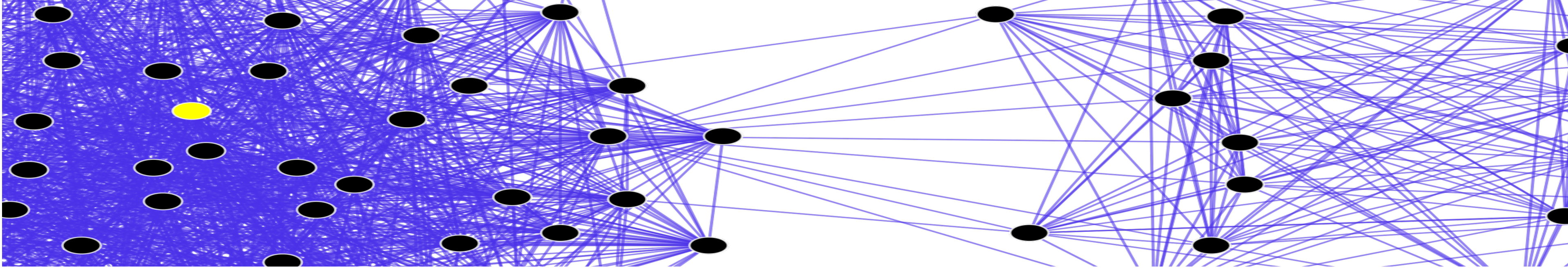

# Computational Intelligence

## Master in Artificial Intelligence

## 2021-22

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## Introduction to Evolutionary Computation

Soft Computing Research Group

UNIVERSITAT POLITÈCNICA DE CATALUNYA
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# Natural Selection General Law

**(taken from *The Origin of Species*)**

**IF** there are organisms that reproduce
AND offspring inherit traits from their progenitor(s)
AND there is a variability of traits
AND the environment cannot support all members of a growing population (competition for limited resources)

**THEN** those members of the population with *less-adaptive traits* (determined by the environment) will die
AND those members with *more-adaptive traits* (determined by the environment) will prosper

# Origins of the Theory of Natural Selection

| Year | Event |
|---|---|
| 1831-1836 | Second expedition of the HMS Beagle visiting mainly |
| | SouthAmerica and Pacific islands (e.g. Galapagos) |
| 1839 | *The Voyage of the Beagle* published by Charles Darwin |
| 1842 | Darwin’s unpublished draft of his theory |
| 1858 | Article sent to Darwin by Alfred Russel Wallace |
| | describing his own theory of natural selection |
| 1859 | *On the Origin of the Species* published by Darwin |
| 1865 | Mendel published *Experiments in Plant Hybridization* |
| | (in German) setting the foundations of Genetics |
| 1869 | *The Malay Archipelago* published by Russel Wallace |
| | and dedicated to Darwin |

