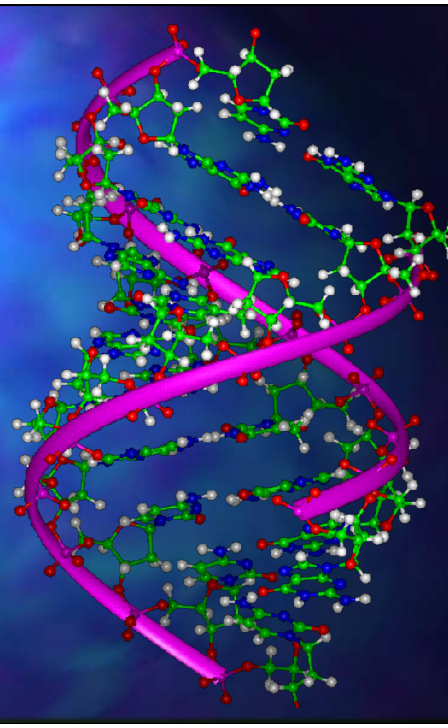
Evolutionary Computation

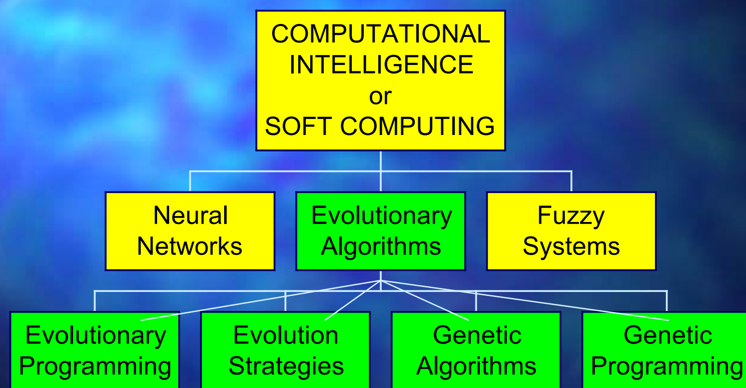
Solving problems with techniques inspired by biology.



What is Evolutionary Computation?

An abstraction from the theory of biological evolution that is used to create optimization procedures or methodologies, usually implemented on computers, that are used to solve problems.

Taxonomy



Components of Evolutionary Computing

- Genetic Algorithms
  - invented by John Holland (University of Michigan) in the 1960's
- Evolution Strategies
  - invented by Ingo Rechenberg (Technical University Berlin) in the 1960's
- Started out as individual developments, but have begun to converge in the last few years

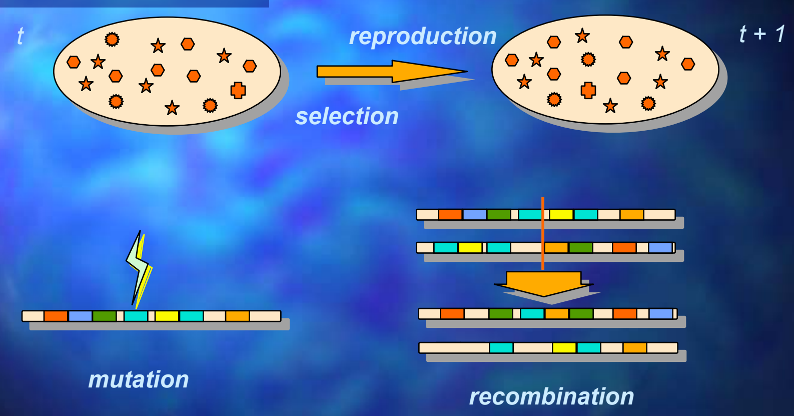
History

- L. Fogel 1962 (San Diego, CA): *Evolutionary Programming*
- J. Holland 1962 (Ann Arbor, MI): *Genetic Algorithms*
- I. Rechenberg & H.-P. Schwefel 1965 (Berlin, Germany): *Evolution Strategies*
- J. Koza 1989 (Palo Alto, CA): *Genetic Programming*

The Metaphor

EVOLUTION		PROBLEM SOLVING
Individual	↔	Candidate Solution
Fitness	↔	Quality
Environment	↔	Problem

The Ingredients



Intelligence and Evolution

- One way of understanding intelligence is as the capability of a creature to adapt its behaviour to an ever-changing environment
- We normally think of adaptation as changes in the characteristics (including behaviours) of a single animal in response to experiences over its history
- But adaptation is also change over the characteristics of a species, over the generations in response to environmental change
- A creature must deal with other creatures of the same species who *compete* for resources, mates etc.
- There is also *rivalry* from other species which may be a direct (predator) or indirect (food, water, land, etc.) threat
- In nature, evolution operates on populations of organisms, ensuring by *natural selection* that characteristics that serve the members well tend to be passed on to the next generation, while those that didn't die out

