Unit III - GENETIC ALGORITHM

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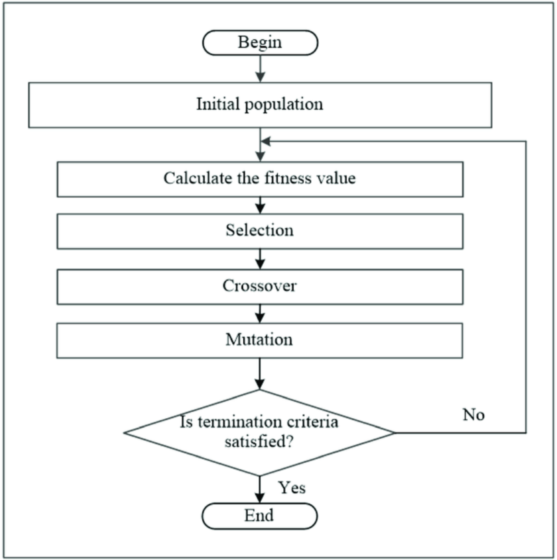
Contents


Begin
Initial population
Calculate the fitness value
Selection
Crossover
Mutation
Is termination criteria satisfied?
No
Yes
End

Main features of Genetic Algorithms (GA)

Genetic Algorithms (GA) use principles of natural evolution. There are five important features of GA:

- **Encoding :** possible solutions of a problem are considered as individuals in a population. If the solutions can be divided into a series of small steps (building blocks), then these steps are represented by genes and a series of genes (a chromosome) will encode the whole solution. This way different solutions of a problem are represented in GA as chromosomes of individuals.
- **Fitness Function** represents the main requirements of the desired solution of a problem (i.e. cheapest price, shortest route, most compact arrangement, etc). This function calculates and returns the fitness of an individual solution.
- **Selection operator** defines the way individuals in the current population are selected for reproduction. There are many strategies for that (e.g. roulette–wheel, ranked, tournament selection, etc), but usually the individuals which are more fit are selected.
- **Crossover operator** defines how parents' chromosomes are mixed to obtain genetic codes of their offspring (e.g. one–point, two–point, uniform crossover, etc). This operator implements the inheritance property (offspring inherit genes of their parents).
- **Mutation operator** creates random changes in genetic codes of the offspring. This operator is needed to bring some random diversity into the genetic code. In some cases GA cannot find the optimal solution without mutation operator (local maximum problem).

```
Algorithm GA(Population,Fitness_Function)
repeat
    new_population :=   ;
    for i in 1 to size(Population) do
        Parent1 := SELECT-OPR(Population,Fitness_Function) ;
        Parent2 := SELECT-OPR(Population,Fitness_Function) ;
        Child := CROSSOVER(Parent1, Parent2) ;
        if P_c less than limit_probability then
            Child := MUTATION(Child) ;
        new_population.add(Child) ;
    Population := new_population ;
until some individual is fit enough, or total generation reached;
return the best individual in the Population, according to Fitness_Function
```

Definition:

- Parent selection is the process of selecting parents for mating and recombination to create offspring for the next generation.
- Crucial for the convergence rate of the Genetic Algorithm (GA).

Considerations:

- Prevent premature convergence, where one fit solution takes over the population, leading to reduced diversity.
- Maintain diversity to ensure the success of the GA.

Overview:

- A popular method in genetic algorithms for selecting parents based on their fitness.
- The probability of selection is proportional to the individual's fitness.

Algorithm Steps:

1. Calculate S as the sum of all fitness values in the population.
2. Generate a random number r between 0 and S.
3. Starting from the top of the population, add the fitness values sequentially to a partial sum P until $P < S$.
4. The individual for which P exceeds r is the chosen parent.

Explanation:

- This method ensures that individuals with higher fitness values have a higher probability of being selected.
- The process simulates the rotation of a wheel where fitter individuals have larger sections.

Tournament Selection

Method:

- Select K individuals at random from the population.
- Choose the best individual from this group as a parent.
- Repeat for the next parent.

Advantages:

- Can work with negative fitness values.
- Provides more flexibility in parent selection.

Rank Selection

Overview:

- Individuals are ranked based on fitness.
- Parent selection depends on rank rather than fitness.
- Ensures higher-ranked individuals have a better chance of selection.

Use Case:

- Useful when individuals have very close fitness values, reducing selection pressure.

Method:

- Parents are randomly selected from the population.

Considerations:

- No selection pressure towards fitter individuals.
- Generally avoided due to lack of emphasis on fitter individuals.

Definition:

- The crossover operator in genetic algorithms is analogous to reproduction and biological crossover.
- More than one parent is selected, and one or more off-springs are produced using the genetic material of the parents.

Key Point:

- Crossover is usually applied in a GA with a high probability p_c.

