CS380
Artificial Intelligence for Games

Genetic Algorithm

Evolutionary Algorithms

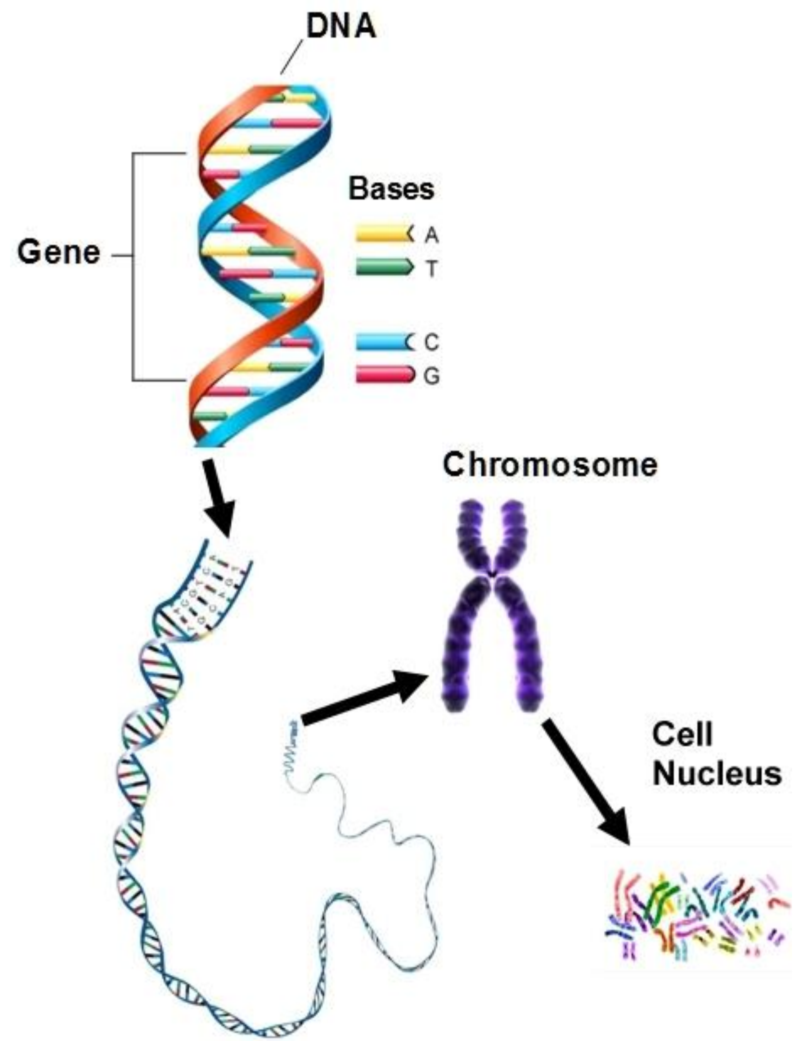
- From 60's
- Based on the principles of **natural selection**
- "Maintain a population of solutions in which the fittest survive and breed while weaker solutions perish"

Principles of Natural Selection

- All populations of organisms, no matter how similar, will have genetic variations.
- The environment creates obstacles that challenge the creation of new offspring.
- Individual organisms that are more suited for survival in their environment will produce more offspring than those that are not.
- Individual organisms that produce more offspring than their environment can support will struggle for the right to keep living.

Genes and Chromosomes

- The **gene** is the basic physical unit of inheritance
  - Genes are passed from parents to offspring and contain the information needed to specify traits.
- Our genetic information is stored in **chromosomes**
  - Individual organisms have unique sets of chromosomes



Crossover and Mutation

- When 2 organisms mate, they share their genes
- During this combination process, we get most of the time offspring chromosomes that are half-half inherited genes from both parents. We call this **crossover** or a normal recombination
- During the crossover very rarely some genes may be mutated
- Mutation may have good or bad affection on the organism and may lead to a dead end for those holding it or a total domination of this kind of genotype with new traits after many reproduction generations

