

From the Origin of Species to Evolutionary Computation

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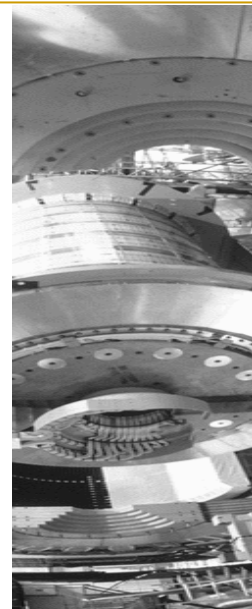


<http://gea.unex.es>



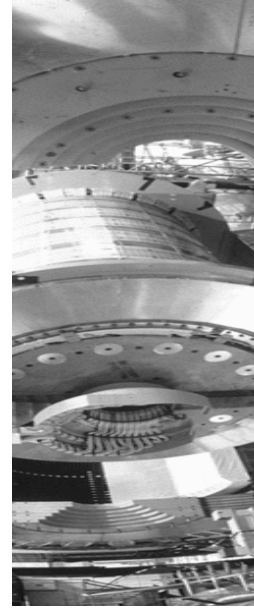
Summary:

- Evolution.
- Evolutionary Algorithms.



Summary:

- Evolution.
- Evolutionary Algorithms.



Evolution

- In biology, **evolution** is a change in the heritable traits of a population over successive generations, as determined by changes in the allele frequencies of genes.
 - Over time, this process can result in **speciation**, the development of new species from existing ones.

<http://www.wikipedia.org/>

Evolution

□ Different Theories:

- Lamarkian Evolution.
- Darwinian Evolution.
- Theory of Genetics.
- Modern Evolutionary Synthesis.

Evolution: Lamarkism

□ Lamark based his theory on two observations, in his day considered to be generally true:

- Use and disuse – Individuals lose characteristics they do not require (or use) and develop characteristics that are useful.
- Inheritance of acquired traits – Individuals inherit the traits of their ancestors.

Philosophie Zoologique, 1809

Evolution: Lamarckism



1. Giraffes stretch their necks to reach leaves high in trees.
2. This gradually lengthens their necks.
3. These giraffes have offspring with slightly longer necks.

Evolution: Lamarckism

- Cultural Evolution: Cultures and Societies develop over time.
- Meme: Unit of cultural information transferable from one mind to another (coined by R. Dawkins).
- Case of Interest: Free Software.

Evolution: Darwinism

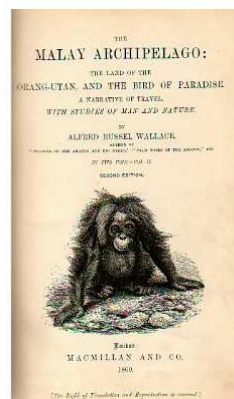
- One Theory: Natural Selection.
- Two Authors:

Charles Darwins.
Arthur Wallace.

Evolution: Natural Selection

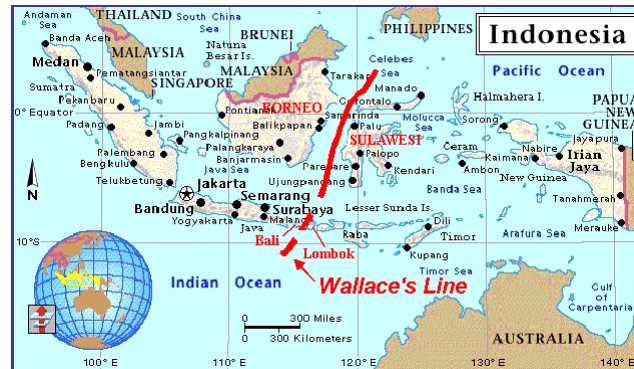


Alfred Wallace



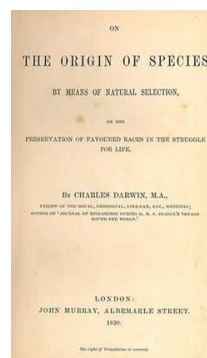
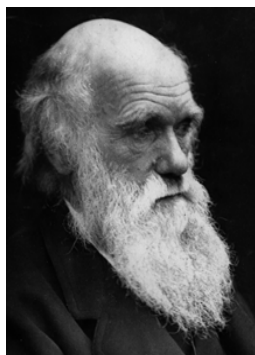
Evolution: Natural Selection

- Wallace Line (at Malay Archipelago) – Biogeography.