Commonly Used Crossover Operators:

- **One Point Crossover:** A random crossover point is selected, and the tails of the two parents are swapped to produce new off-springs.
- **Multi Point Crossover:** A generalization of the one-point crossover where alternating segments are swapped to produce new off-springs.
- **Uniform Crossover:** Each gene is treated separately, flipping a coin to decide which parent's gene is included in the offspring. A bias can be applied to favor one parent.

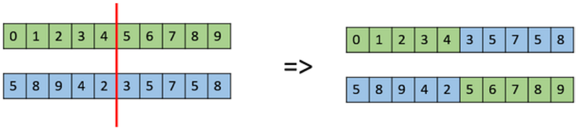


Figure 1: One Point Crossover

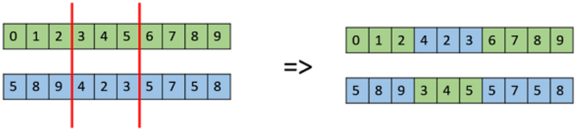


Figure 2: Multi Point Crossover

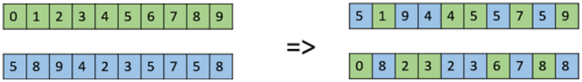


Figure 3: Uniform Crossover

Example

Suppose a genetic algorithm uses chromosomes of the form x = abcdefgh with a fixed length of eight genes. Each gene can be any digit between 0 and 9. Let the fitness of individual x be calculated as:
$f(x) = (a + b)(c + d) + (e + f)(g + h)$
and let the initial population consist of four individuals with the following chromosomes: $x1 = 65413532$, $x2 = 87126601$, $x3 = 23921285$, $x4 = 41852094$

- Evaluate each individual's fitness, showing all your workings, and arrange them in order with the fittest first and the least fit last.
- Perform the following crossover operations:
  - Cross the fittest two individuals using one–point crossover at the middle point.
  - Cross the second and third fittest individuals using a two-point crossover (points b and f).
  - Cross the first and third fittest individuals (ranked 1st and 3rd) using a uniform crossover.
- Suppose the new population consists of the six offspring individuals received by the crossover operations in the above question. Evaluate the fitness of the new population, showing all your workings. Has the overall fitness improved?

a. Fitness Evaluation Calculations:

$$f(x_1) = (6+5) - (4+1) + (3+5) - (3+2) = 9$$

$$f(x_2) = (8+7) - (1+2) + (6+6) - (0+1) = 23$$
$$f(x_3) = (2+3) - (9+2) + (1+2) - (8+5) = -16$$
$$f(x_4) = (4+1) - (8+5) + (2+0) - (9+4) = -19$$

Order of Fitness:

$$\text{The order is } x_2, x_1, x_3, \text{ and } x_4.$$

b) Perform the following crossover operations:

1. **Cross the fittest two individuals using one-point crossover at the middle point.**
   Answer: One-point crossover on x_2 and x_1:

$$x_2 = 8712 \mid 6601 \quad x_1 = 6541 \mid 3532 \quad \Rightarrow \quad O_1 = 87123532, \quad O_2 = 65416601$$

2. **Cross the second and third fittest individuals using a two-point crossover (points b and f).**
   Answer: Two-point crossover on x_1 and x_3:

$$x_1 = 65 \mid 4135 \mid 32 \quad x_3 = 23 \mid 9212 \mid 85 \quad \Rightarrow \quad O_3 = 65921232, \quad O_4 = 23413585$$

3. **Cross the first and third fittest individuals using uniform crossover.**
   Answer: Uniform crossover on x_2 and x_3:
   In the simplest case, uniform crossover involves a random exchange of genes between two parents. For example, swapping genes at positions a, d, and f:

$$x_2 = 87126601 \quad x_3 = 23921285 \quad \Rightarrow \quad O_5 = 27126201, \quad O_6 = 83921685$$

c. New Population and Fitness Evaluation:

- $O_1 = 87123532$
- $O_2 = 65416601$
- $O_3 = 65921232$
- $O_4 = 23413585$
- $O_5 = 27126201$
- $O_6 = 83921685$

Applying the fitness function $f(x) = (a + b) - (c + d) + (e + f) - (g + h)$**:**

$$f(O_1) = (8 + 7) - (1 + 2) + (3 + 5) - (3 + 2) = 15$$

$$f(O_2) = (6 + 5) - (4 + 1) + (6 + 6) - (0 + 1) = 17$$

$$f(O_3) = (6 + 5) - (9 + 2) + (1 + 2) - (3 + 2) = -2$$

$$f(O_4) = (2 + 3) - (4 + 1) + (3 + 5) - (8 + 5) = -5$$

$$f(O_5) = (2 + 7) - (1 + 2) + (6 + 2) - (0 + 1) = 13$$

$$f(O_6) = (8 + 3) - (9 + 2) + (1 + 6) - (8 + 5) = -6$$

Conclusion: The overall fitness has improved.