Crossover

Parent 1	Parent 2
A	T
D	W
Z	H
Y	A
R	H
N	D
X	E
E	Y

Child
A
W
Z
A
R
D
X
Y

Random Mutation

Parent 1	Parent 2
A	T
D	W
Z	H
Y	A
R	H
N	D
X	E
E	Y

Child
A
W
Z
A
R
D
X
Y

Child
A
W
J
A
B
D
X
Y

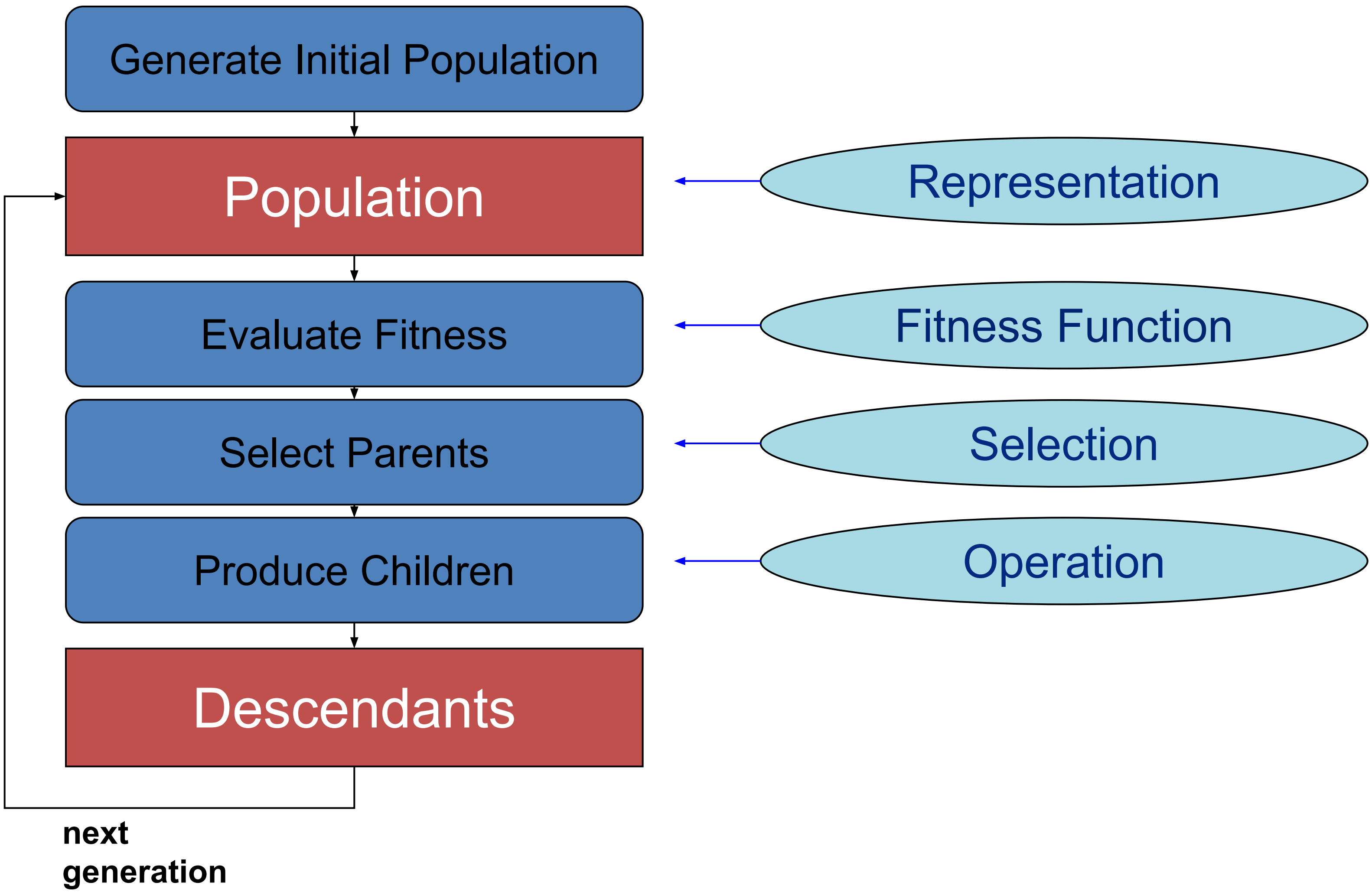
Genetic Algorithms

- Is an **optimization technique** that simulates the natural selection
- Algorithm maintains a **population of individuals** (organisms, chromosomes)
- A **fitness function** evaluates the quality of **individuals**.
  - Fitness is a measure that indicates the fitness of a particular individual.
- Individuals are selected probabilistically based on their fitness to form a mating pool.
- Pairs of individuals are selected randomly from the mating pool to produce new individuals by crossover and mutations.

Chromosomes in GA

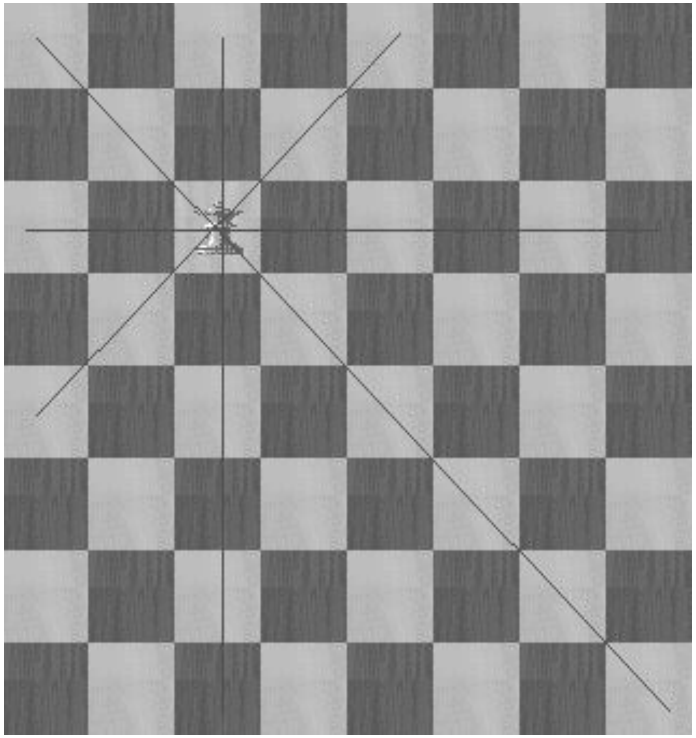
- Bit strings (0101 ... 1100)
- Real numbers (43.2 -33.1 ... 0.0 89.2)
- Permutations of element (E_{11} E_3 E_7 ... E_1 E_{15})
- Lists of rules (R_1 R_2 R_3 ... R_{22} R_{23})
- Program elements (genetic programming)
- ... any data structure ...

Framework of GAs

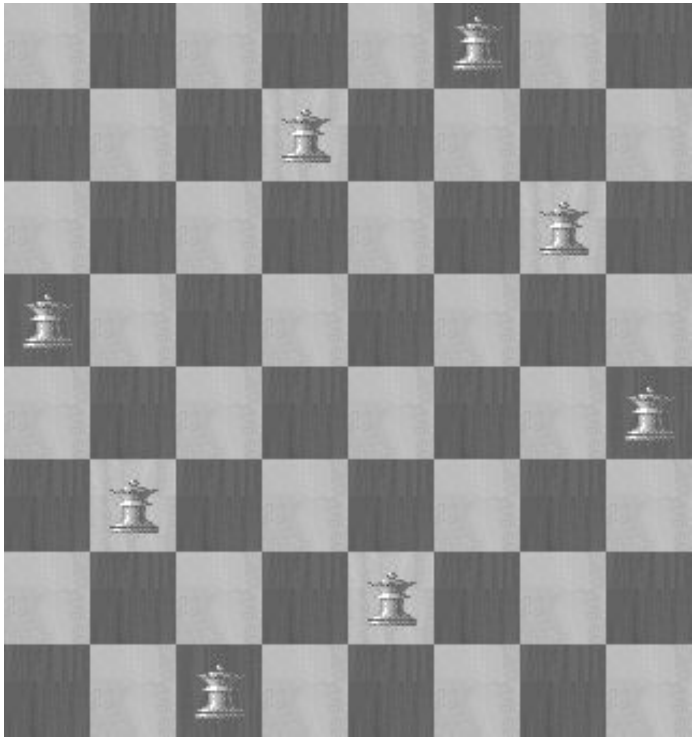


8-Queens Problem

Queen’s Movements



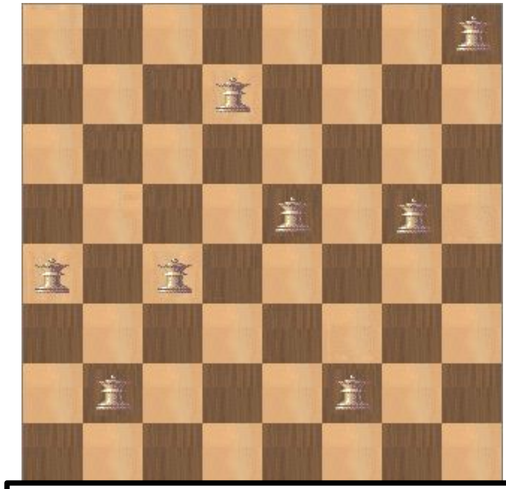
A Solution



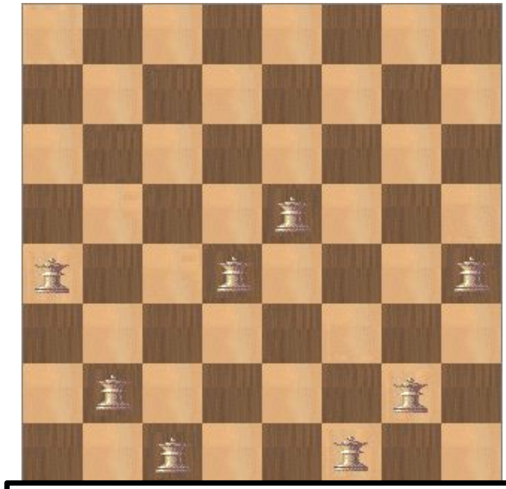
Initialization

- 1 chromosome = 1 solution
- A chromosome is made of 8 genes (1 gene = a position of 1 queen in its correspondent column
- The best way to create a population of initial N candidate solutions is to do it randomly