Evolution as Optimisation

- Evolution can be seen as a process leading to the *optimisation of a population's ability to survive* and thus reproduce in a specific environment. This ability is measured as *evolutionary fitness*
- This evolutionary fitness - the measure of the ability to respond adequately to the environment, is the quantity that is actually optimised in natural life
- Consider a normal population of rabbits. Some rabbits are faster than others. Any characteristic has a range of variation is natural, and is due to sexual reproduction and mutation
- We may say that the faster rabbits possess superior fitness, since they have a greater chance of avoiding foxes, surviving and then breeding
- If two parents have superior fitness, there is a good chance that a combination of their genes will produce an offspring with even higher fitness. We say there is *crossover* between the parents genes
- Over successive generations, the entire population of rabbits tends to become faster to meet their environment challenges in the face of foxes

Sexual Reproduction

- The key to understanding evolution in nature lies in the basic biology of reproduction
- The *chromosome* is the basic carrier of the *genes*, which are the units of the genetic code that control an individual's characteristics. Each gene can take on one of a number of possible forms, called an *allele*
- An allele is like the value of a variable, and represents the effect that a gene will have on the physical makeup of a body
- An individual's particular sequence of alleles is called the *genotype* and it determines the expression of characteristics in the individual's body, called the *phenotype*
- In humans, most cells contain 23 pairs of chromosomes. But reproductive cells (sperm and ova) contain 23 single chromosomes, because they must merge with their opposite number to produce a new offspring
- During fertilization of the ova by the sperm, the chromosomes from each recombine to form the 23 pairs of the new individual

Sexual Reproduction

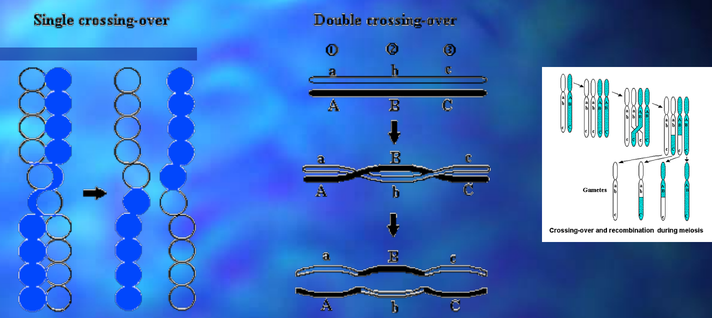


Image: Osvego City School District Regents Exam Prep Center

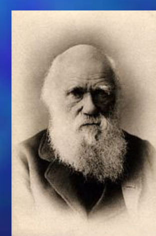
- Selection operates as survival and choice of mates between parents
- Recombination of genes is the mechanism that generates the next generation's characteristics
- Sometimes random copying errors, called *mutations*, occur during the recombination process. These are also important because they lead to new characteristics, usually useless, occasionally adaptive

Evolutionary Computation

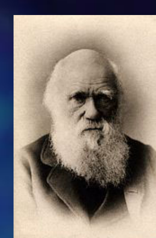
- *Evolutionary computation* simulates evolution on a computer. The result of such a simulation is a series of optimisation algorithms, usually based on a simple set of characteristics – the equivalent of genome
- Recall that optimisation iteratively improves the quality of solutions to some problem until an optimal (or at least feasible) solution is found
- Evolutionary computation is an umbrella term that includes *genetic algorithms* (Holland, 1975) , *evolution strategies* (Schwefel, 1981) and *genetic programming* (Koza, 1994)
- A-life researchers frequently experiment with populations of organisms put into artificial competition and subjected to the laws of natural selection

Darwinian Evolution

- Survival of the fittest
- Selection on phenotype
  - Through environment
- Genotypic inheritance
- Reproduction
- Blind variation



Darwinian Evolution



- Four Postulates
  1. Individuals within species are variable
  2. Some of the variations are passed on to offspring
  3. In every generation, more offspring are produced than can survive
  4. 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 favourable variations. They are naturally selected.

