Computational Intelligence

Unit # 3

Acknowledgement

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Evolutionary Computing

What is evolution?

Evolution

- Evolution is the change in the inherited traits of a population of organisms through successive generations.

Examples of evolution

- Organisms/Species
- Languages
- Cuisines
- Automobiles
- Cellular reproduction
- Hardware/Software

Biological Evolution

- "The change in the properties of populations of organisms over the course of generations."
- This evolution generally happens via changes in genetic material, from one generation to the other.

Evolution in Animals

- Giraffes developed elongated necks over time to fulfil two important biological needs: feeding and breeding. Over time, giraffes’ necks became longer and longer, which now allows modern day giraffes to reach the highest food sources, unrivalled.

[giraffe evolution Archives - Laurie O'Keefe Illustration (laurieokeefe.com)](laurieokeefe.com)

Evolution in Animals

- **POLLUTION DROVE THE COLOR CHANGE IN A POPULATION OF MOTHS**
- The peppered moth, historically, was a light-colored moth which adapted rapidly to the pollution brought on by the Industrial Revolution. The moths mutated to become much darker in color, allowing individuals to camouflage with the sooty environment, and avoid being eaten by predators. Whereas the individuals that were still lighter in color were more easily preyed upon.

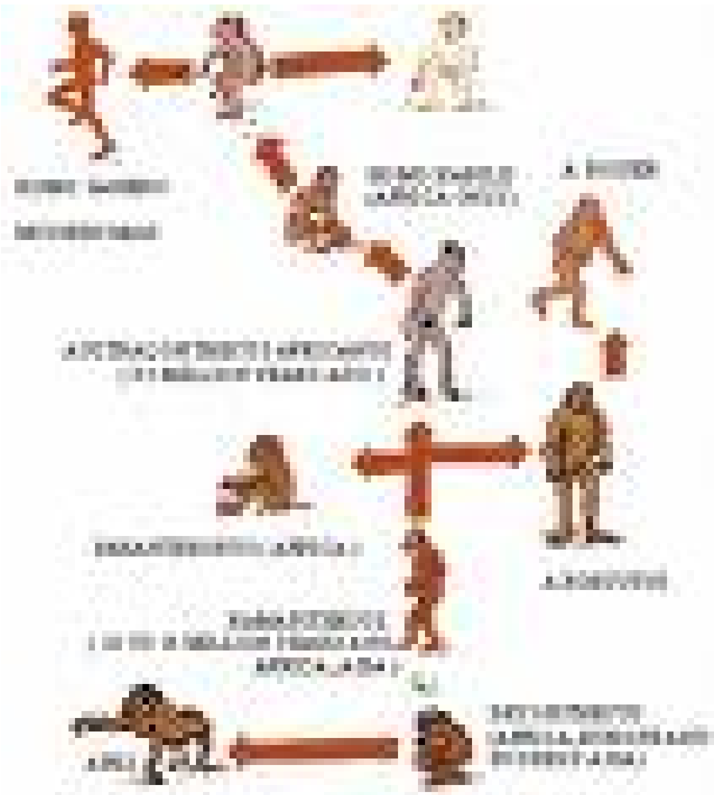
[10 Examples of Animal Evolution in Nature - Wildlife Informer]

Evolutionary Computing(EC)

- EC is the study of computational systems which are inspired by natural evolution.
- In artificial intelligence, an evolutionary algorithm (EA) is **a generic population-based meta-heuristic optimization algorithm**.

Evolutionary Algorithm (Source: Wikipedia)

Evolution (also known as biological or organic evolution) is the change over time in one or more inherited traits found in populations of organisms.



- An EA uses some mechanisms inspired by biological evolution: reproduction, mutation, recombination, and selection.

History

- Several efforts were started in parallel during 1960s
  - Evolutionary Strategies (Berlin Technical University)
  - Genetic Algorithms (University of Michigan)
  - Evolutionary Programming (UCLA)
- During 1990s the above communities agreed to the term "Evolutionary Algorithms".

Biology

- A gene is a sequence of DNA bases that code for a trait, e.g., eye color, hair color etc.
- An allele is a value of a trait. The eye color gene could have a blue allele or a hazel allele in different people.

- **Definition:** Evolution is the variation of allele frequencies in populations over time.

Genotype and phenotype

Genotype

- The set of genes an organism has.
- Genes exist in DNA, in every cell in the organism's body.