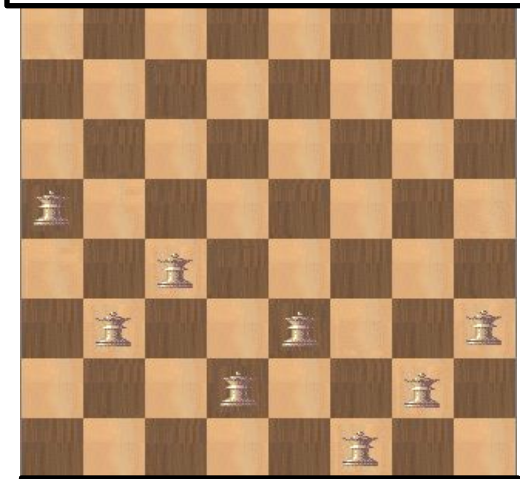
Initialization (N=4)



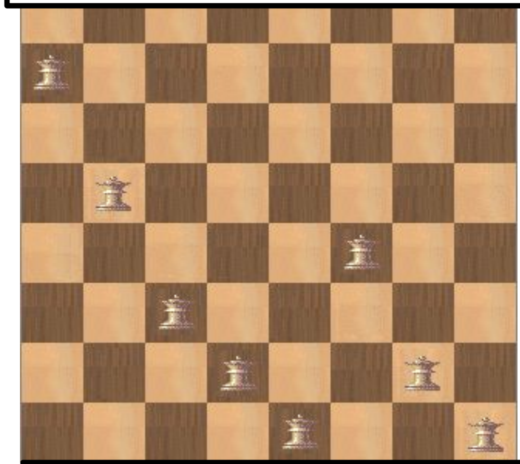
4 2 4 7 5 2 5 8



4 2 1 4 5 1 2 4



5 3 4 2 3 1 2 3



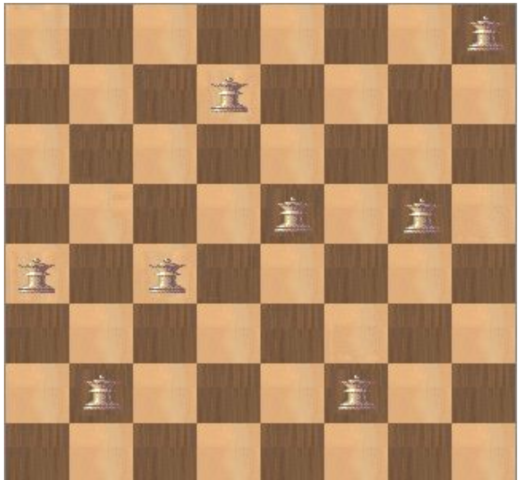
7 5 3 2 1 4 2 1

Evaluation

- Aims to identify the most successful members of the population

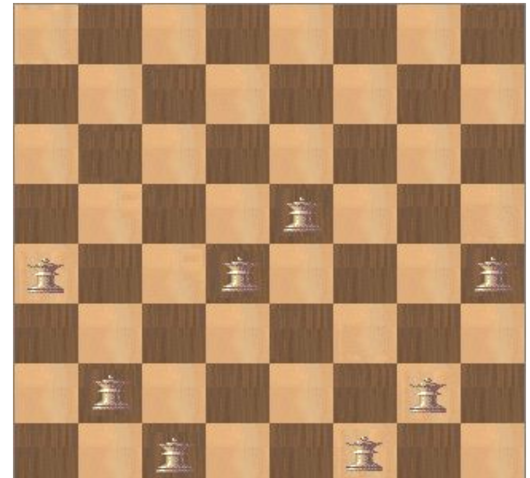
- Fitness function: the number of non-attacking pairs of queens. What is the maximum possible value in the 8-queens problem?

Evaluation



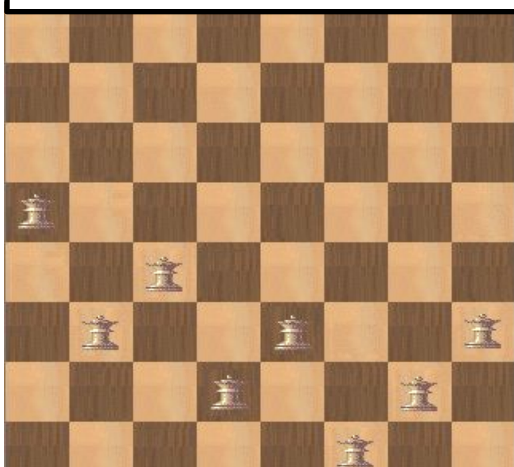
21

4 2 4 7 5 2 5 8



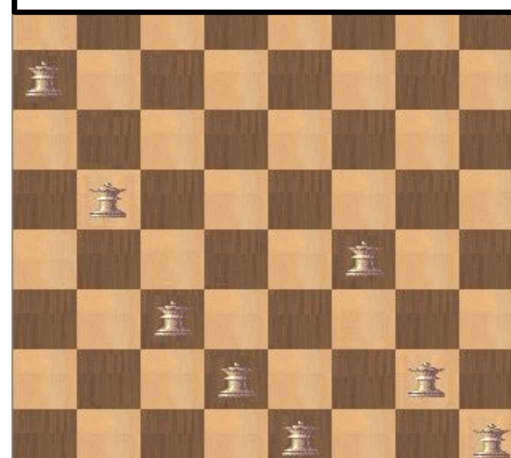
18

4 2 1 4 5 1 2 4



17

5 3 4 2 3 1 2 3



21

7 5 3 2 1 4 2 1

Selection

- Based on the fitness of the chromosomes.
  - The "most fit" members of the population survive
  - The "least fit" members are mostly eliminated

- Selection methods:
  - Roulette wheel selection
  - Stochastic universal sampling
  - Tournament selection

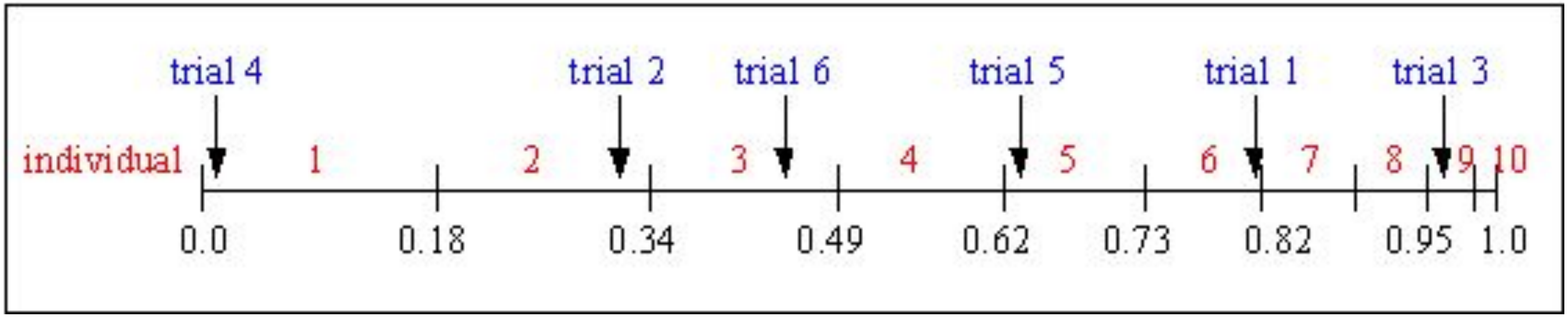
Roulette Wheel Selection

- The probability of an individual to be selected is directly proportional to its fitness

Roulette Wheel Selection

Number of individual	1	2	3	4	5	6	7	8	9	10	11
Fitness value	2.0	1.8	1.6	1.4	1.2	1.0	0.8	0.6	0.4	0.2	0.0
Selection probability	0.18	0.16	0.15	0.13	0.11	0.09	0.07	0.06	0.03	0.02	0.0

Random numbers generated in (0,1) : 0.81, 0.32, 0.96, 0.01, 0.65, 0.42.