# It's a long and winding road ...

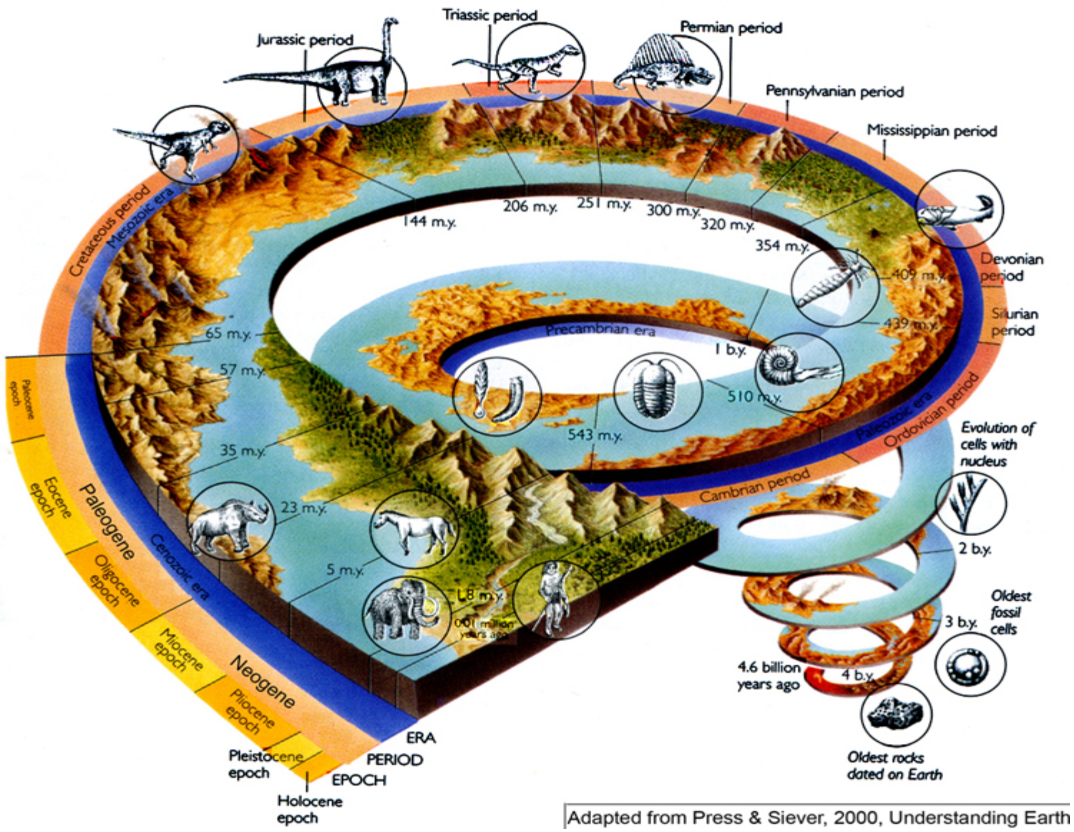
## History of life

Interaction of different biological (physical/behavioral) **processes** operating on **individuals** and **species**

These **processes** are:

- Reproduction
- Mutation
- Competition
- Selection

collectively leading to **<u>EVOLUTION</u>**



Adapted from Press & Siever, 2000, Understanding Earth

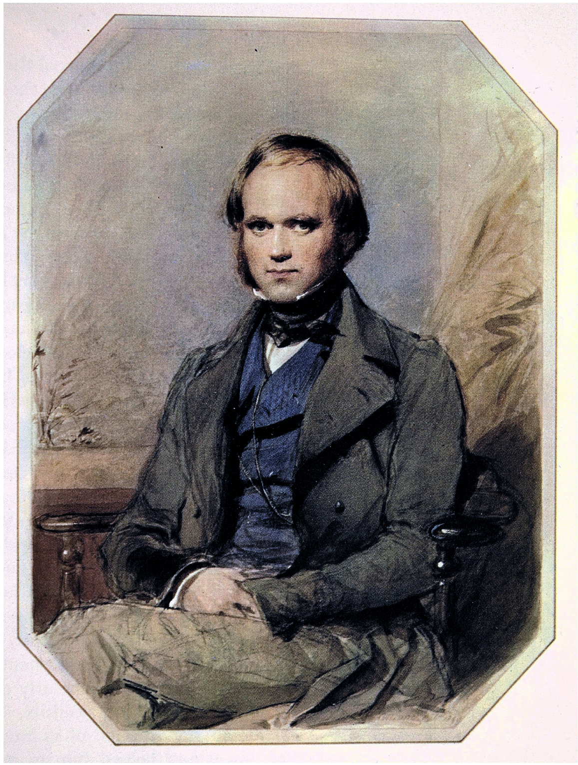
# What is EVOLUTION?

Evolution is **change** (structural, physiological, behavioral) which occurs over time through **interaction** with the **environment**

- What major mechanisms are responsible for evolution? **mutation** and **natural selection**
- **Mutations**
  - Caused by a copying error in the sequence of A, C, G and T nucleotides when DNA is copied
  - This error may cause a change in a protein leading to a modification in the individual that is inheriting the gene
- For example, the new instruction could be "build a human baby with a longer middle finger"
- Since the change is random and unpredictable, it is very difficult to tell *a posteriori* which gene(s) may have been involved

# What is EVOLUTION?

**Charles Darwin** (and independently **Alfred Russell Wallace**) suggested that evolution occurs, and he was the first to suggest a plausible mechanism and to present an overwhelming case that evolution occurs.



Careful!

- Darwin used the word **selection** but nature doesn't care about who gets “selected” for survival
- Evolution has no goal. Certain individuals survive because they have structural, physiological, behavioral or other characteristics that prevent them from being eliminated *before* reproduction

# What is EVOLUTION?

Darwin defined evolution as **“descent with modification”**

He didn't know about genetics ...