On the Origin of Species by Means of Natural Selection (Darwin 1859)

Nature of Natural Selection

Based on "Evolutionary Analysis (Freeman & Herron, 2001)"

- **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 exixting traits, but can produce new traits
- **Evolution...**
  - Is backward looking
  - Is not perfect
  - Is nonrandom
  - Is not progressive

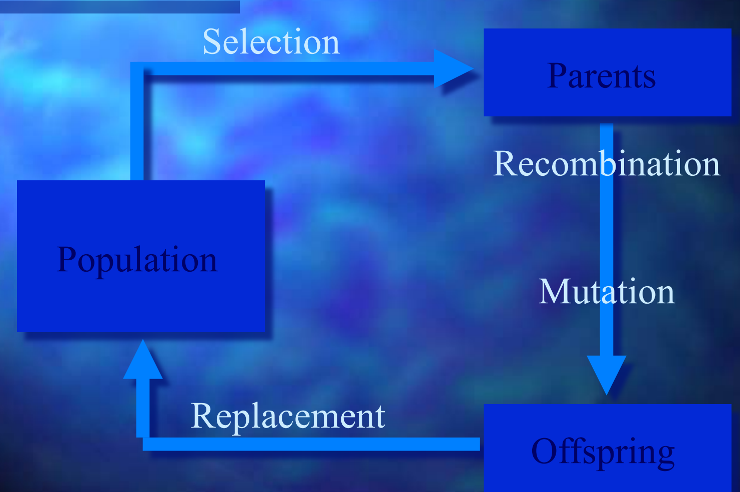
Evolutionary Algorithms

- Algorithms that are inspired by natural evolution
- Four Main Elements:
  - Group of Individuals - *Population*
  - Source of Variation - *Genetic Operators*
  - Reproductive Fitness - *Fitness*
  - Survival of the Fittest - *Selection*
- Search Process
  - Trial and Error
  - Recipe for chosing next trial

The Evolution Mechanism

- Increasing diversity by genetic operators
  - mutation
  - recombination
- Decreasing diversity by selection
  - of parents
  - of survivors

The Evolutionary Cycle



Domains of Application

- Numerical, Combinatorial Optimization
- System Modeling and Identification
- Planning and Control
- Engineering Design
- Data Mining
- Machine Learning
- Artificial Life

Performance

- Acceptable performance at acceptable costs on a wide range of problems
- Intrinsic parallelism (robustness, fault tolerance)
- Superior to other techniques on complex problems with
  - lots of data, many free parameters
  - complex relationships between parameters
  - many (local) optima

Advantages

- No presumptions w.r.t. problem space
- Widely applicable
- Low development & application costs
- Easy to incorporate other methods
- Solutions are interpretable (unlike NN)
- Can be run interactively, accommodate user proposed solutions
- Provide many alternative solutions

Disadvantages

- No guarantee for optimal solution within finite time
- Weak theoretical basis
- May need parameter tuning
- Often computationally expensive, i.e. slow

The Argument

Evolution has optimized biological processes;

therefore

Adoption of the evolutionary paradigm to computation and other problems can help us find optimal solutions.

The Concept of Natural Selection

- Limited number of resources
- Competition results in struggle for existence
- Success depends on fitness --
  - fitness of an individual: how well-adapted an individual is to their environment. This is determined by their genes (blueprints for their physical and other characteristics).
- Successful individuals are able to reproduce and pass on their genes

When changes occur ...

- Previously "fit" (well-adapted) individuals will no longer be best-suited for their environment
- Some members of the population will have genes that confer different characteristics than "the norm". Some of these characteristics can make them more "fit" in the changing environment.

Major Agents of Genetic Change in Individuals

- Mutation in genes
  - may be due to various sources (e.g. UV rays, chemicals, etc.)

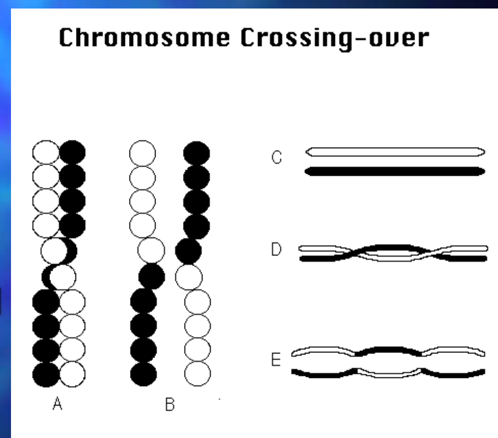
Location of Mutation

Start:
1001001001001001001001

After Mutation:
1001000001001001001001

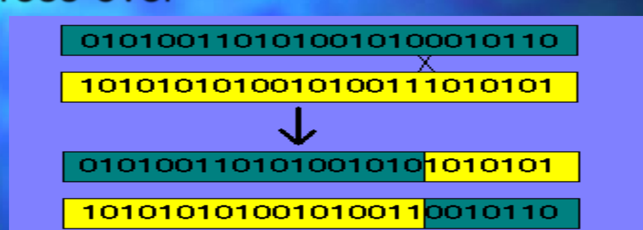
Major Agents of Genetic Change in Individuals (2)

