Computational Intelligence
(Part I, Fall 2021)

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EVOLUTIONARY COMPUTATION

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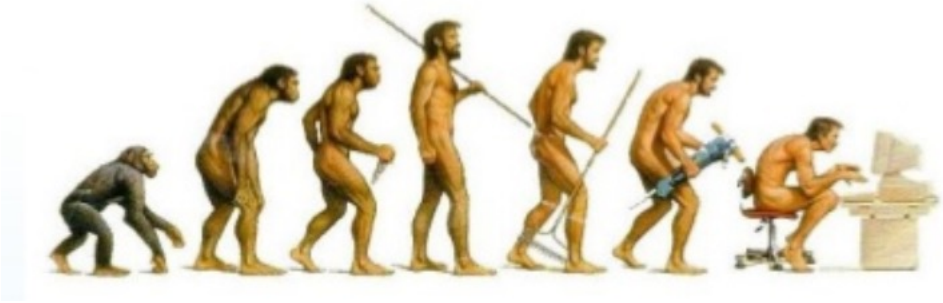
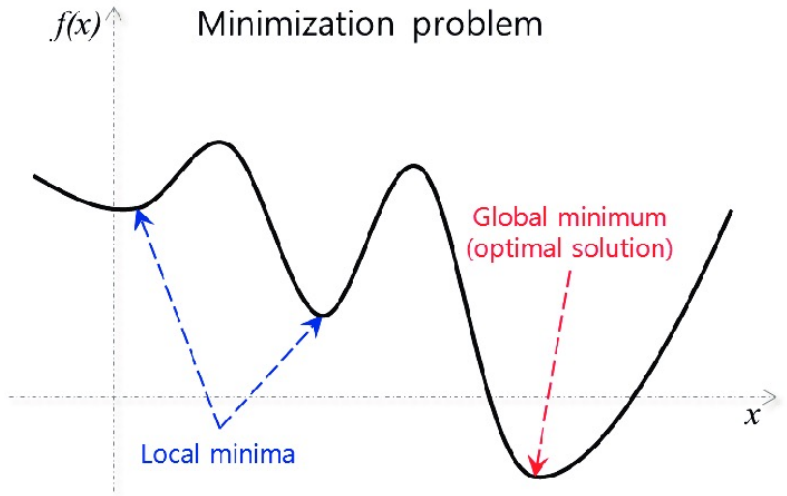
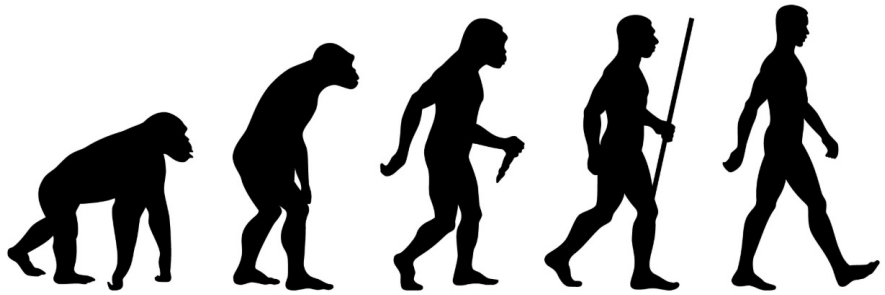


Definition

- Evolutionary Computation (EC) is a family of algorithms for global optimization inspired by biological evolution
  - The objective of global optimization is to find the globally best solution of models, in the presence of multiple local optima





Biology

Biology is a natural science concerned with the study of life and living organisms, including structure, function, growth, origin, evolution, and taxonomy.

Biology is a vast subject containing many topics. The most important topics are the fundamental axioms of modern biology:

- Cells are the basic unit of life
- New species and inherited traits are the product of evolution
- Genes are the basic unit of heredity
- An organism regulates its internal environment to maintain stable and constant condition
- Living organisms consume and transform energy

Darwin's Theory of Evolution

- All life related has descended from a common ancestor
- Natural selection
  - "survival of the fittest "
- Organisms can produce more offspring than their surroundings can support -> natural struggle to survive
- Organisms whose variations best adapt them to their environments survive, the others die.
- Variations are heritable -> can be passed on to the next generation ->i.e., evolution

Common Misconceptions(1)

- Phenotypic changes induced solely by changes in environment do not count as evolution because they are not inheritable.
  - An organism's phenotype is determined by its genes and its environment.
  - Most changes due to environment are fairly subtle.
  - Large scale phenotypic changes are obviously due to genetic changes, and therefore are evolution.