(he couldn't know that these characteristics were caused by *mutations* and that they could be passed on through the *genes)*

**<u>How does it work?</u>**

After a mutation changes an individual, the environment determines if the change gives the individual an advantage. If the new trait is helpful, the mutated individual is more likely to survive, reproduce and **pass the new trait to offspring**

# What is EVOLUTION?

Mutation is not the only source of genetic variation. Other mechanisms (sometimes interacting) are **genetic drift**, **gene flow**, and **symbiosis:**

- **Genetic drift** happens when random events cause gene frequencies to vary between generations (more important in small populations)

  Example: a car-bus accident
- **Gene flow** (or migration) is the movement of genes in a species from one population to another as the result of inter-breeding

  Example: evidence of gene flow between cultivated plants and their wild relatives
- **Symbiosis** is the cooperative (close and often long-term) interaction between different organisms

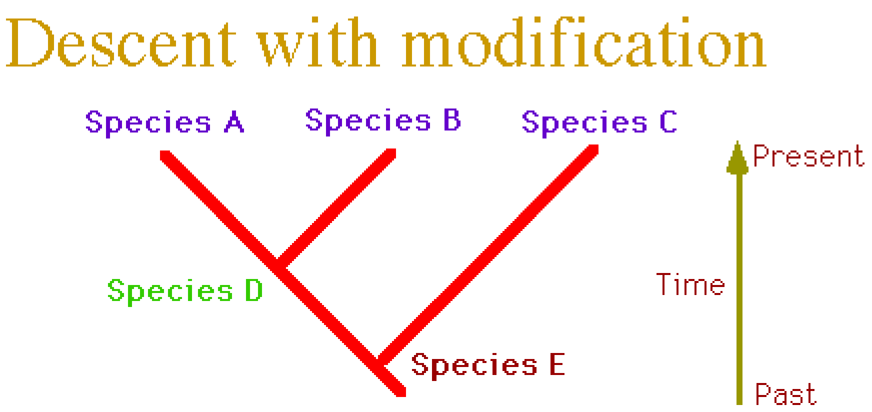
  Example: in the ocean, when shrimp and gobies clean fish, receiving nutrients

Natural selection is not the only mechanism that changes organisms over time … but it is the only known process that seems to *adapt* organisms over time

# What is EVOLUTION?

A **phylogenetic tree** shows the inferred evolutionary relationships among various biological species —their phylogeny— based upon similarities and differences in their physical or genetic characteristics

**Hypothesis**: all species alive today have evolved from simpler, more primitive forms of life. Since every living thing uses the same genetic code, life descended from a distant common ancestor that had that code:




A **cladogram** (from Greek *clados* (branch) and *gramma* (character))

