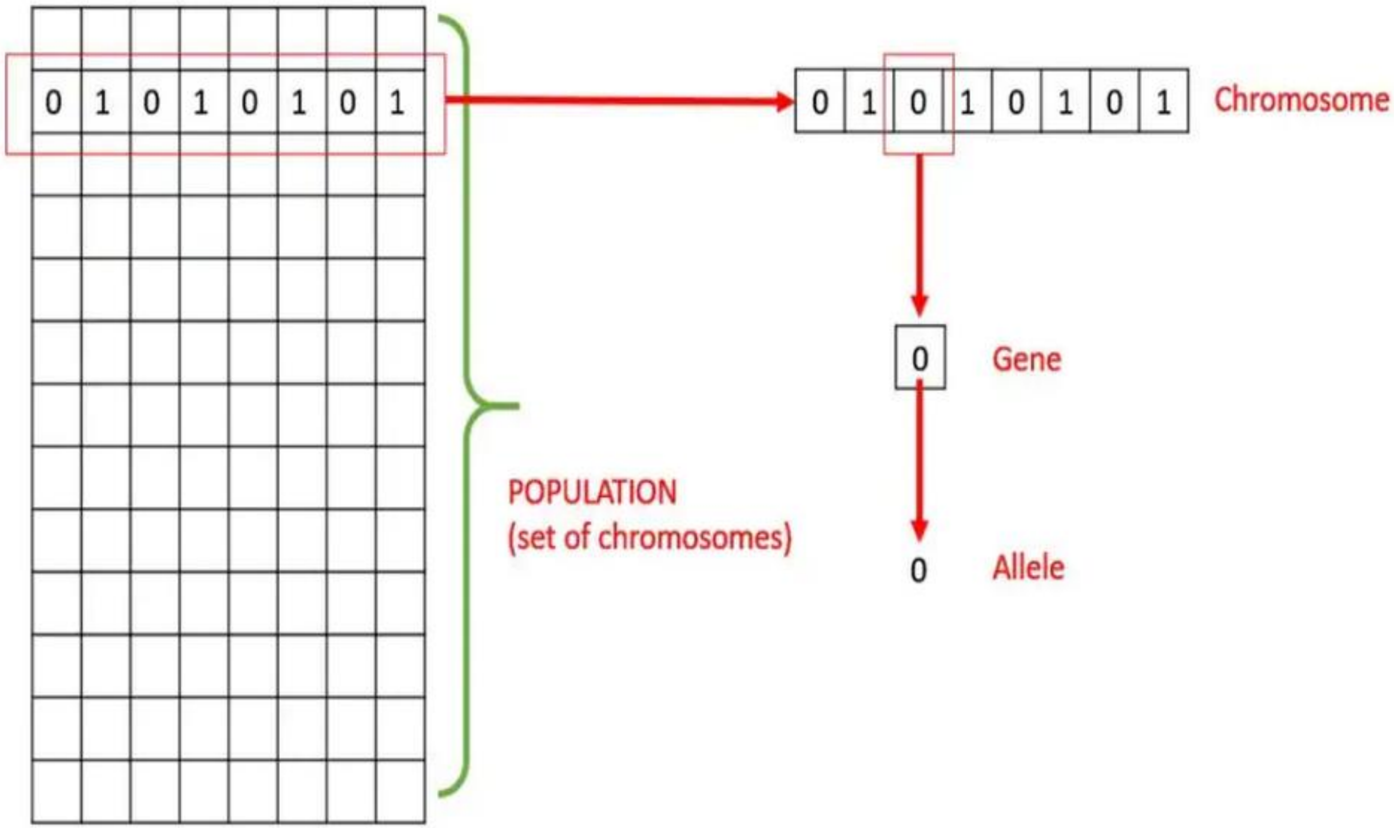
- It is frequently used to find optimal or near optimal solutions to NP Hard problem and problems which are very difficult to model mathematically.

- Can be used to solve a variety of problems that are not easy to solve using other techniques.