Phenotype

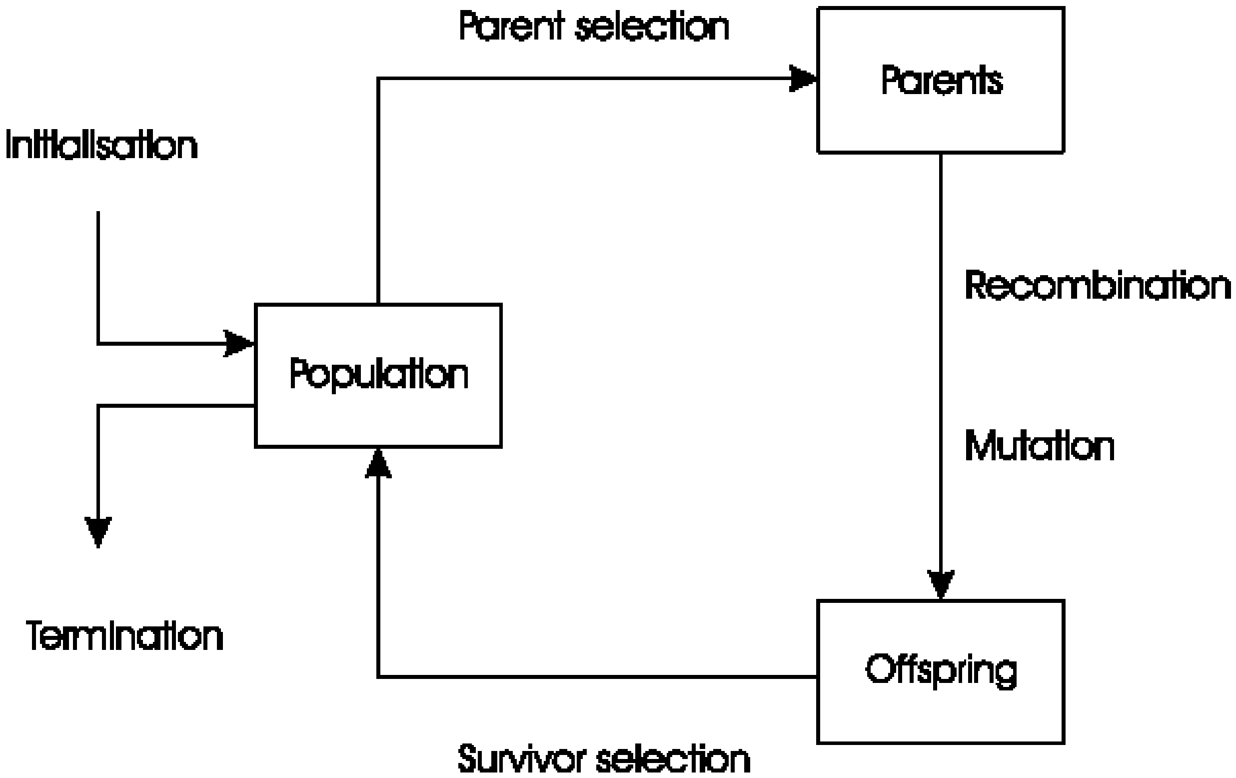
- The phenotype is the physical expression of the genotype, including:
  - an organism's morphology, its behaviour, its physiology, etc.
- An organism's phenotype is the product of its genotype and its environment.

Theory of Evolution

- Evolution is a set of principles that tries to explain how life, in all its various forms, appeared on Earth.
- The theory of evolution is just that -- a theory.
- Many theories are works in progress, and evolution is one of them. There are several big questions that the theory of evolution cannot answer right now. This is not unusual.
- In answering the open questions that still remain unsolved, the theory of evolution will either become complete or it will be replaced by a new theory that better explains the phenomena we see in nature. That is how the scientific process works.