# Evidence for descent with modification

Biogeography

Functional morphology

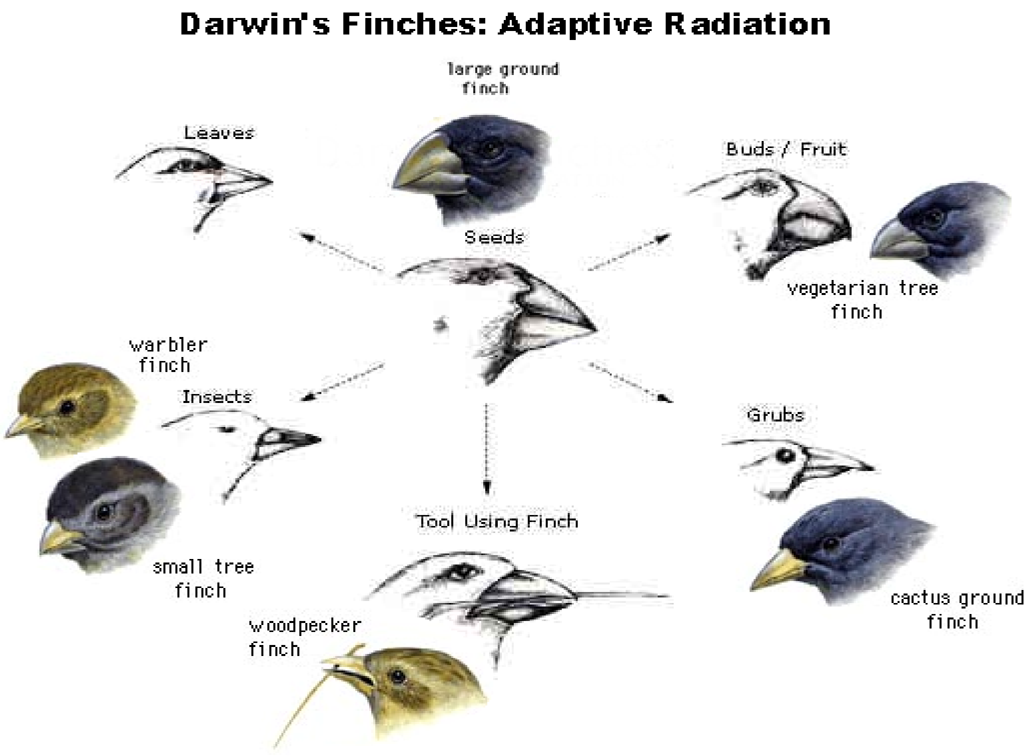
Paleontology

Comparative embryology

Animal and plant breeding

Molecular biology

# Evidence from biogeography: an example



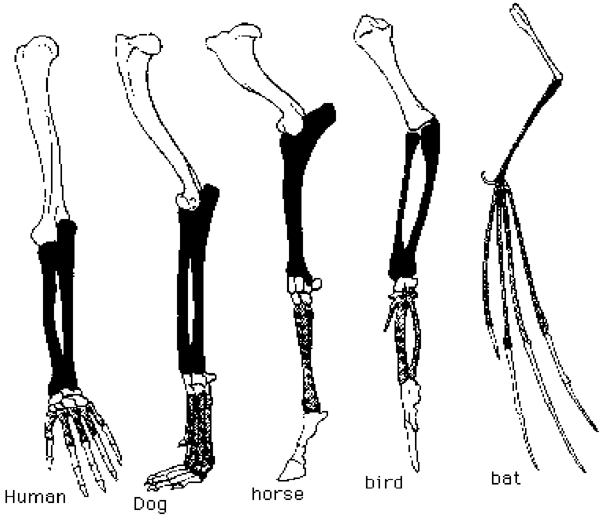

**Each island has a slightly different species of finch, all of which appear close to a single species found on the South American mainland**

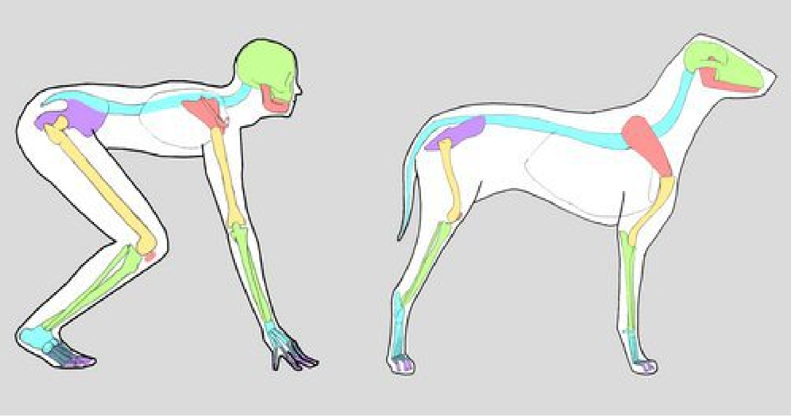
**The finch has adapted to take advantage of feeding in different ecological niches**

**For example, the finches who eat grubs have a thin extended beak to poke into holes in the ground and extract the grubs**

**Molecular basis of beak evolution:** Developmental research in 2004 found that bone morphogenetic protein 4 (BMP4), and its differential expression during development resulted in variation of beak size and shape among finches.

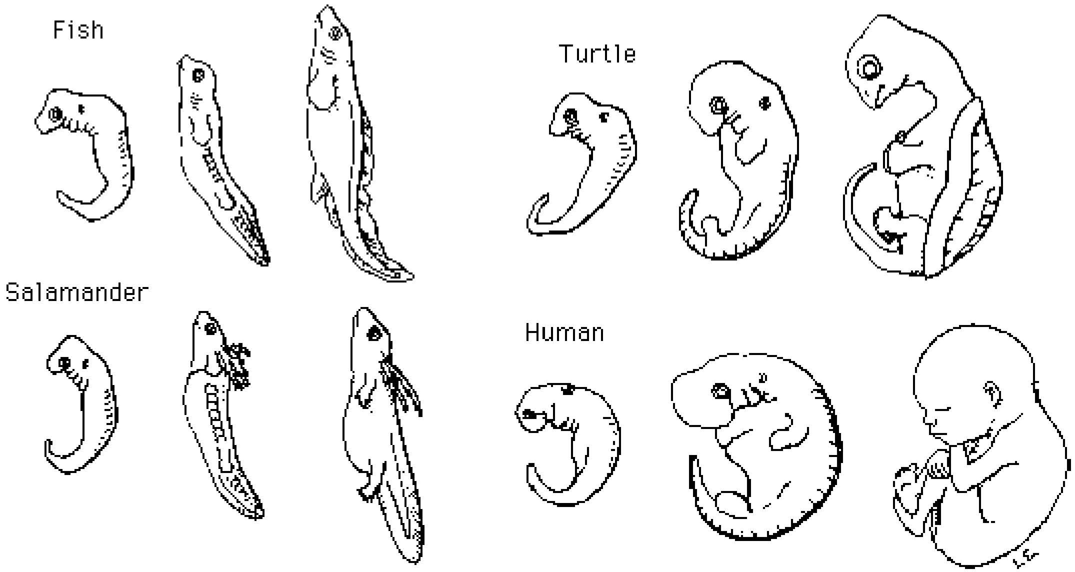
# Evidence from functional morphology: an example