Biological Background: Genetics and Evolution

- All living organism consists of **cells**.
- Each cell of a living thing contains ***chromosomes*** - strings of *DNA(DeoxyriboNucleicAcid).*
- Each chromosome contains a set of ***genes*** - blocks of DNA.
- Each gene **encodes** a particular protein that represents a **trait**/feature(e.g eye colour)
- Possible settings for a **trait** (e.g. blue, brown) are called **alleles**.
- A collection of genes is sometimes called as ***genotype.***
- The physical expression of genotype (like eye colour, intelligence, etc.) is called ***phenotype.***

Biological Background: Genetics and Evolution



Biological Background: Genetics and Evolution

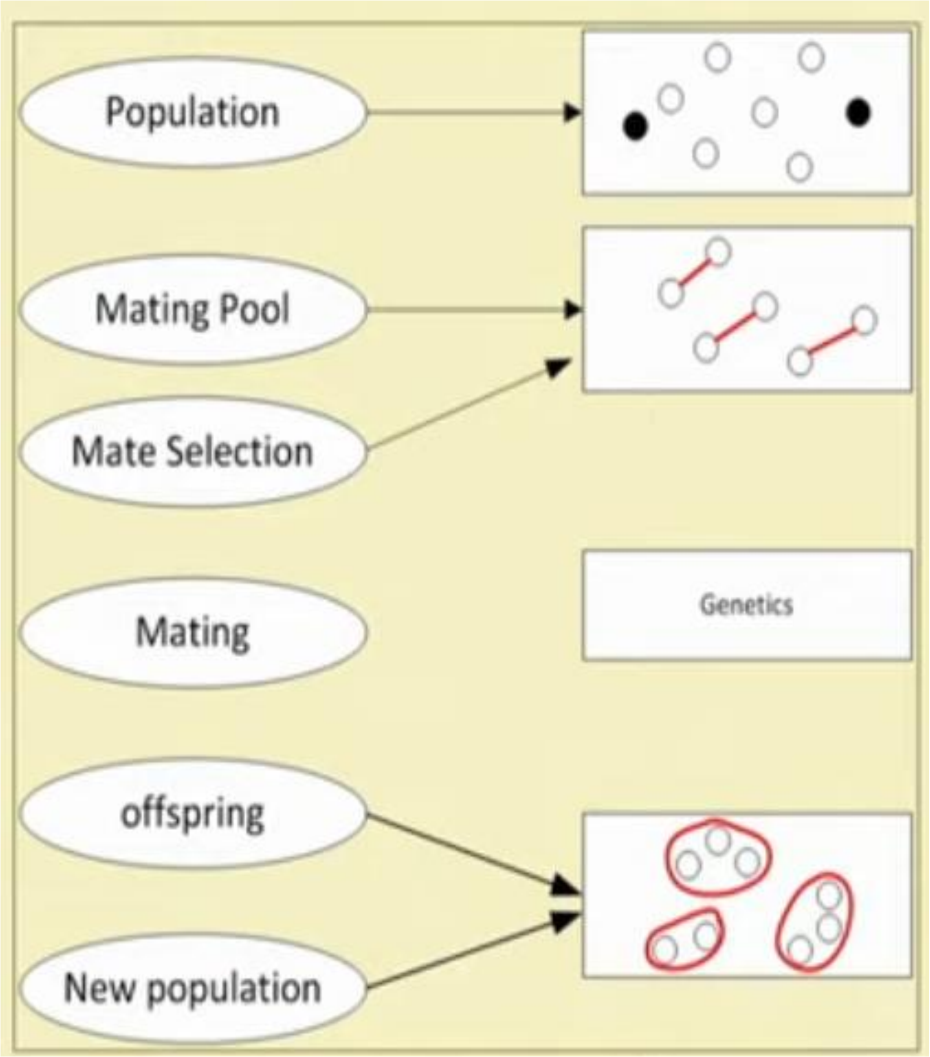
- **Reproduction** involves recombination (**cross over**) of genes from parents. When two organisms mate they share their genes; the resultant offspring may end up having half the genes from one parent and half from another.

- The new created offspring can then be mutated. **Mutation** means, that the elements of DNA are bit changed.

- The ***fitness*** of an organism is how much it can reproduce before it dies.