Mating populations selected: 6,2,9,1,5,3

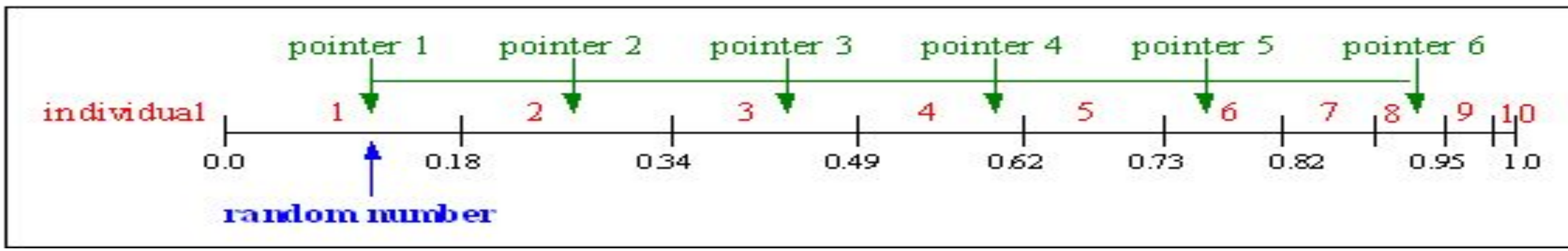
Stochastic Universal Sampling

- Again, a roulette wheel is constructed. But, instead of spinning the wheel, we take the requested number of individuals (n) and we select the owner of the roulette slice at $\frac{1}{n}$ increments along the wheel.

Stochastic Universal Sampling

Number of individual	1	2	3	4	5	6	7	8	9	10	11
Fitness value	2.0	1.8	1.6	1.4	1.2	1.0	0.8	0.6	0.4	0.2	0.0
Selection probability	0.18	0.16	0.15	0.13	0.11	0.09	0.07	0.06	0.03	0.02	0.0

For 6 individuals to be selected, the distance between the pointers is 1/6=0.167. Sample of 1 random number in the range [0, 0.167]: 0.1.



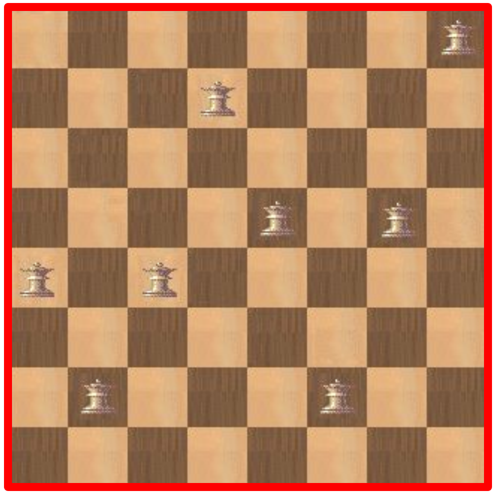
Mating populations selected: 1, 2, 3, 4, 6, 8.

This selection method has an advantage over the regular roulette selection method by keeping genetic diversity high.

Tournament Selection

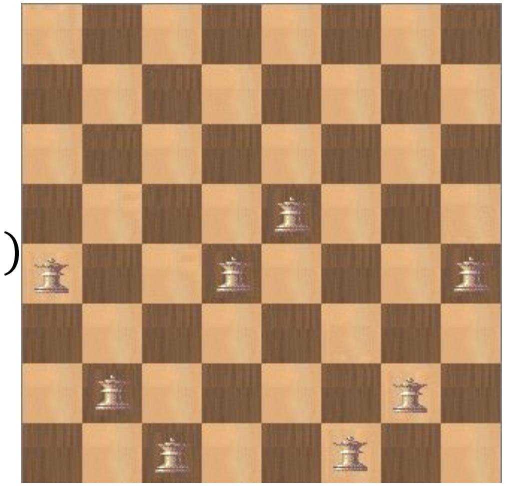
- A number of individuals are randomly drawn and the highest scorer is selected
- We repeat this process as many times as needed to have enough number of selected individuals for reproduction