**Homologous structures** are anatomical resemblances representing variations on a structural theme present in a common ancestor

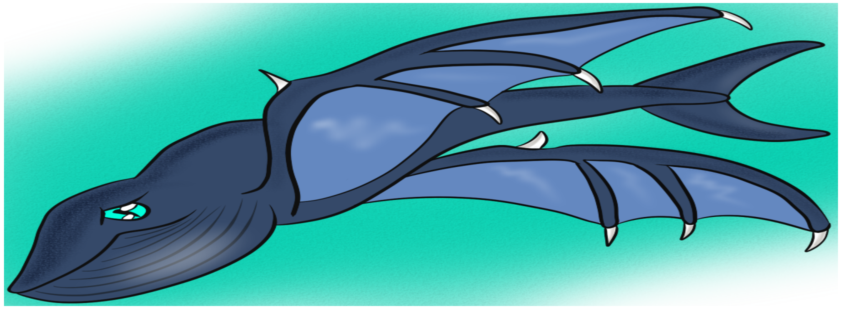
# Evidence from comparative embryology: an example




Early **embryos** of very different organisms closely resemble each other

# Evidence from molecular biology: an example

The **biochemistry** of a bat is much closer to that of a whale, rather than that of a bird … not expected unless bat and whale have a more recent common ancestor than bat and bird



**Example: paternity testing** (how do you tell who's dad?)

→ **DNA profiling** (aka genetic fingerprinting) can determine whether two individuals are biologically <u>parent and child</u>, or the likelihood of someone being a biological <u>grandparent to a grandchild</u>

# Modern example of natural selection “in action”

## Rabbits & myxomatosis

In 1859, 24 cute and cuddly rabbits were brought to Australia. By 1886, the army of rabbits was advancing at over 66 miles a year, smashing through “rabbit-proof” barriers. They spanned entire Australia by 1907. In the 1940s, it was estimated that rabbit population was as high as 800 million.

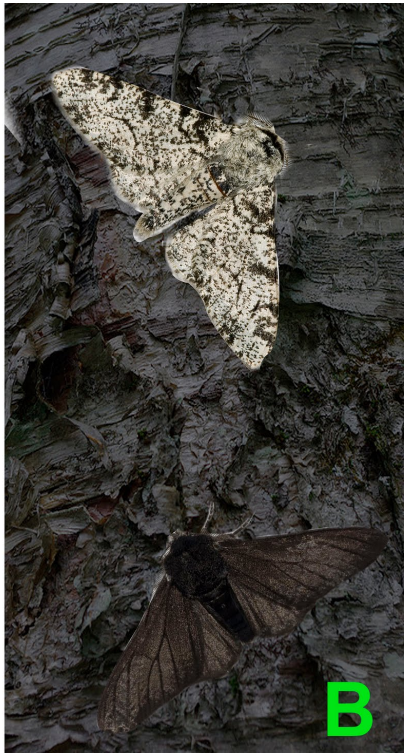
**Myxomatosis** was introduced in 1950, with an initial mortality rate of 99.9%, quickly dwindling to 95%. Mortality rate today is about 40%.