https://science.howstuffworks.com/life/evolution/evolution8.htm

General Scheme of EAs



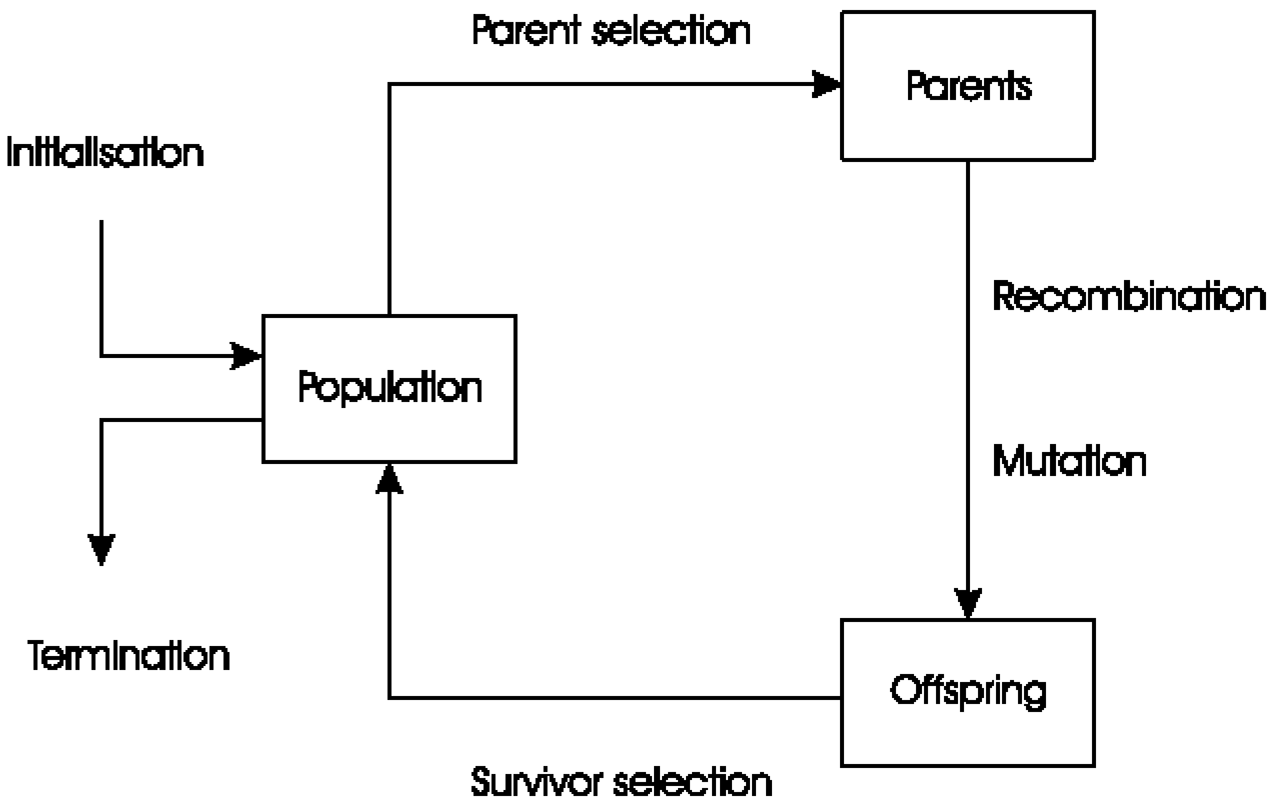
Survival of the Fittest

- “Evolution is the result of survival of the fittest” is a pretty good description of many evolutionary computation systems.
- When we use evolutionary computation to solve a problem, we operate on a collection (population) of data structures (creatures).
- These creatures will have explicitly computed fitness used to decide which creatures will be partially or completely copied (have offspring).

Exploitation vs. Exploration

- Any efficient optimization algorithm must use two techniques to find a global maximum:
  - Exploration: to investigate new and unknown areas in the search space
  - Exploitation: to make use of knowledge found at points previously visited to help find better points.
  - These two requirements are contradictory, and a good search algorithm must find a tradeoff between the two.

General Scheme of EAs



Basic Idea of EAs

- Generate a population of structures
- Repeat
  - Test the structures for quality
  - Select structures to reproduce
  - Produce new variations of selected structures
  - Replace old structures with new ones
- Until Satisfied

A Typical Evolutionary Algorithm Cycle

1. Let $g = 0$ be the generation counter.
2. Initialize a population C_g of N individuals, i.e. $C_g = \{\vec{C}_{g,n} | n = 1, \cdots, N\}$.
3. While no convergence
   (a) Evaluate the fitness $\mathcal{F}_{EA}(\vec{C}_{g,n})$ of each individual in population C_g
   (b) perform cross-over:
      i. select two individuals $\vec{C}_{g,n_1}$ and $\vec{C}_{g,n_2}$
      ii. produce offspring from $\vec{C}_{g,n_1}$ and $\vec{C}_{g,n_2}$
   (c) perform mutation
      i. select one individual $\vec{C}_{g,n}$
      ii. mutate $\vec{C}_{g,n}$
   (d) select the new generation C_{g+1}
   (e) evolve the next generation: let $g = g + 1$

Components of Evolutionary Algorithms

- Representation (definition of individuals)
- Evaluation function (or fitness function)
- Population
- Parent selection mechanism
- Variation operators, recombination and mutation
- Survivor selection mechanism (replacement)

Representation

- The first step in defining an EA is to link the "real world" to the "EA world".
- Objects forming possible solution within the original problem context are referred to as **phenotypes**, while their encoding in the EA are called **genotypes**.