Common Misconceptions(2)

- Evolution is not progress. Populations simply adapt to their current surroundings. They do not necessarily become better in any absolute sense over time. A trait or strategy that is successful at one time may be unsuccessful at another.
- Species do not simply change to fit their environment; they modify their environment to suit them as well.

Genetic Variations(1)

- Evolution requires genetic variation.
- Genetic Variation
  - In order for continuing evolution there must be mechanisms to increase or create genetic variation (i.e., mutation, recombination and gene flow) and mechanism to decrease it (natural selection, sexual selection and genetic drift).

Genetic Variations(2)

- Natural Selection
  - Some types of organisms within a population leave more offspring than others. Over time, the frequency of the more prolific type will increase. The difference in reproductive capability is called natural selection.
  - The most common action of natural selection is to remove unfit variants as they arise via mutation.
  - Natural selection can maintain or delete genetic variation.
  - Organisms do not perform any behaviors that are for the good of their species. An individual organism competes primarily with others of its own species for its reproductive success

Genetic Variations(3)

- Sexual Selection
  - Sexual selection is natural selection operating on factors that contribute to an organism's mating success. Traits that are a liability to survival can evolve when the sexual attractiveness of a trait outweighs the liability incurred for survival.
  - A male who lives a short time but produces many offspring is much more successful than a long-lived one that produces few. The former's genes will eventually dominate the gene pool of his species.

Genetic Variations(4)

- Mutation
  - The cellular machinery that copy DNA sometimes makes mistakes. These mistakes alter the sequence of a gene. A point mutation is a mutation in which one “letter” of the genetic code is changed to another. Lengths of DNA can also be deleted or inserted in a gene. Finally genes or parts of genes can become inverted or duplicated. Typical rates of mutation are between 10^{-10} and 10^{-12} mutations per base pair of DNA per generation.
  - Mutation creates new alleles. Each new allele enters the gene pool as a single copy amongst many. Most are lost from the gene pool, the organism carrying them fails to reproduce, or reproduces but does not pass on that particular allele.

Genetic Variations(5)

- Recombination
  - Recombination can be thought of as gene shuffling. In most sexually reproducing organisms, there are two of each chromosome type in every cell (one from mother and another from father). When an organism produces gametes, the genes end up with only one of each chromosome per cell. Recombination is a mechanism of evolution because it adds new alleles and combinations of alleles to the gene pool.
- Gene Flow
  - New organisms enter a population by migration from another population. If they mate within the population, they can bring new alleles to local gene pool.
  - Gene flow between more distantly related species occurs infrequently.

Summary(1)

- Evolution is a change in the gene pool of a population over time; it can occur due to several factors.
- Three mechanisms add new alleles to the gene pool: mutation, recombination and gene flow.
- Two mechanisms remove alleles, genetic drift and natural selection. Drift removes alleles randomly from the gene pool. Selection removes deleterious alleles from the gene pool.
- The amount of genetic variation found in a population is the balance between the actions of these mechanisms.

Summary(2)

- Natural selection can also increase the frequency of an allele. Selection that weeds out harmful alleles is called negative selection. Selection that increases the frequency of helpful alleles is called positive, or sometimes positive Darwinian, selection.
- A new allele can also drift to high frequency. But, since the change in frequency of an allele each generation is random, nobody speaks of positive or negative drift.

Summary(3)

- Except in rare cases of high gene flow, new alleles enter the gene pool as a single copy. Most new alleles added to the gene pool are lost almost immediately due to drift or selection; only a small percent ever reach a high frequency in the population.
- Even most moderately beneficial alleles are lost due to drift when they appear. But, a mutation can reappear numerous times.