- Recombination (Crossing-Over)
  - occurs during reproduction -- sections of genetic material exchanged between two chromosomes

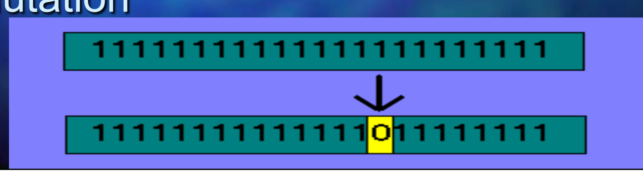


Genetic Operators

- Cross-over

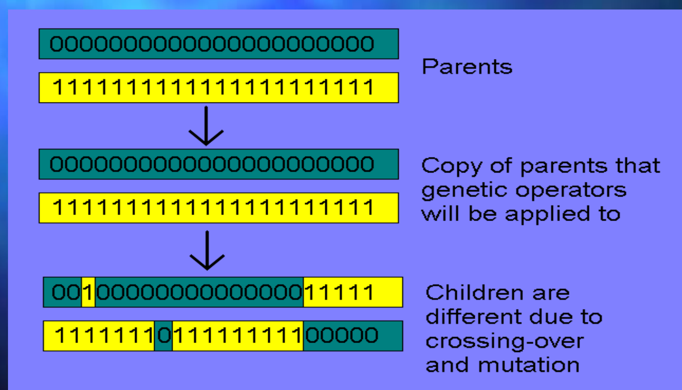


- Mutation



Production of New Chromosomes

- 2 parents give rise to 2 children



Why use evolution as a model for solving computational problems?

The Nature of Computational Problems

- Require search through many possibilities to find a solution
  - (e.g. search through sets of rules for one set that best predicts the ups and downs of the financial markets)
  - Search space too big -- search won't return within our lifetimes
  - These types of problems are better solved using a parallel approach

The Nature of Computational Problems (2)

- Require algorithm to be adaptive or to construct original solution
  - (e.g. interfaces that must adapt to idiosyncrasies of different users)

Why Evolution Proves to be a Good Model for Solving these Types of Problems

- Evolution is in effect a method of searching for the best (optimal) solution from a great number of possibilities
  - Possibilities -- all individuals
  - Best solution -- the most “fit” or well-adapted individual
- Evolution is a parallel process
  - Testing and changing of numerous species and individuals occur at the same time (or, in parallel)

Why Evolution Proves to be a Good Model for Solving these Types of Problems (2)

- Evolution can be seen as a method that designs new (original) solutions to a changing environment

When to Use Evolutionary Computing Strategies

- When space to be searched is large
- When the “best” solution is not necessarily required
- Approach to solving a problem not well-understood
- Problems with many parameters that need to be simultaneously optimized
- Problems that are difficult to describe mathematically

Genetic Algorithms

- Closely follows a biological approach to problem solving
- A simulated population of randomly selected individuals is generated then allowed to evolve

Basic Genetic Algorithm

- Step 1. Generate a random population of *n* chromosomes
- Step 2. Assign a fitness to each individual
- Step 3. Repeat until *n* children have been produced
  - Choose 2 parents based on fitness proportional selection
  - Apply genetic operators to copies of the parents
  - Produce new chromosomes

Fitness Function

- For each individual in the population, evaluate its relative fitness
- For a problem with *m* parameters, the fitness can be plotted in an *m*+1 dimensional space

Sample Search Space

- A randomly generated population of individuals will be randomly distributed throughout the search space

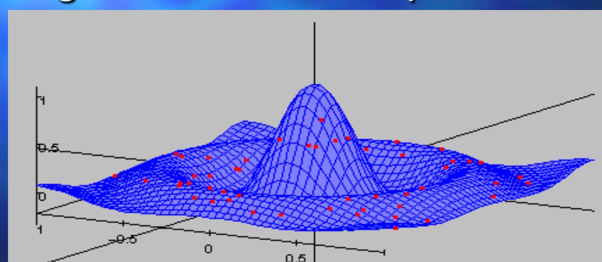


Image from http://www2.informatik.uni-erlangen.de/~jacob/Evolvica/Java/MultiModalSearch/rats.017/Surface.gif

Generations

- As each new generation of *n* individuals is generated, they replace their parent generation

- To achieve the desired results, 500 to 5000 generations are required

Ultimate Goal

- Each subsequent generation will evolve toward the global maximum
- After sufficient generations a near optimal solution will be present in the population of chromosomes

Dynamic Evolution

- Genetic algorithms can adapt to a dynamically changing search space
- Seek out the moving maximum via a parasitic fitness function
  - as the chromosomes adapt to the search space, so does the fitness function