# Modern example of natural selection “in action”

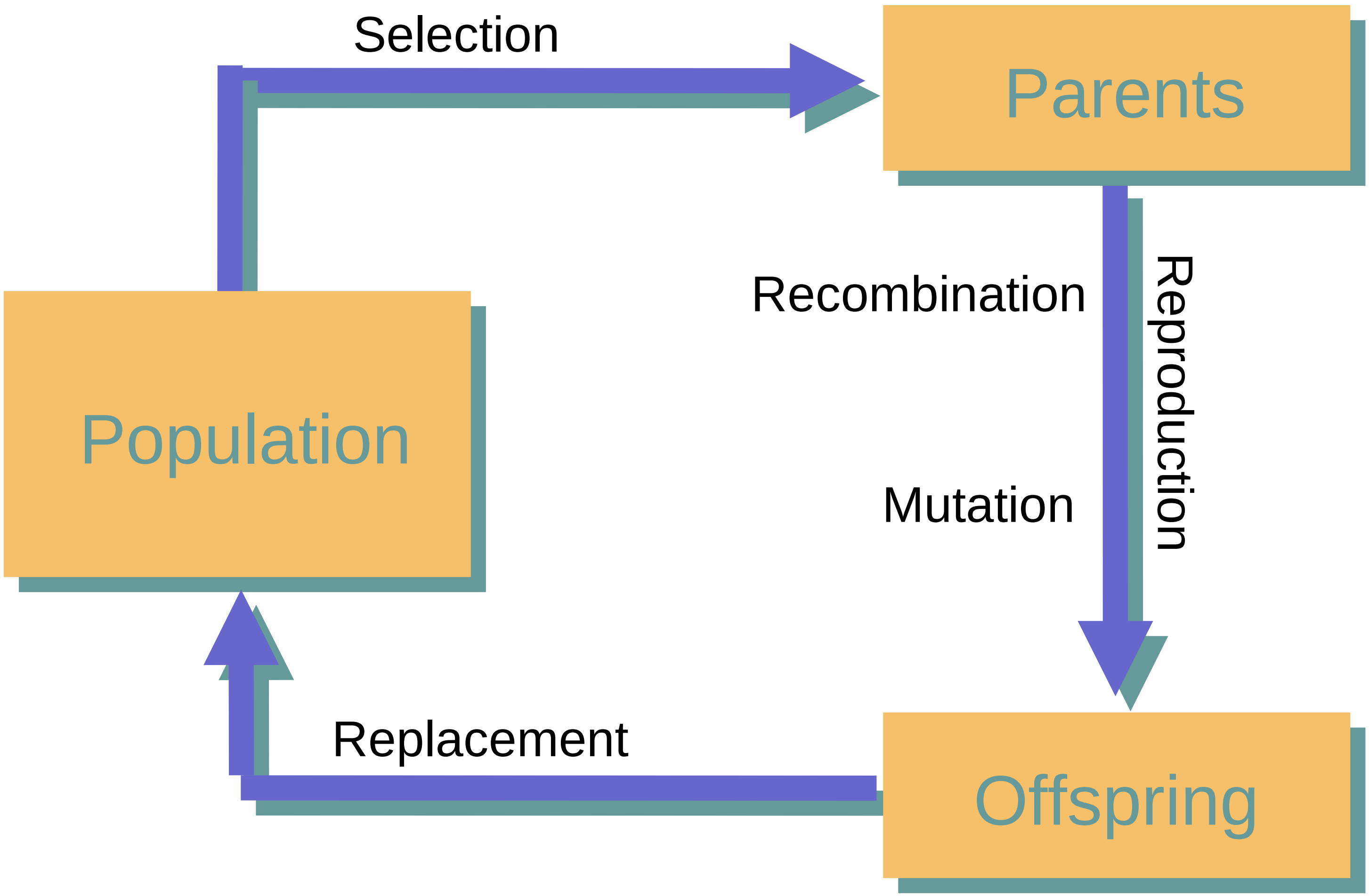
## The peppered moth

The black and patterned (peppered) moth populations changed drastically during the **Industrial Revolution** in England. Soot blackened the trees and killed the lichen growing on the trees. The new environment elicited changes in the number of both peppered and black moths (B)

As pollution controls were put in place, the lighter form of the moth prevailed again (A)

# The evolutionary cycle in Nature



# Some biological terms used in EC

- **Chromosome** (individual): a candidate solution to the problem
- **Gene**: single variable to be optimized
- **Locus** (plural *loci*): the specific location of a gene or position on a chromosome
- **Allele**: possible assignment of a value to a variable (a locus in a gene)

# What is an Evolutionary Algorithm?

An EVOLUTIONARY ALGORITHM is a computer simulation in which a population of abstract representations of candidate solutions (**individuals**) to an optimization problem are stochastically **selected**, **recombined**, **mutated**, and then removed or kept, based on their relative **fitness** to the problem:

1. maintain population of individuals

2. select individuals according to fitness

3. breed them & mutate the offspring

4. form a new generation using the offspring and the old one

# Basic evolutionary algorithm

```
t := 0
Initialize P(t)
Evaluate P(t)
WHILE NOT (termination condition) DO
    t := t+1
    Select P'(t) from P(t-1)
    Recombine and/or Mutate P'(t)
    Evaluate P'(t)
    Form P(t) by using P'(t) and P(t-1)
  END
```