- Evolution is based on **"survival of the fittest"**

Biological Background: Genetics and Evolution

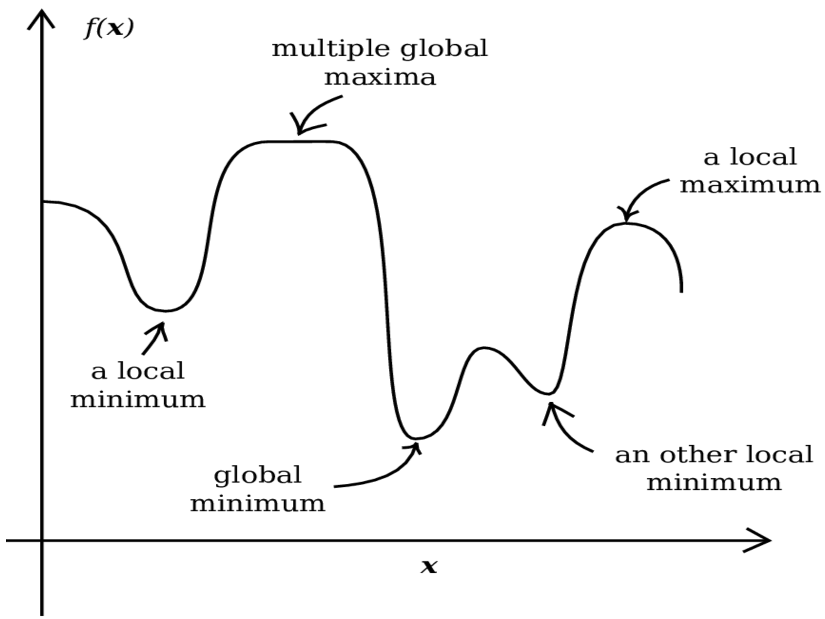


Simple GA

```
{
    initialize population;
    evaluate population;
    while TerminationCriteriaNotSatisfied
    {
        select parents for reproduction;
        perform crossover and mutation;
        evaluate population;
    }
}
```

Genetic Algorithm (GA)

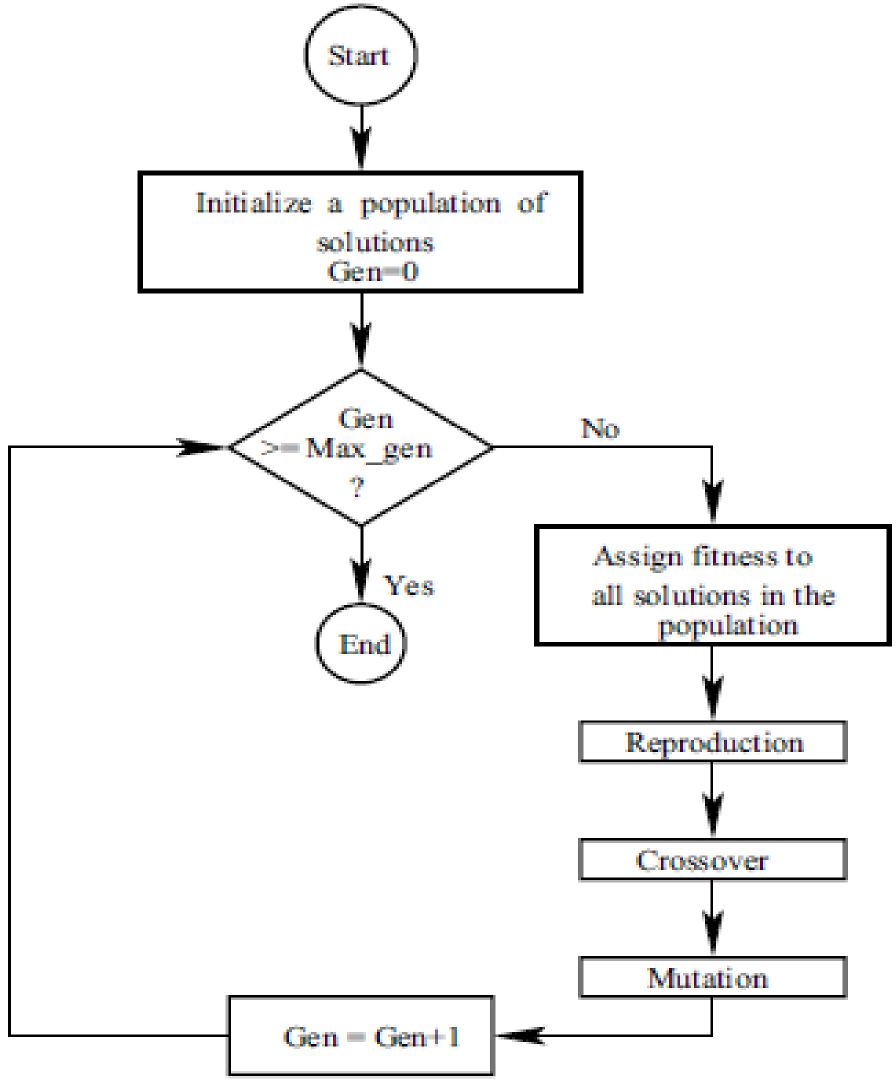
- GA is an iterative process and a searching technique.
- Each iteration is called a generation.
- A typical number of generations for a simple GA can range from 50 to over 500.
- The entire set of generations is called a run.
- Working cycle with/without convergence.
- Solution is not necessarily guaranteed. Usually, terminated with a local optima.