- *On the Law Which has Regulated the Introduction of Species, 1855.*

Evolution: Natural Selection



Charles Darwin

The Beagle around the world



Evolution: Natural Selection

- **Natural selection** is the process by which individual organisms with favorable traits are more likely to survive and reproduce than those with unfavorable traits.
- Darwin and Wallace reach the same ideas independently.

Evolution: Natural Selection

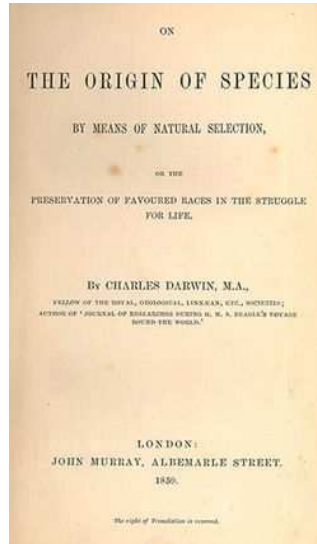
- Wallace knew Darwin's interest in the question of how species originate.
- He sent him his essay "On the Tendency of Varieties to Depart Indefinitely from the Original Type", and asked him to review it.
- It was the same theory that Darwin had worked on for twenty years.

Evolution: Natural Selection

- And published together their conclusions:

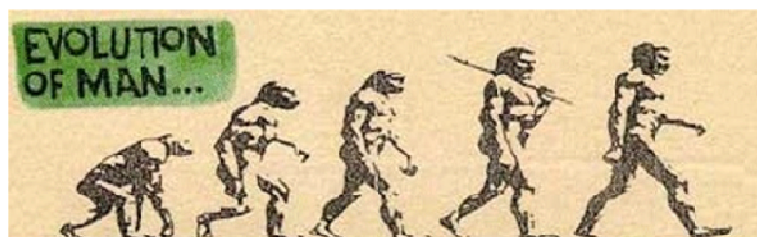
On the Tendency of Species to form Varieties; and on the Perpetuation of Varieties and Species by Natural Means of Selection. By CHARLES DARWIN, Esq., F.R.S., F.L.S., & F.G.S., and ALFRED WALLACE, Esq. Communicated by Sir CHARLES LYELL, F.R.S., F.L.S., and J. D. HOOKER, Esq., M.D., V.P.R.S., F.L.S. &c.

Evolution: Natural Selection



Natural Selection

- ✦ Individual organism with favourable traits are more likely to survive and reproduce.



Natural Selection: Some Problems

- Darwin was able to observe variation, infer natural selection and thereby adaptation.
- He did not know the basis of heritability.
- It seemed that when two individuals were crossed, their traits must be *blended* in the progeny

Theory of Genetics



- Gregor Mendel

Population Genetics

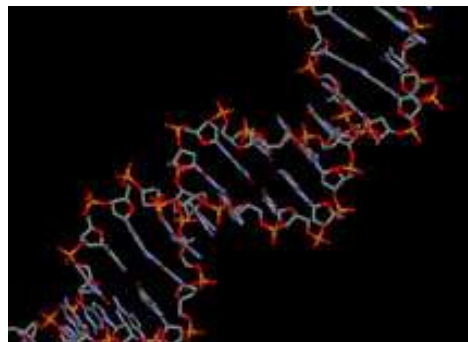
- **Population genetics** is the study of the allele frequency distribution and change under the influence of the four evolutionary forces:
 - natural selection, genetic drift, mutation, and gene flow.
- It also takes account of population subdivision and population structure in space.
- As such, it attempts to explain such phenomena as
 - adaptation and speciation.



Founders: Sewall Wright, J. B. S. Haldane and R. A. Fisher

Theory of Molecular Evolution

- **Molecular evolution** is the process of evolution at the scale of DNA, RNA, and proteins.