Roulette Wheel Selection



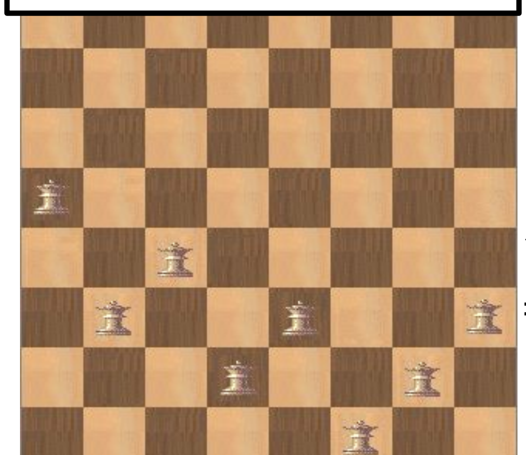
21/(21+18+17+21)
=27.27%

4 2 4 7 5 2 5 8



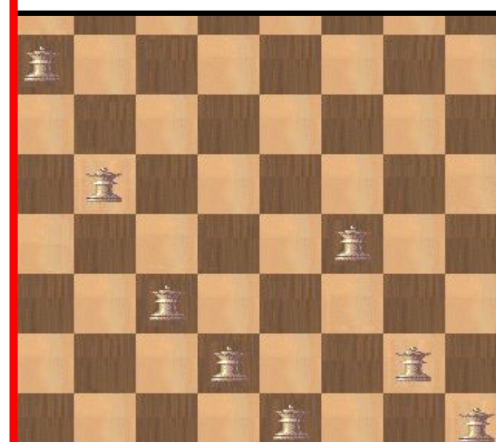
18/77
=23.37%

4 2 1 4 5 1 2 4



17/77
=22.07%

5 3 4 2 3 1 2 3



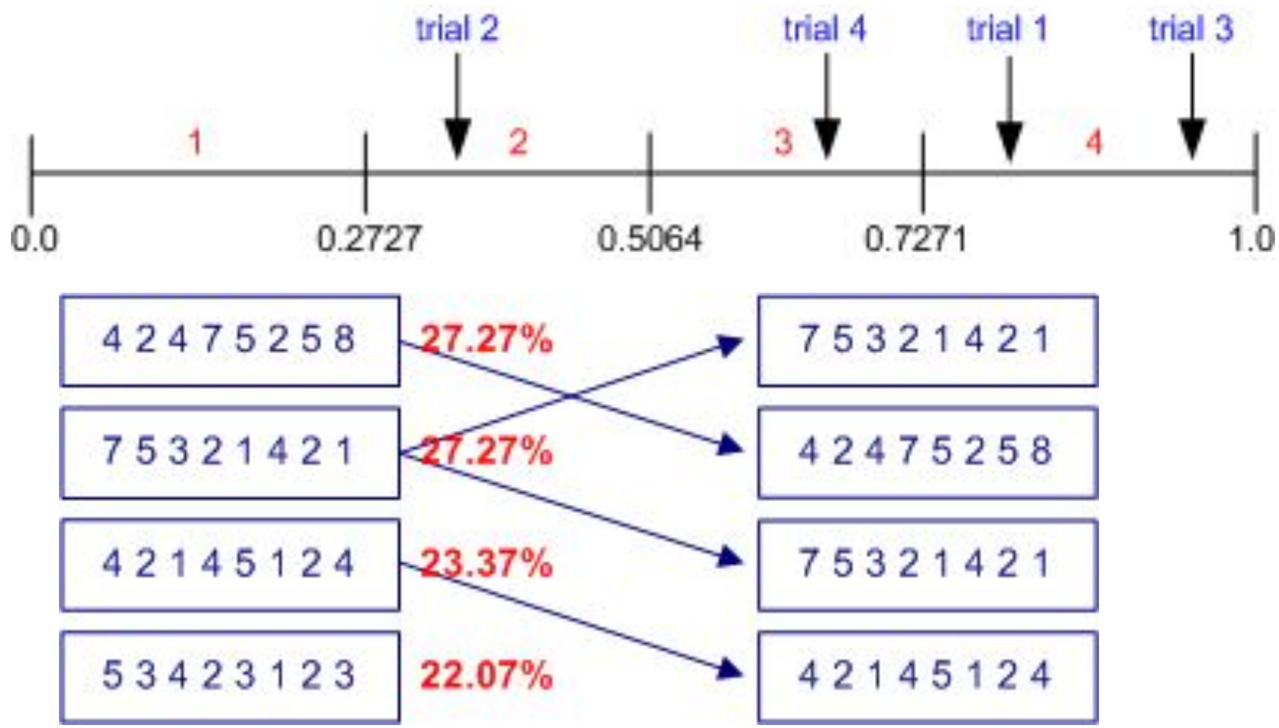
21/77
=27.27%

7 5 3 2 1 4 2 1

Roulette Wheel Selection

Number of individual	1	2	3	4
fitness value	21	18	17	21
selection probability	27.27 %	23.37 %	22.07%	27.27%

Random numbers generated in (0,1) : 0.8, 0.35, 0.95, 0.65



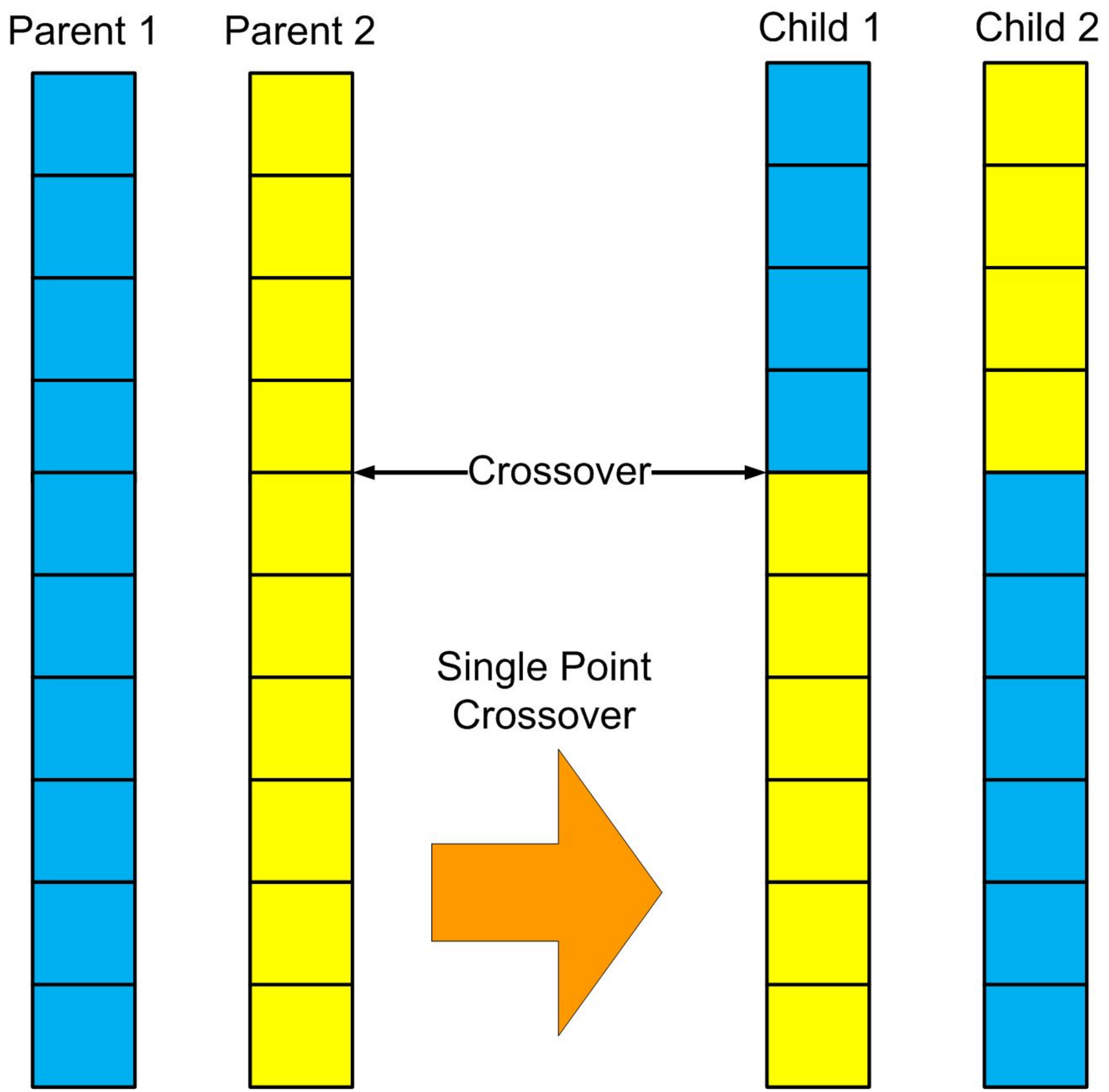
Recombination (Evolution)

- Recall: We create new individuals by taking the chromosomes from selected members of the population and combining these chromosomes using crossover and/or mutation.