Components of a GA

- Encoding technique (*gene, chromosome*)
- Initialization procedure *(creation)*
- Evaluation function *(fitness function)*
- Selection of parents *(reproduction)*
- Genetic operators *(cross over, mutation)*
- Parameter settings *(crossover rate, mutation rate,…)*

Working Cycle of GA



Steps of Simple GA

Step 1: Represent the problem variable domain as a chromosome of a fixed length, choose the size of a chromosome population N, the crossover rate and the mutation probability/rate.

Step 2: Define a fitness function to measure the performance, or fitness, of an individual chromosome in the problem domain. The fitness function establishes the basis for selecting chromosomes that will be mated during reproduction.

Step 3: Randomly generate an initial population of chromosomes of size N:

x1, x2 , . . . , xN

Step 4: Calculate the fitness of each individual chromosome:

f (x1), f (x2), . . . , f (xN)

Step 5: Select a pair of chromosomes for mating from the current population. Parent chromosomes are selected with a probability related to their fitness.

Steps of Simple GA

Step 6: Create a pair of offspring chromosomes by applying the genetic operators - crossover and mutation.

Step 7: Place the created offspring chromosomes in the new population.

Step 8: Repeat **Step 5** until the size of the new chromosome population becomes equal to the size of the initial population, N.

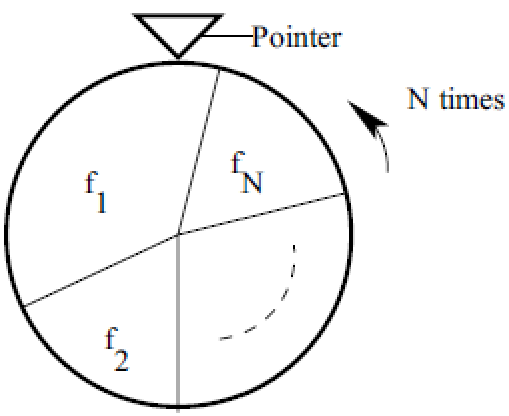
Step 9: Replace the initial (parent) chromosome population with the new (offspring) population.

Step 10: Go to **Step 4**, and repeat the process until the termination criterion is satisfied.

SGA operators: Selection/Reproduction

Roulette wheel Selection/ Proportionate Selection :