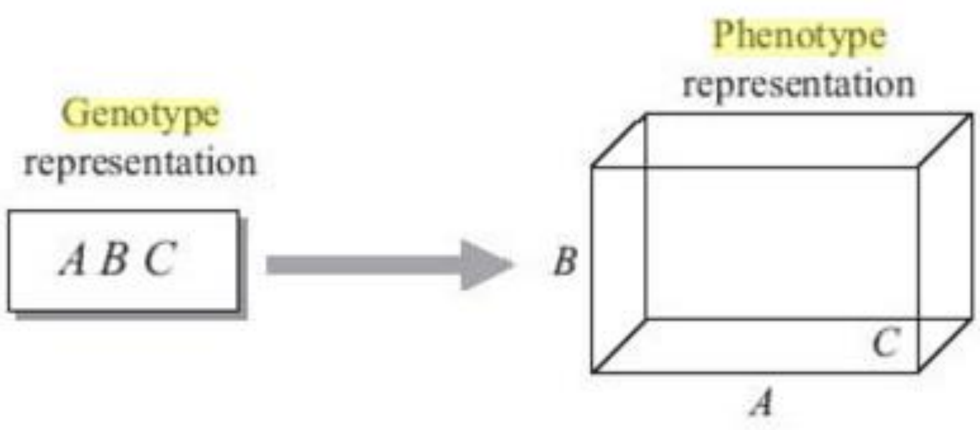
Representation

Within the EC literature many synonyms can be found:

Candidate solution and **individuals** denote points in the **phenotype space**.

Chromosome and **individuals** denote points in the **genotype space**.

A placeholder is commonly called a variable, a **locus**, or – in a biology-oriented terminology – a **gene**. An object in such a place can be called a value or an **allele**.



Representation Example

- An individual is typically described as a fixed length vector of L features which are chosen presumably because of their (potential) relevance to estimating an individual's fitness. For example,
  - <hair color, eye color, skin color, height, weight>

Evaluation Function

- The role of the evaluation function is to represent the requirements the population should adopt to.
- Technically, it is a function or procedure that assigns a quality measure to genotypes.
- The evaluation function is commonly called the **fitness function** in EC. This might cause a counterintuitive terminology if the original problem requires minimization, because the term fitness is usually associated with maximization.

Parent Selection Mechanism

- The role of parent selection is to distinguish among individuals based on their quality, and, in particular, to allow the better individuals to become parents of the next generation.
- An individual is a **parent** if it has been selected to undergo variation in order to create offspring.
- In EC, parent selection is typically probabilistic.

Variation Operators

- The role of **variation operators** is to create new individuals from old ones.
- In the corresponding phenotype space this amounts to generating new candidate solutions.
- Variation operators in EC are divided into two types:
  - Mutation
  - Crossover

Crossover

- A binary variation operators is called **recombination** or **crossover**.
- This operator merges information from two parent genotypes into one or two offspring genotypes.
- Like mutation, recombination is a stochastic operator: the choices of what parts of each parent are combined and how this is done, depend on random drawings.
- The principle behind recombination is simple – *by mating two individuals with different but desirable features, we can produce an offspring that combines both of those features.*

Mutation

- Mutation is a unary variation operator.
- It is applied to one genotype and delivers a (slightly) modified mutant, the **child** or **offspring**.
- A mutation operator is always stochastic: its output – the child – depends on the outcomes of a series of random choices.

Mutation

- Mutations of data structures can be “good” or “bad.”
- A good mutation is one that increases the fitness of a data structure.
- A bad mutation is one that reduces the fitness of a data structure.

Crossover OR Mutation?

- Exploration: Discovering promising areas in the search space, i.e. gaining information on the problem
- Exploitation: Optimizing within a promising area, i.e. using information
- There is co-operation AND competition between them
- Crossover is explorative, it makes a big jump to an area somewhere “in between” two (parent) areas
- Mutation is exploitative, it creates random small diversions, thereby staying near (in the area of) the parent
- Only crossover can combine information from two parents
- Only mutation can introduce new information (alleles)

Survival Selection Mechanism

- The role of survival selection (**replacement**) is to distinguish among individuals based on their quality.
- It is similar to parent selection, but it is used in a different stage of the evolutionary cycle.
- In contrast to parent selection, which is typically stochastic, survivor selection is often deterministic.