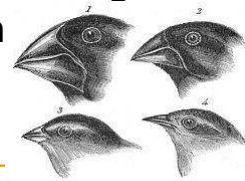


Modern Synthesis

- Darwin and Wallace observe variation, and infer natural selection and adaptation.
- Population-Genetics (Mendelian genetics), solved by Fisher, Wright and Haldane.
- Avery identified DNA as the genetic material.
- Watson and Crick showed how genes were encoded in DNA.

Can we watch evolution?

- Peter & Rose Mary Grant (Princeton University)
- They are noted for their work on Darwin's Finches on the Galapagos Island named Daphne Major.
- The Grants spent six months of the year each year since 1973 capturing, tagging, taking blood samples, and releasing finch the islands.

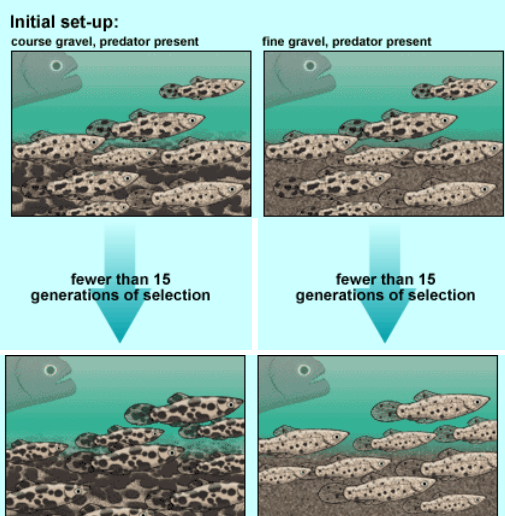


1. *Geospiza magnirostris*
2. *Geospiza fortis*
3. *Geospiza parvula*
4. *Certhidea olivacea*
Finches from Galapagos Archipelago

Can we watch evolution?

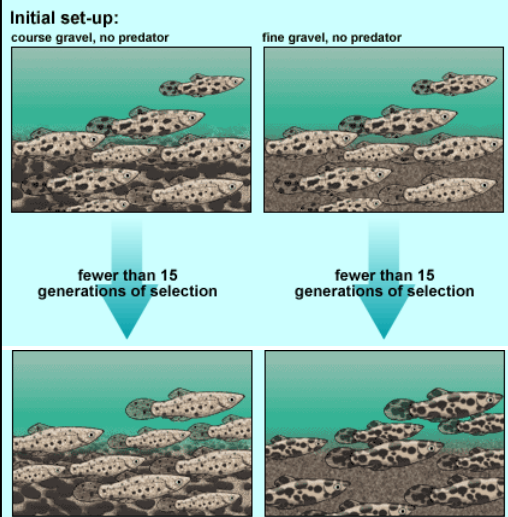
- They won the 2005 **Balzan Prize** for Population Biology [2].
- They demonstrated evolution in action in Galápagos finches:
 - very rapid changes in body and beak size in response to changes in the food supply are driven by natural selection. They also elucidated the mechanisms by which new species arise and how genetic diversity is maintained in natural populations.

Can we Watch evolution



- John Endler University of California.
- Evolution and ecology of animal color patterns, vision, and morphology.
- Relationship among:
 - Predation Level.
 - Guppies coloration patterns.
 - Island Drainages.
- Large Level or Predation: Guppies try to hide.