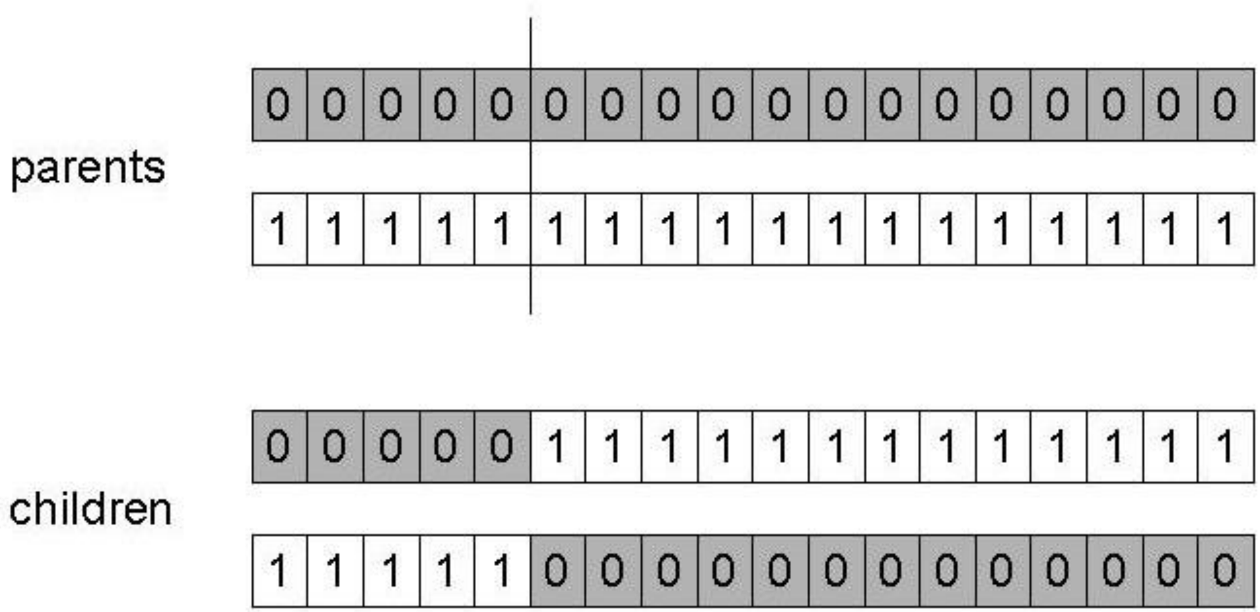
- Main idea: better individuals get higher chance
- The probability of an individual selected in the mating pool is proportional to its fitness.
- Assign to each individual a part of the roulette wheel.
- Spin the wheel n times to select N individuals.



$$p = \frac{f_i}{\sum_{i=1}^{N} f_i}.$$

SGA operators: Crossover (1-point)

- Choose a random point on the two parents
- Split parents at this crossover point
- Create children/offspring by exchanging tails
- P_c typically in range (0.6, 0.9)



SGA operators: Mutation

- Alter each gene independently with a probability p_m
- p_m is called the mutation rate
  Typically between 1/pop_size and 1/ chromosome_length

parent	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
child	0	1	0	0	1	0	1	1	0	0	0	1	0	1	1	0	0	1

An example: Binary Coded GA (By Goldberg)

- Simple problem: max x^2 over {0,1,…,31}
- GA approach:
  - Representation: binary code, e.g. 01101 $\leftrightarrow$ 13
  - Population size: 4
  - 1-point crossover, bitwise mutation
  - Roulette wheel selection
  - Random initialization
- We show one generational cycle done by hand

x^2 example: selection

String no.	Initial population	x Value	Fitness $f(x) = x^2$	$Prob_i$	Expected count	Actual count
1	0 1 1 0 1	13	169	0.14	0.58	1
2	1 1 0 0 0	24	576	0.49	1.97	2
3	0 1 0 0 0	8	64	0.06	0.22	0
4	1 0 0 1 1	19	361	0.31	1.23	1
Sum			1170	1.00	4.00	4
Average			293	0.25	1.00	1
Max			576	0.49	1.97	2

$$prob_i = \frac{f_i}{\sum f} \qquad Expected\ count \quad E_i = \frac{f_i}{\bar{f}}$$

We may use another formula

$$E_i = N * prob_i$$

X^2 example: crossover

String no.	Mating pool	Crossover point	Offspring after xover	x Value	Fitness $f(x) = x^2$
1	0 1 1 0 | 1	4	0 1 1 0 0	12	144
2	1 1 0 0 | 0	4	1 1 0 0 1	25	625
2	1 1 | 0 0 0	2	1 1 0 1 1	27	729
4	1 0 | 0 1 1	2	1 0 0 0 0	16	256
Sum					1754
Average					439
Max					729

X^2 example: Mutation

String no.	Offspring after xover	Offspring after mutation	x Value	Fitness $f(x) = x^2$
1	0 1 1 0 0	$\boxed{1}$ 1 1 0 0	26	676
2	1 1 0 0 1	1 1 0 0 1	25	625
2	1 1 0 1 1	1 1 0 1 1	27	729
4	1 0 0 0 0	1 0 $\boxed{1}$ 0 0	18	324
Sum				2354
Average				588.5
Max				729


Each of your
actions will
have an
impact on your
future.


Once you know
who is walking
with you on your path.
you will never
be afraid.

Thank you