CAD Algorithms

Genetic Algorithms

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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)

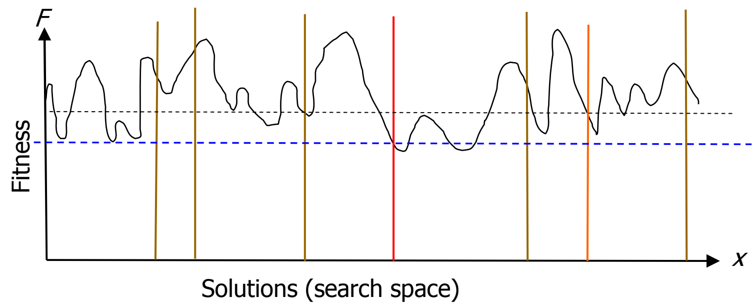
- Genetic algorithms are inspired by Darwin's theory of evolution.
  - http://www.darwins-theory-of-evolution.com/
- Solution to a problem solved by genetic algorithms uses an evolutionary process (it is evolved).

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.

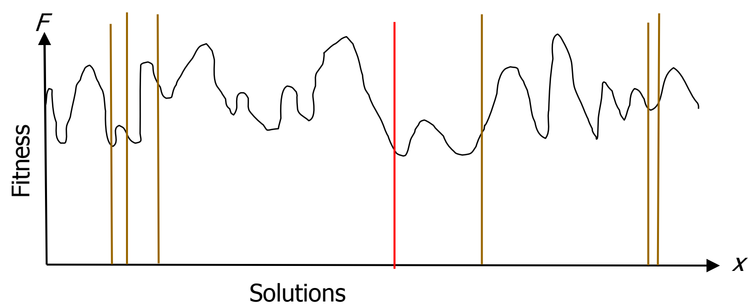
Example

Population 1



Cont.

Population 2



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: 1101101100110100

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