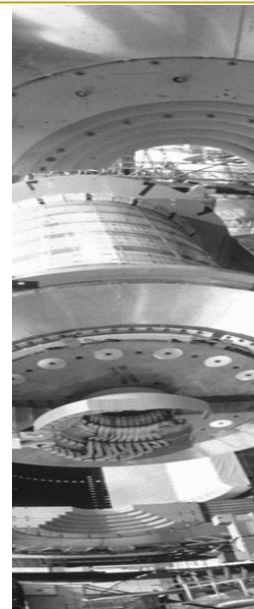
Algunas pruebas



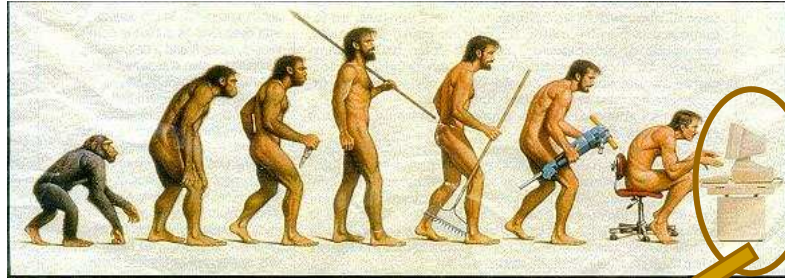
- Low Level of Predation: Guppies try to show.

Summary:

- Evolution.
- Evolutionary Algorithms.



Evolutionary Computation: The next step.



Artificial Evolution

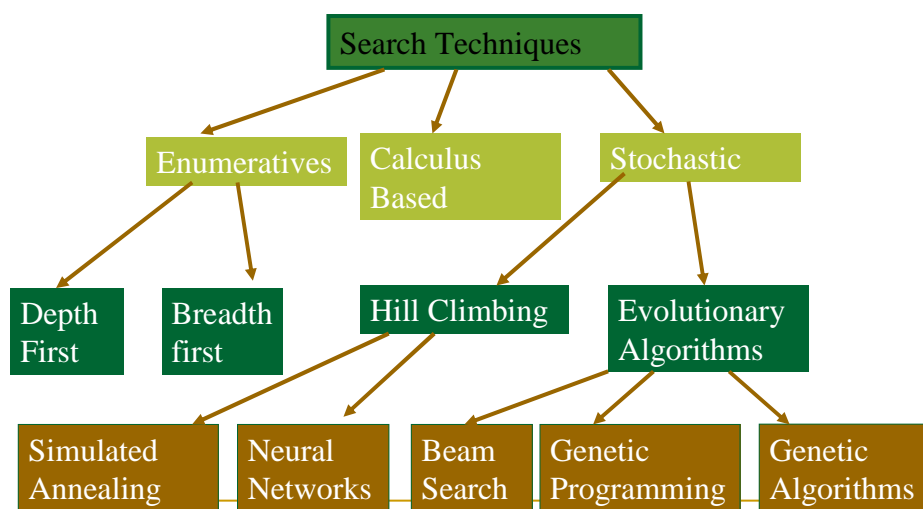
Evolutionary Computation

- Subfield of Artificial Intelligence.
- Involves Combinatorial Optimization problems.
- Stochastic and parallel by nature, based on populations.
- Includes:
 - Evolutionary Algorithms.
 - Swarm Intelligence.
 - Artificial Life, Inmune Systems...

What are Evolutionary Algorithms?

- Generic population-based metaheuristic optimization algorithms.
- inspired by biological evolution: reproduction, mutation, recombination, natural selection and survival of the fittest
- Can be also considered a Search technique.

Different Search Techniques

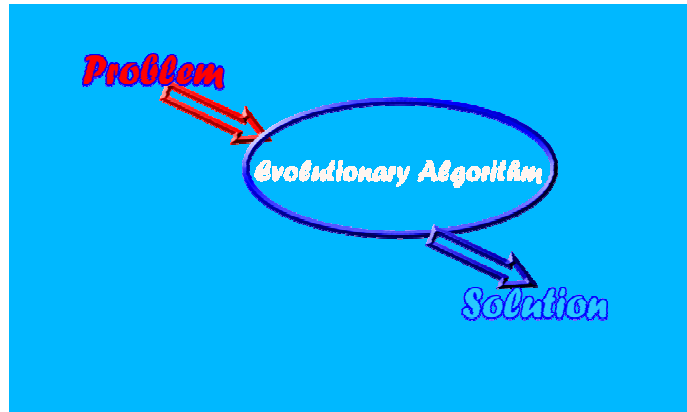


As classified by Banzhaf et al

Introduction

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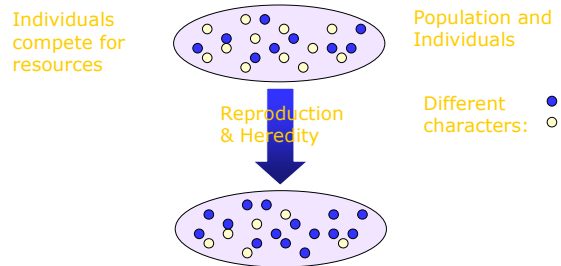
How Do EAs work?