Summary(4)

- The fate of any new allele depends a great deal on the organism it appears in. This allele will be linked to the other alleles near it for many generations. A mutant allele can increase in frequency simply because it is linked to a beneficial allele at a nearby locus. This can occur even if the mutant allele is deleterious, although it must not be so deleterious as to offset the benefit of the other allele. Likewise a potentially beneficial new allele can be eliminated from the gene pool because it was linked to deleterious alleles when it first arose. An allele "riding on the coat tails" of a beneficial allele is called a hitchhiker. Eventually, recombination will bring the two loci to linkage equilibrium. But, the more closely linked two alleles are, the longer the hitchhiking will last.

Summary(5)

- The effects of selection and drift are coupled. Drift is intensified as selection pressures increase. This is because increased selection (i.e. a greater difference in reproductive success among organisms in a population) reduces the effective population size, the number of individuals contributing alleles to the next generation.

Darwinian's Evolution

- 4 postulates
  - Individuals within species are variables
  - Some of the variations are passed onto offsprings
  - In every generation, more offspring are produced than can survive
  - The survival and reproduction of individuals are not random: the individuals who survive and go on to reproduce or who reproduce the most, are those with the most favorable variations. They are "naturally selected."

Natural Selection

- Natural evolution acts…
  - On individuals, but the consequences occur in the population
  - On individuals, not groups
  - On phenotypes, but evolution consist of changes in the genotype.
  - On existing traits, but can produce new traits.
- Evolution…
  - Is backward looking
  - Is not perfect
  - Is nonrandom
  - Is not progressive

- Results of Evolution are…
  - Creative, surprising, unexpected
  - Highly adapted to environmental niches
  - Unsupervised (no conscious design, no knowledge involved)
- Natural evolution had an extremely long time (3.7B years)
- Natural evolution acts in parallel

Terms from Genetics

- DNA(DeoxyribonucleicAcid): very large linear self-replicating molecules found in all living cells, the physical carrier of genetic information
- Chromosome: a single, very long molecule of DNA
- Gene: the base unit of inheritance, a length of DNA which exerts its influence on an organisms form and function by encoding and directing the synthesis of a protein
- Allele: one of a number of alternative forms of a gene that can occupy a given genetic locus on a chromosome
- Locus: location of a gene on a chromosome

- Evolution computation…
  - –Is based on biological metaphors
  - –Has great practical potentials
  - –Is getting popular in many fields
  - –Yield powerful, diverse applications
  - –Give high performance against low costs
  - –And its fun.
- Evolution Algorithms are inspired by natural evolution with four key elements:
  - –Group of individuals-population
  - –Source of variations-genetic operators
  - –Reproductive fitness-fitness
  - –Survival of fittest-selection

EC Variants and Their Origins

- Genetic Algorithm (GA) by John Holland in 1962 for numerical optimization
  - Simulate Darwinian evolution
  - Essential recombination (crossover) operation
  - Mainly binary representation
  - Schemata theory
- Evolutionary Programming (EP) by Larry Fogel for simulated intelligence in 1962; finite state machine representation
  - Close to Lamarckian representation
  - No recombination
  - Adaptive mutation
  - Apply to phenotypes directly

- Evolutionary Strategy (ES) by I. Rochenberg and H.P. Schwefel for numerical optimization in 1965
  - Real-valued representation
  - Mutation based
  - Adaptive mutation
- Genetic Programming (GP) by John Koza in 1989
  - Evolve LISP programs
  - Tree representation

- Particle Swarm Optimization (PSO) by James Kennedy and Russell Eberhart in 1995
  - Based on a metaphor of social interactions, searches a space by adjusting the trajectories of individual vectors called particle as they are conceptualized as moving points in multidimensional space. The individual particles are drawn stochastically toward the positions of their own previous best performance and the best previous performance of their neighbors.
- Ant Colony System (ACS) by Marco Dorigo in 1996
  - Inspired by how real ants are capable of finding the shortest path from a food source to their nest without using visual cues by exploiting pheromone information

Reading Materials

http://www.talkorigins.org/