Initialization and Termination

- Initialization is kept simple in most EA applications, the first population is seeded by randomly generated individuals.
- Problem specific heuristics can also be used in this step to create an initial population with higher fitness.
- The following options are used for **termination**:
  - The maximally allowed CPU time elapses.
  - The fitness improvement remains under a threshold value for a given period of time.
  - The population diversity drops under a given threshold.

Convergence

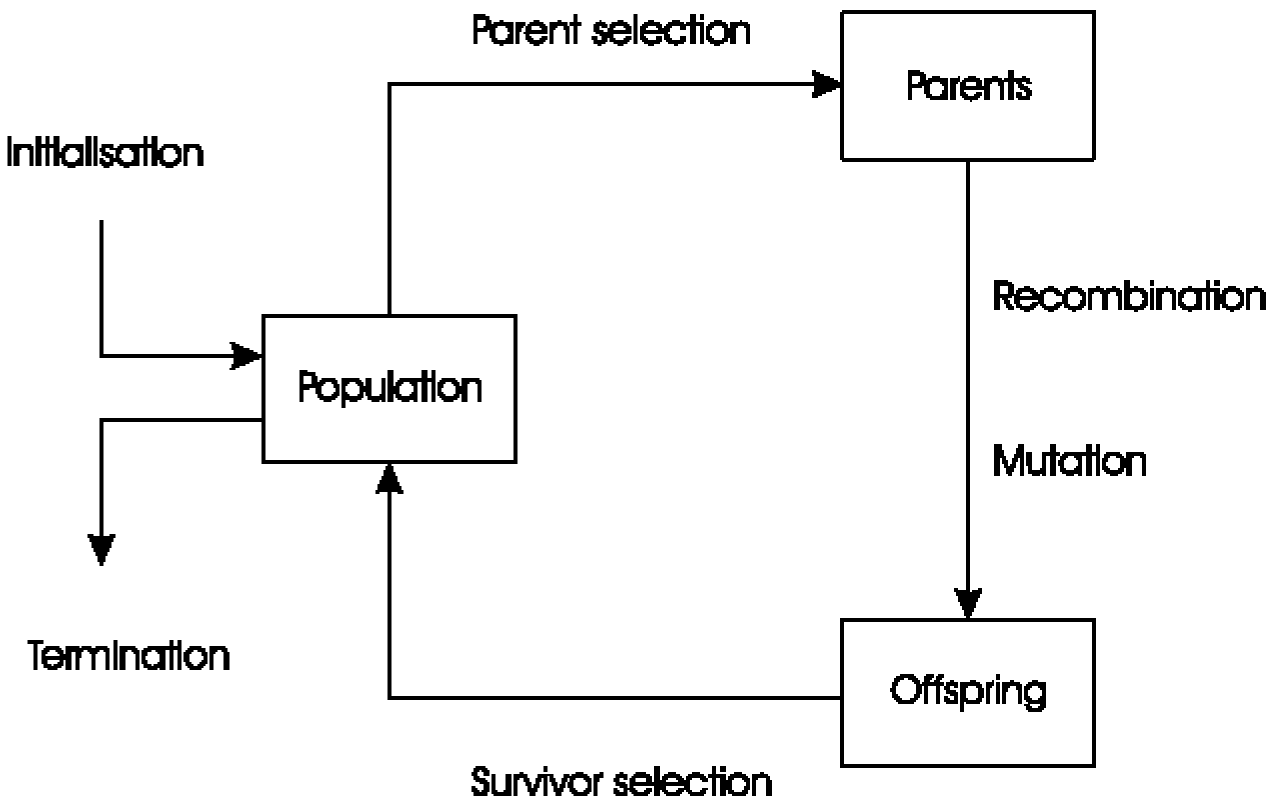
Convergence is reached when, for example:

- the maximum number of generations is exceeded
- an acceptable best fit individual has evolved
- the average and/or maximum fitness value do not change significantly over the past *g* generations.

A Typical Evolutionary Algorithm Cycle

- Step 1: Initialize the population randomly or with potentially good ***solutions***.
- Step 2: Compute the ***fitness*** of each individual in the population.
- Step 3: Select parents using a ***selection procedure***.
- Step 4: Create offspring by ***crossover*** and ***mutation*** operators.
- Step 5: Compute the ***fitness*** of the new offspring.
- Step 6: Select members of population to die using a ***selection procedure***.
- Step 7: Go to Step 2 until termination criteria are met.

General Scheme of EAs



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Thanks