How Do EAs work?

- They find acceptably good solutions, acceptably quick.
- Don't require complex mathematics to run.
- Don't need to know the shape of the objective function.
- Well suited for parallel execution.
- Get a set of answers to the problem.

How do EAs work?



Main Conditions

For Evolutionary Algorithms to work:

- Individuals can reproduce.
- Variations affect individual traits and their survival
- Characters are transferred from parents to children by inheritance.
- Individuals struggle for resources.

VARIATION.
INHERITANCE
SUPERPOPULATION

How does an Ea Work?

■ Summary:

- $T=0$;
- Generate and Evaluate initial population $[P(t)]$
- While *end-condition* not reached do
 - $P'(t)=\text{variation } [P(t)]$
 - Evaluate $P'(t)$
 - $P(t+1)=\text{select } [P'(t),P(t)]$
 - $T=t+1$
- end while

How to build an EA

■ 4 Ingredients:

- A Genetic Encoding of possible solutions.
- An initialization function: How to create the initial population.
- A Fitness Function for evaluating individuals.
- Genetic Operators.
- Values for the parameters of the Algorithm

(Michalewicz 1996)

Basic Operations

- Evaluation.
- Selection.
- Crossover.
- Mutation.

Why do they work?

- Informally, EAs perform two tasks:
 - Exploration of the search space.
 - Exploitation of good areas.
- Rigorously: Convergence has been mathematically demonstrated.
 - Nevertheless, consider the No Free Lunch Theorem.

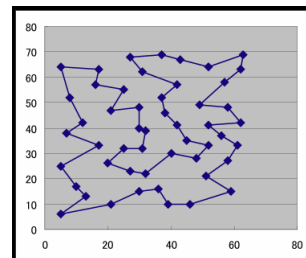
Fitness Landscape

- **Candidates solutions** are evaluated according the problem to be solved.
- The **fitness function** computes the fitness values when evaluating individuals.



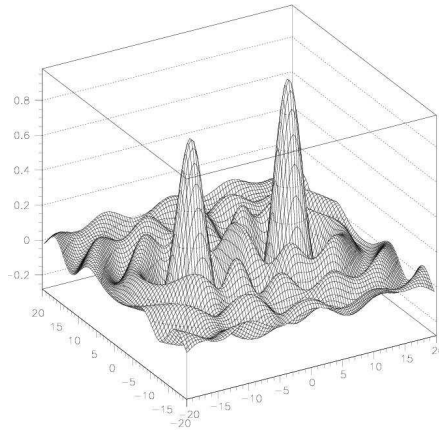
Genotype - Phenotype

- **Phenotype:** □ Domain-dependent representation of a potential solution
- **Genotype:** □ Domain-independent representation of a potential solution



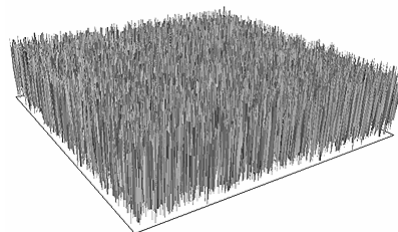
Fitness Landscape

- The **fitness landscape** corresponds to all possible fitness values for all possible individuals that could be generated for the problem at hand.



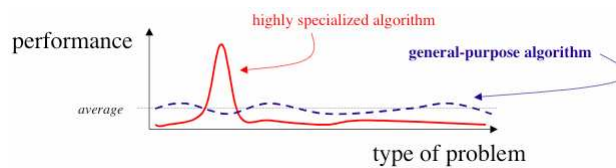
Fitness Landscape

- Be careful:
 - Not all the problems can be solved with GAs.



