Search Space

- If we are solving a problem, we are usually looking for some solution which will be the best among others.
- The space of all feasible solutions (the set of solutions among which the desired solution resides) is called search space (also state space).
- Each point in the search space represents one possible solution.
- Each possible solution can be "marked" by its value (or fitness) for the problem.
Search Space

- With **GA** we look for the best solution among a number of possible solutions - represented by one point in the search space.

- Looking for a solution is then equal to looking for some extreme value (minimum or maximum) in the search space.

- In the process of using **GA**, the process of finding solutions generates other points (possible solutions) as *evolution* proceeds.

Search Space

- The problem is that the search can be very complicated.

- One may not know:
  - where to look for a solution
  - where to start

- Many methods can be used for finding a **suitable solution**, but these methods do not necessarily provide the **best solution**.
  - **Hill Climbing**, **Simulated Annealing**, and **Genetic Algorithm**
  - The solutions found by these methods are often considered as good solutions, because it is not often possible to prove what the optimum is.
Biological Background

- Genetic algorithms are a part of evolutionary computing, which is a rapidly growing area of artificial intelligence.

- Chromosome:
  - All living organisms consist of cells.
  - In each cell there is the same set of chromosomes.
  - A chromosome consists of genes, blocks of DNA.
  - Each gene has its own position in the chromosome.

Biological Background

- Reproduction:
  - During reproduction, recombination (or crossover) first occurs.
  - Genes from parents combine to form a whole new chromosome.
  - The newly created offspring can then be mutated.
  - Mutation means that the elements of DNA are a bit changed.
  - These changes are mainly caused by errors in copying genes from parents.
  - The fitness of an organism is measured by success of the organism in its life (survival).
Genetic Algorithm (GA)

- Genetic algorithms are inspired by Darwin's theory of evolution.

- Solution to a problem solved by genetic algorithms uses an evolutionary process (it is evolved).

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GA

- Algorithm begins with a set of solutions (represented by chromosomes) called population.
- Solutions from one population are taken and used to form a new population.
- This is motivated by a hope, that the new population will be better than the old one.
- Solutions which are then selected to form new solutions (offspring) are selected according to their fitness - the more suitable they are the more chances they have to reproduce.
- This is repeated until some condition (for example number of populations or improvement of the best solution) is satisfied.
Example

Population 1

Fitness

Solutions (search space)

Cont.

Population 2

Fitness

Solutions
Outline of the Basic Genetic Algorithm

- [Start] Generate random population of $n$ chromosomes
- [Fitness] Evaluate the fitness $f(x)$ of each chromosome $x$ in the population
- [New population] Create a new population by repeating following steps until the new population is complete
  - [Selection] Select two parent chromosomes from a population according to their fitness (the better fitness, the bigger chance to be selected)
  - [Crossover] With a crossover probability cross over the parents to form new offspring (children). If no crossover was performed, offspring is the exact copy of parents.
  - [Mutation] With a mutation probability mutate new offspring at each locus (position in chromosome).
  - [Accepting] Place new offspring in the new population
- [Replace] Use new generated population for a further run of the algorithm
- [Test] If the end condition is satisfied, stop, and return the best solution in current population
- [Loop] Go to step 2

Operators of GA

- Encoding of a Chromosome
  - A chromosome should contain information about solution that it represents. The most used way of encoding is a binary string.
  - Example:
    - Chromosome 1: 1101100100110110
    - Chromosome 2: 1101111000011110
  - Each chromosome is represented by a binary string.
  - Each bit in the string can represent some characteristics of the solution.
  - Another possibility is that the whole string can represent a number.
Encoding of a Chromosome

- There are many other ways of encoding.
- The encoding depends mainly on the solved problem and potential solution.
- For example, one can encode directly integer or real numbers.
- Binary string is the most widely used one.

Crossover

- After we have decided what encoding we will use, we can proceed to crossover operation.
- Crossover operates on selected genes from parent chromosomes and creates new offspring.
- Choose randomly some crossover point and copy everything before this point from the first parent and then copy everything after the crossover point from the other parent.
Crossover

- Example: ( | is the crossover point):

  Chromosome 1: 11011 | 00100110110
  Chromosome 2: 11011 | 11000011110

  Offspring 1: 11011 | 11000011110
  Offspring 2: 11011 | 00100110110

- There are other ways to make crossover
  - E.g., choose more crossover points
- Crossover can be quite complicated and depends mainly on the encoding of chromosomes.
- Specific crossover made for a specific problem can improve performance of the genetic algorithm.

Mutation

- After a crossover is performed, mutation takes place.
- Mutation is intended to prevent falling of all solutions in the population into a local optimum of the solved problem.
- Mutation operation randomly changes the offspring resulted from crossover.
- In case of binary encoding we can switch a few randomly chosen bits from 1 to 0 or from 0 to 1.
Mutation

- Mutation can be then illustrated as follows:

  Original offspring 1: 1101111000011110
  Original offspring 2: 1101100100110110

  Mutated offspring 1: 1100111000011110
  Mutated offspring 2: 1101101100110110

- The technique of mutation (as well as crossover) depends mainly on the encoding of chromosomes.