# Weak methods vs. strong methods

- Weak methods = general methods

  (methods that work reasonably well on a large variety of problems)

- Strong methods = specific methods

  (methods specially designed to do a good job on particular problems)

# The 7 main components of an EA

- **coding function** to represent potential solutions as valid chromosomes
- **fitness function** to evaluate the goodness of individuals
- **initialization method** to create the initial population
- **selection operator** to determine which individuals will undergo variation
- **replacement strategy** to decide which individuals will be allowed in the next generation
- **genetic variation operators** (mutation, recombination) to perform the variation
- **termination criterion** to stop the process

# Behaviour of components

- Selection, replacement and fitness
  **DECREASE** diversity in a population
- Genetic operators (mutation, recombination)
  **INCREASE** diversity in a population

exploration $\rightleftarrows$ exploitation

# Fitness functions (informal ideas)

"However many ways there may be of being alive, it is certain there are vastly more ways of being dead, or rather not alive."

Richard Dawkins in *The Blind Watchmaker*

"As things get better, increases in fitness show diminishing returns: more food is better, but only up to a point. But as things get worse, decreases in fitness can take you out of the game: not enough food and you're dead."

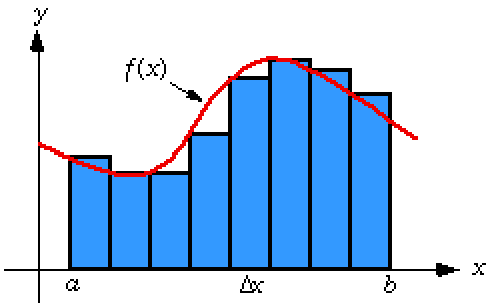
Tim Ketelaar, quoted in Steven Pinker's *How The Mind Works*

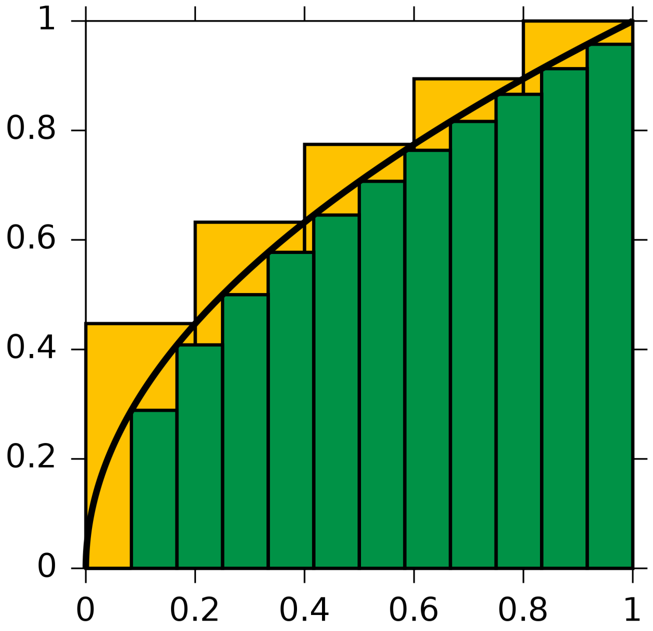
# Fitness functions (formal ideas)

## Design ideas:

**Left:** my “true” fitness function is very costly: use a surrogate

**Right:** my “true” fitness function is impossible to express or compute: use a bounding function (the tighter, the better)



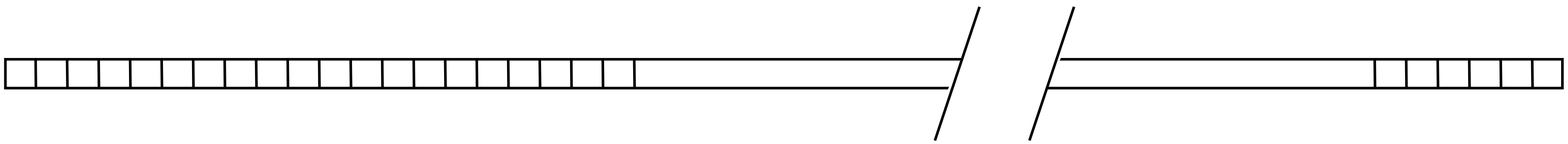
# Termination criteria

1) Maximum number of generations
2) Maximum number of fitness function evaluations
3) Avg/max (relative) fitness function improvement below some tolerance (over a period of time)
4) Diversity below some tolerance (idem)
5) Closeness to optimum below some tolerance

or a **combination** thereof

# The COP (counting ones problem)

Problem: a string of *n* binary variables, $x \in \{0, 1\}^n$ :



Fitness:

$$F(x) = \sum_{i=1}^{n} f(x_i)$$

Objective: maximize the number of ones in the string.