Fitness Landscape

- Be careful:
 - The Free Lunch Theorem: There not exist a better optimization technique for all the possible optimization problems.



Wolpert, D.H., Macready, W.G. (1997), *No Free Lunch Theorems for Optimization*, IEEE Transactions on Evolutionary Computation **1**, 67.

Different flavours

- *Evolution Strategies* [Rechenberg 1973], [Shwefel 1975].
- *Evolutionary Programming* [Fogel 1962].
- *Genetic Algorithms* [Holland 1975].
- *Genetic Programming* [Koza 1992].

Problems solved with EAs

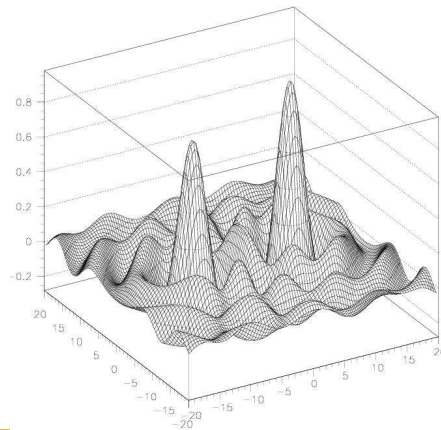
- [Air-Injected Hydrocyclone Optimization](#) Artificial Intelligence Assignment of Radio-Link Frequencies [Automated Parameter Tuning for Sonar Information Processing](#) Bin Packing Clustering Communication Network Design [Conformational Analysis of DNA](#) Data Mining [Dynamic Anticipatory Routing in Circuit-Switched Telecommunications Networks](#) Electronic-Circuit Layout Flow Control [Fuzzy Controller Design](#) Gas-Pipeline Control [Genetic Synthesis of Neural Network Architecture](#) Hybrid EC Systems Image Generation and Recognition [Interdigitation \(Engineering Design Optimization\)](#) Job Shop Scheduling Knowledge Acquisition Learning Mathematical and Numerical Optimization [Models of International Security](#) [Multiple Fault Diagnosis](#) [Neural Network Design](#) [Nonlinear Dynamical Systems](#) [Ordering Problems \(TSP, N-Queens, ...\)](#) Parallel Process Scheduling [Parametric Design of Aircraft](#) Portfolio Optimization [Query Optimization in Databases](#) Real Time Control of Physical Systems [Robot Trajectory Generation](#) [Sequence Scheduling \(Genetic Edge Recombination\)](#) [Strategy Acquisition](#) Symbolic Integration and Differentiation Time-Serie Analysis and Prediction [Traveling Salesman \(Genetic Edge Recombination\)](#) [Validation of Communication Protocols](#) VLSI Design WYSIWYG Artistic Design X-Ray Crystallography

Problems Solved with EAs

- [Virtual creatures](#)
- <http://cs.felk.cvut.cz/~xobitko/ga/>
- <http://www4.ncsu.edu/eos/users/d/dhloughl/public/stable.htm>
- <http://www.rennard.org/alife/english/gavgb.html>

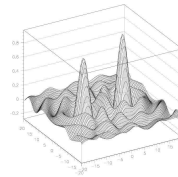
Genetic Algorithms

- Let's Begin with a problem:

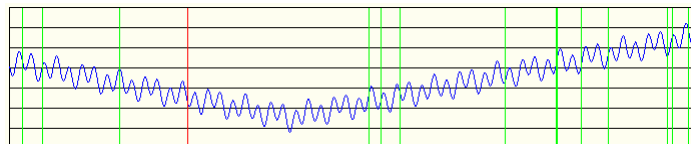


Genetic Algorithms

- Let's Begin with a problem:



- Consider a simpler problem:

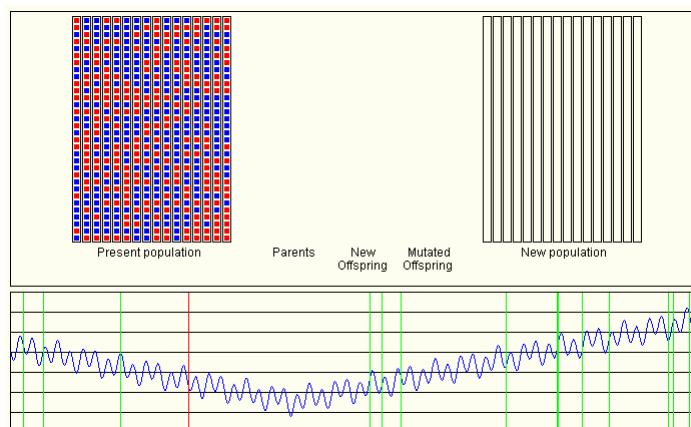


<http://cs.felk.cvut.cz/~xobitko/ga/>

Genetic Algorithms

- What we need:
 - A Genetic Representation of the solution domain (bit string?).
 - A Fitness Function to evaluate the solution domain.
 - And also:
 - Initialization.
 - Selection.
 - Reproduction (Crossover, Mutation).
 - Termination criteria.

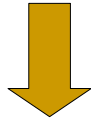
Genetic Algorithms



<http://cs.felk.cvut.cz/~xobitko/ga/>

Genetic Algorithms: Crossover

S1=11`11010101 F(S1)
S2=11`10110101 F(S2)



S1'=11`10110101 F(S1')
S2'=11`11010101 F(S2')

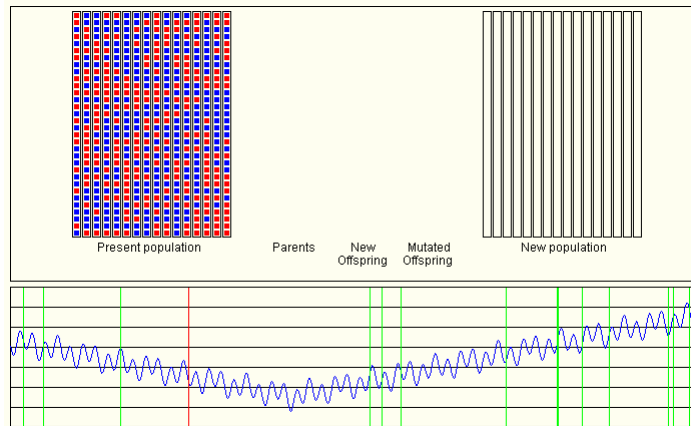
Genetic Algorithms: Mutation

S1' = 11101`10101 F(S1')



S1'' = 11101`00101 F(S1'')

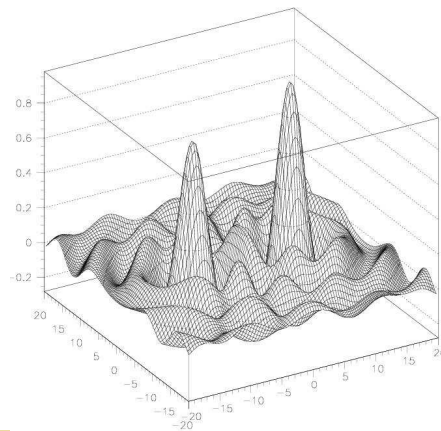
Genetic Algorithms



<http://cs.felk.cvut.cz/~xobitko/ga/>

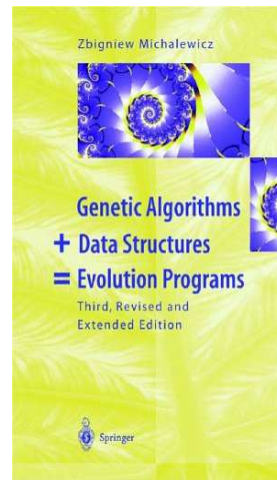
Genetic Algorithms

- A problem with several optima.
- GAs can find each of the optima on several runs.



Bibliografía

- **Genetic Algorithms + Data Structures = Evolution Programs** by Zbigniew Michalewicz



Tools

- GALOPS (Garage Lab, Michigan State University). <http://garage.cse.msu.edu/>
- GAlib. <http://lancet.mit.edu/ga/>
- PGAPack.
- Dream Project.
- Paradiseo.

Questions?