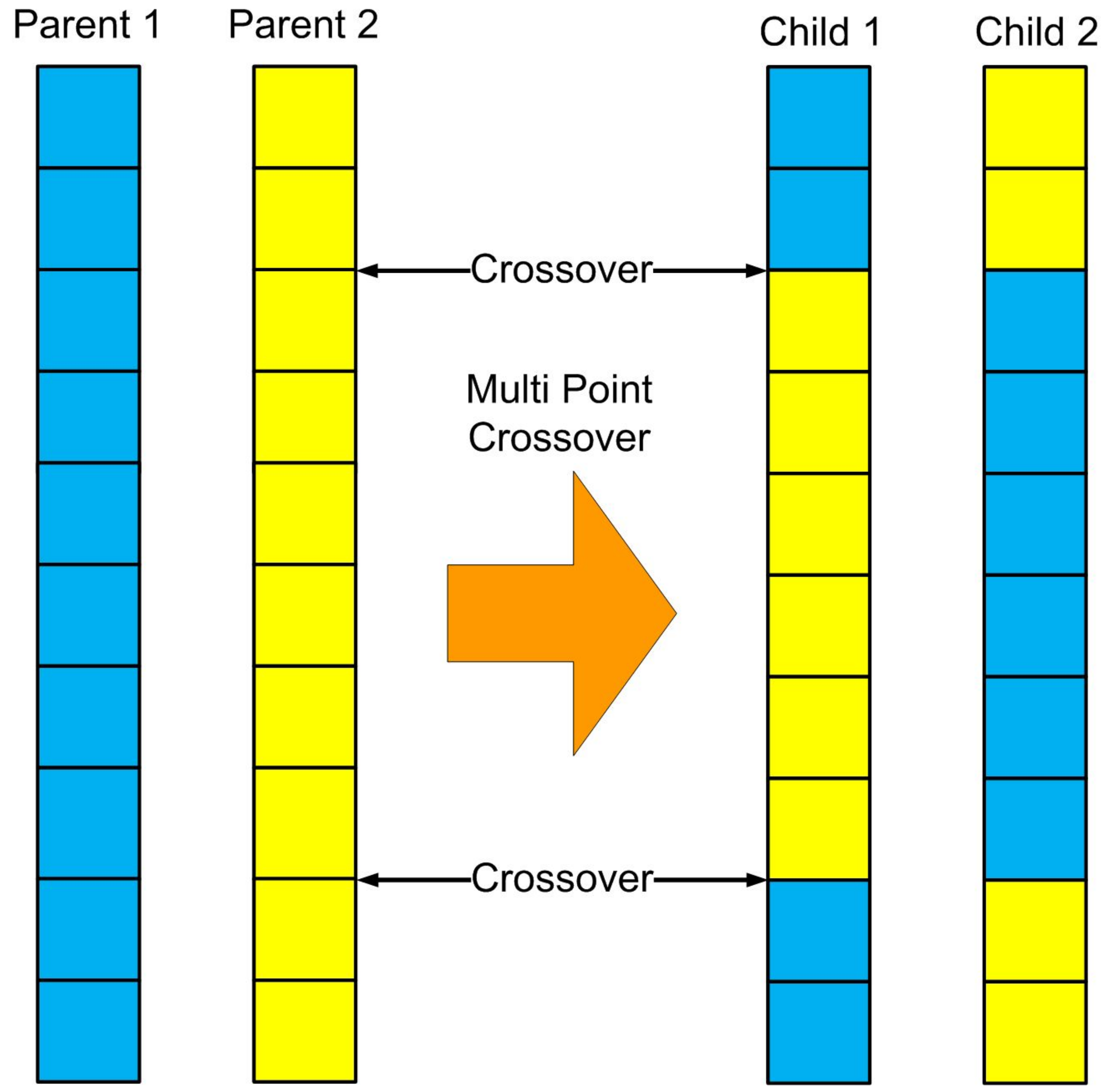
Chromosome Modification

- Modifications are stochastically triggered
- Operator types are:
  - Crossover (recombination): It greatly accelerates search early in evolution of a population and leads to effective combination of schemata (subsolutions on different chromosomes)
  - Mutation: It causes movement in the search space (local or global) and restores lost information to the population.

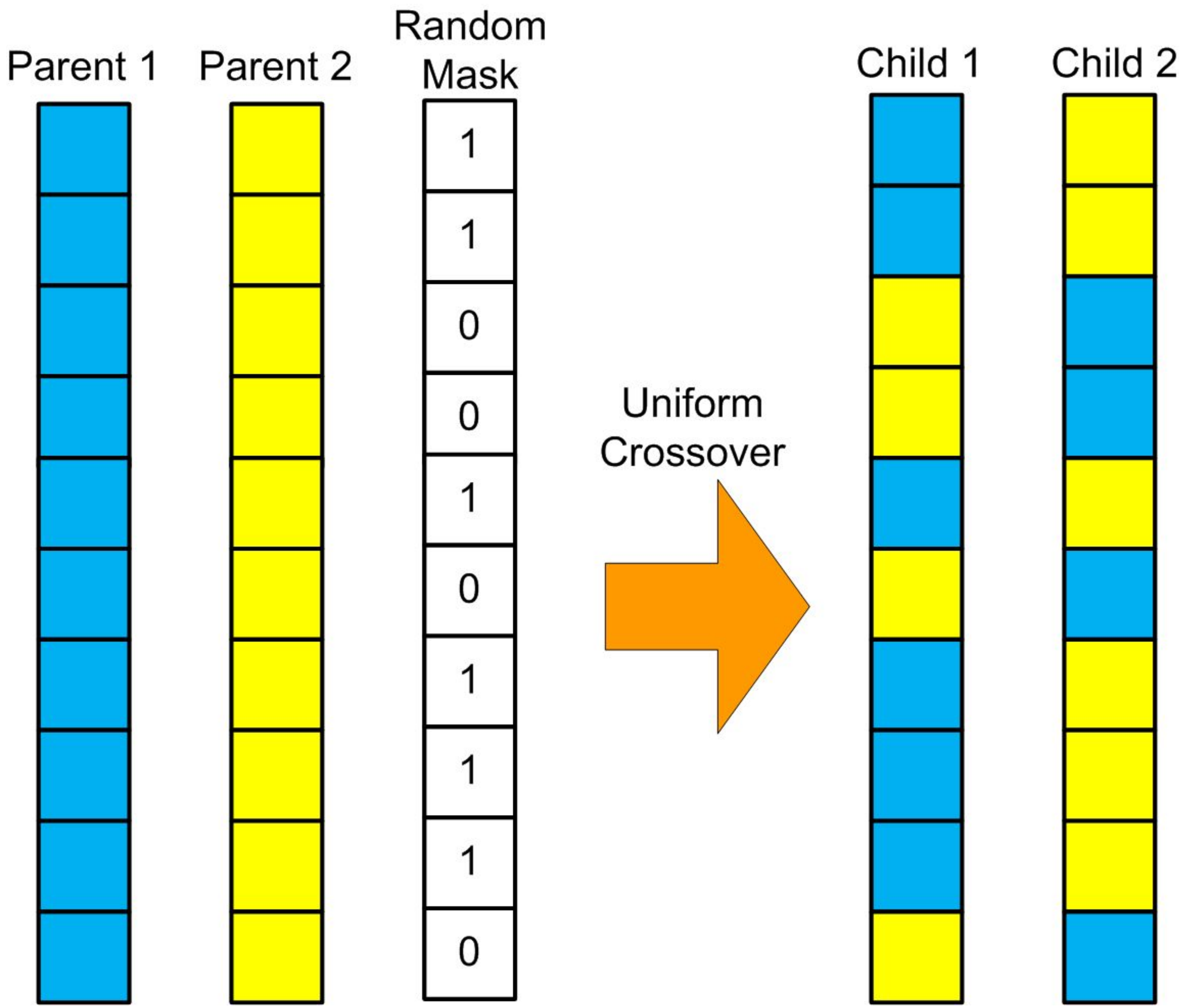
Single Point Crossover



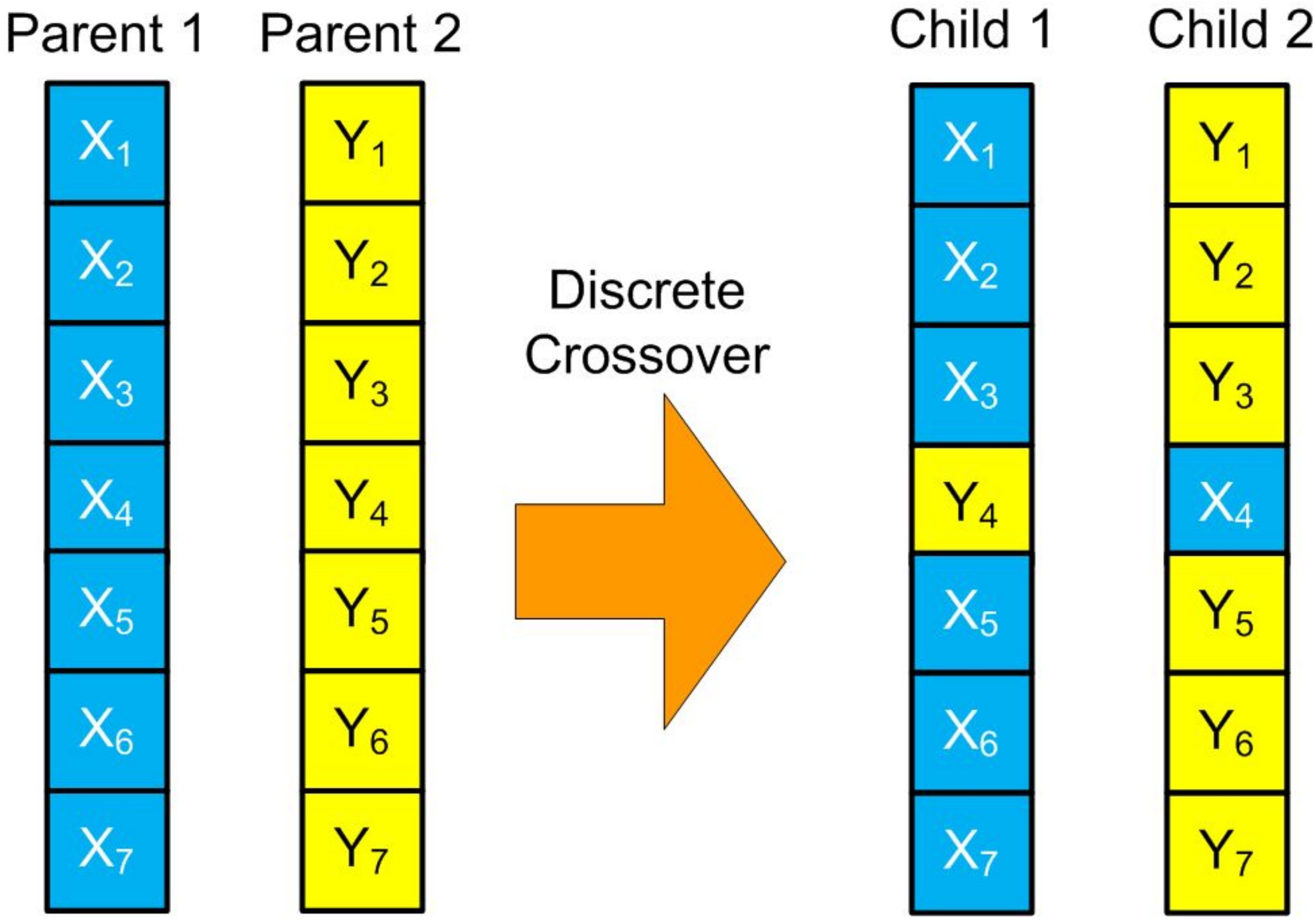
Multi Point Crossover



Uniform Crossover



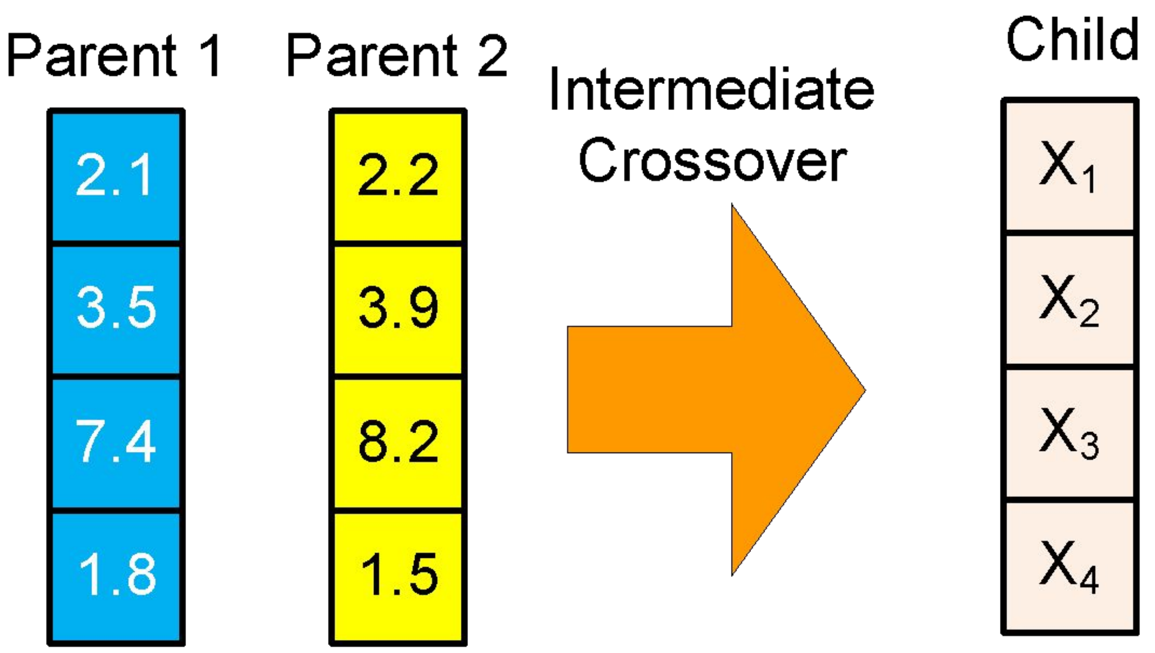
Discrete Crossover



Intermediate Crossover

$$\text{offspringValue} = \text{parent1Value} + \text{scale}\times(\text{parent2Value} - \text{parent1Value})$$

Scale is a random scaling factor chosen for each value in the interval [-i,i+1],



$X_1=2.1+0.5*(2.2-2.1)$

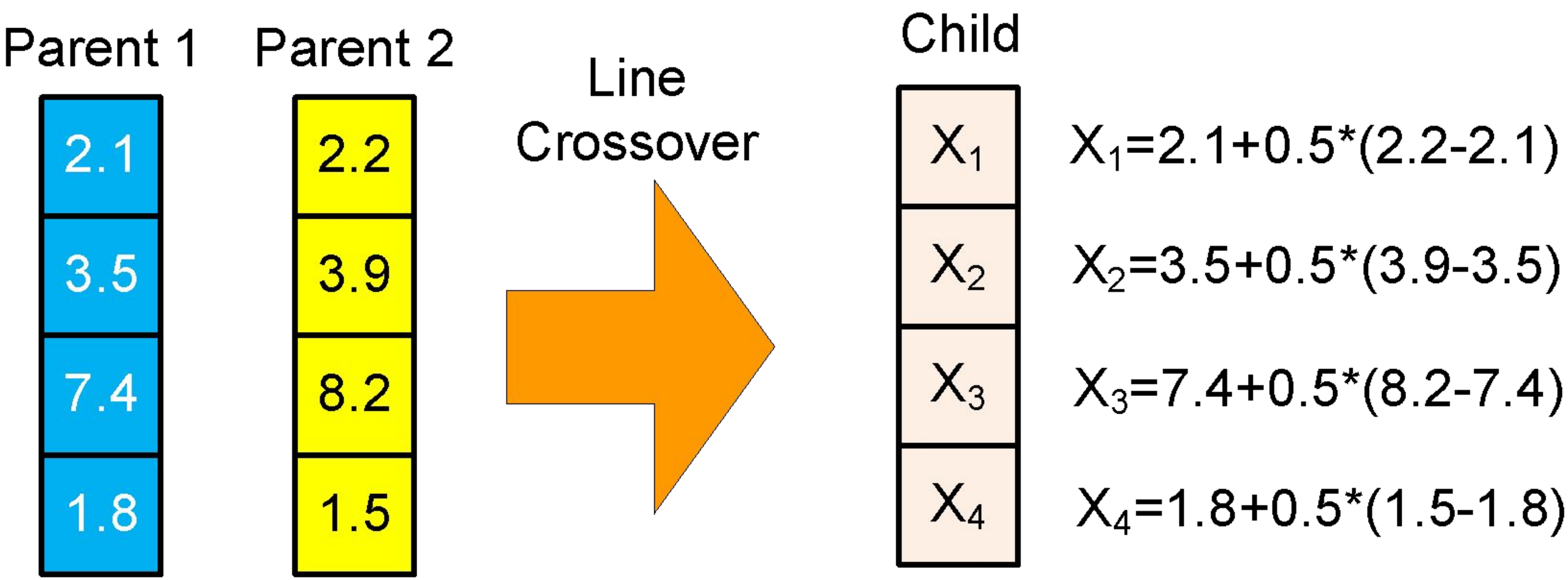
$X_2=3.5+0.8*(3.9-3.5)$

$X_3=7.4+0.6*(8.2-7.4)$

$X_4=1.8+0.75*(1.5-1.8)$

Line Crossover

offspringValue = parent1Value + scale×(parent2Value – parent1Value)
Scale is a random scaling factor chosen in the interval [-i,i+1] and the same scale is applied for each value.



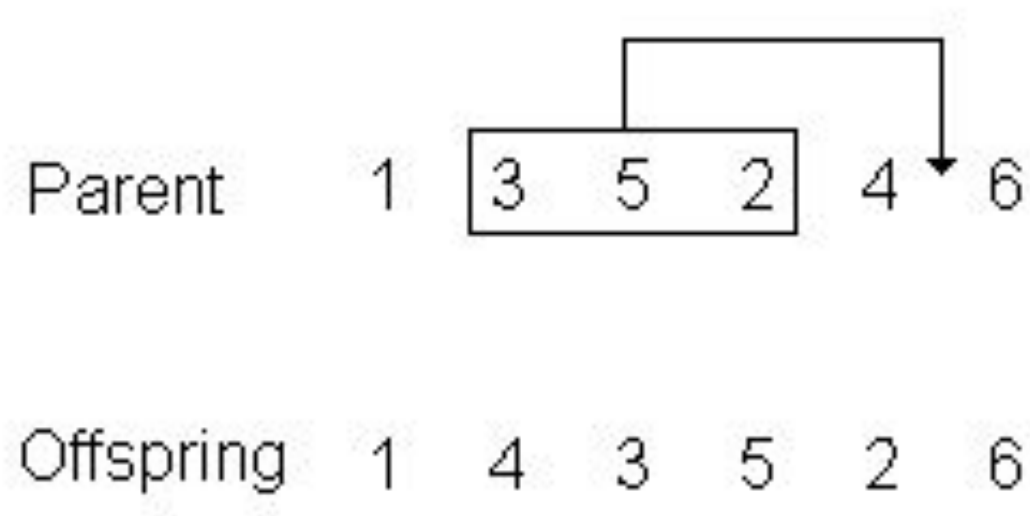
Exchange Mutation

- It simply swaps two genes within the chromosome.

Parent	1	$\boxed{3}$	5	2	$\boxed{4}$	6
Offspring	1	4	5	2	3	6

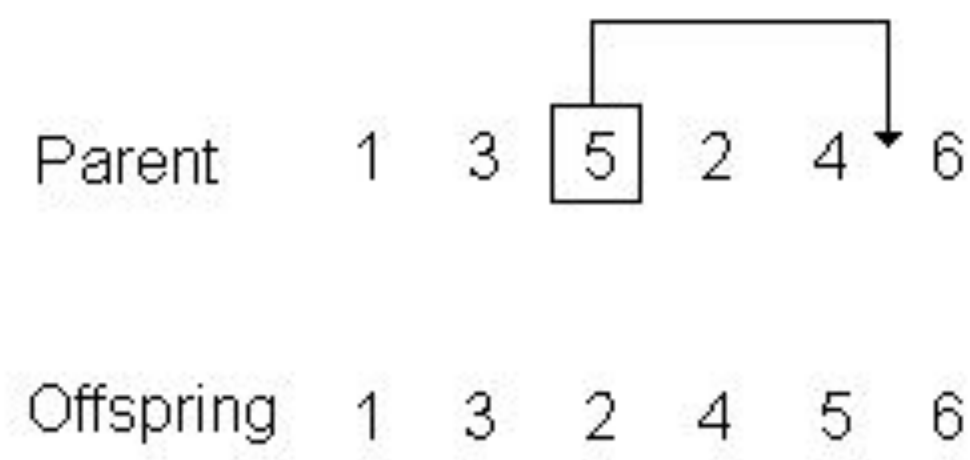
Displacement Mutation

- It selects a part of the chromosome and inserts this part in a randomly selected position.



Insertion Mutation

- It is like the displacement mutation operator with one difference. Instead of moving a block of more than one gene, it simply move one gene.



Binary Mutation

- For chromosomes represented with binary genes (0 and 1), it simply flips the value of a randomly selected gene (from 0 to 1 or 1 to 0)

Parent	1	0	0	0	1	1	$\boxed{0}$	0
Offspring	1	0	0	0	1	1	1	0

Replacement

1. The offspring simply replace their parents. Equal to the current number of individuals or more offspring are generated. In case of more offspring, the best ones replaces their parents.
2. The offspring can replace the worst fit chromosomes in the parent generation. This means some of the chromosomes are just <u>cloned</u> to the next generation.
3. Replacing chromosomes picked randomly.
4. A combination of the above three scenarios with minor changes
5. Etc…

When stop?

- Now, and after all the steps done in one iteration (generating one new population), the same procedure can be repeated using one of the individuals replacement techniques given above.
- The Genetic Algorithm **should return whenever a goal is hit, or the number of maximum iterations is achieved**.