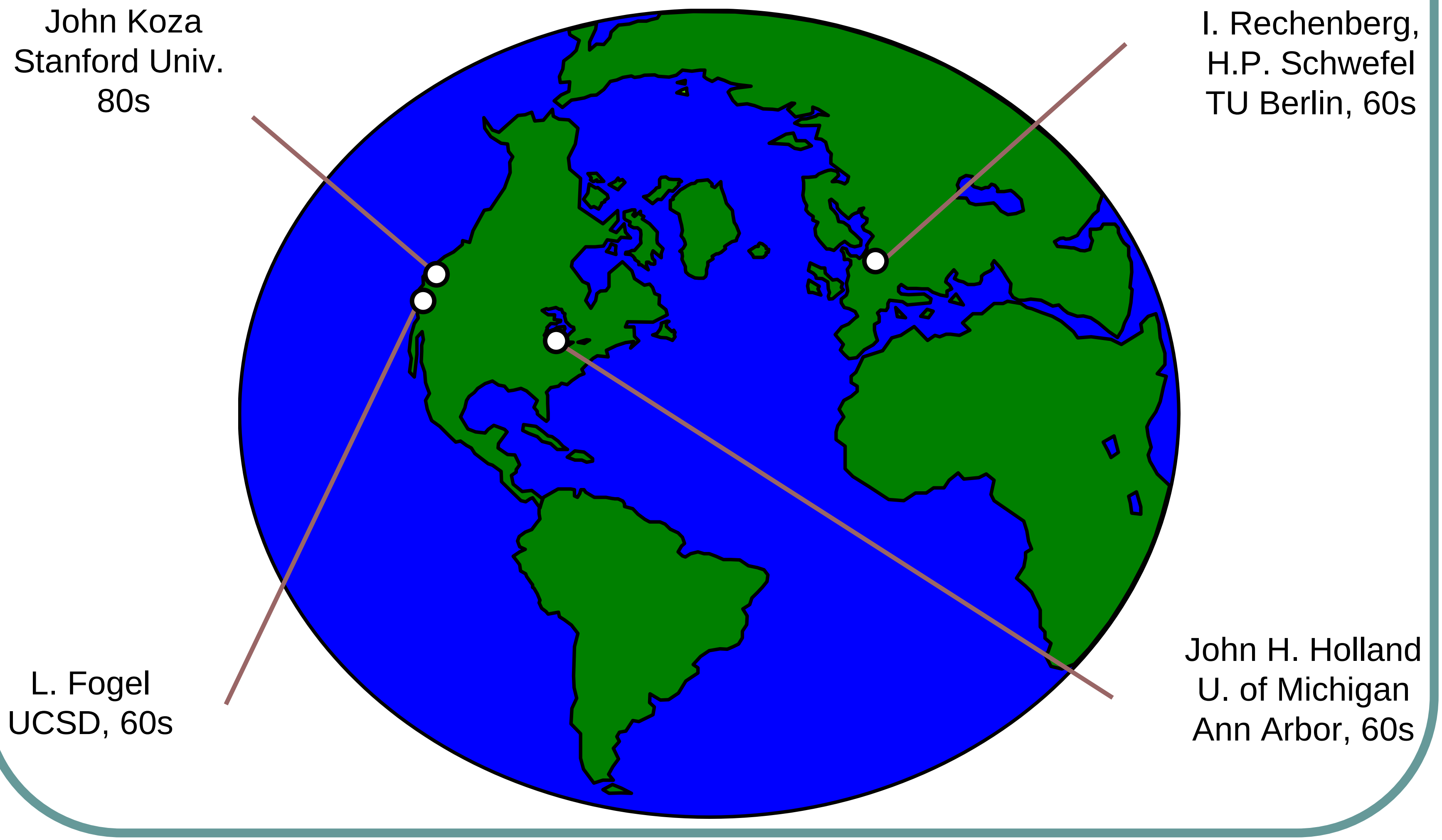
# Replacement strategies

Suppose we maintain a population of $\mu \geq 1$ individuals
At each generation, they produce $\lambda \geq 1$ offspring

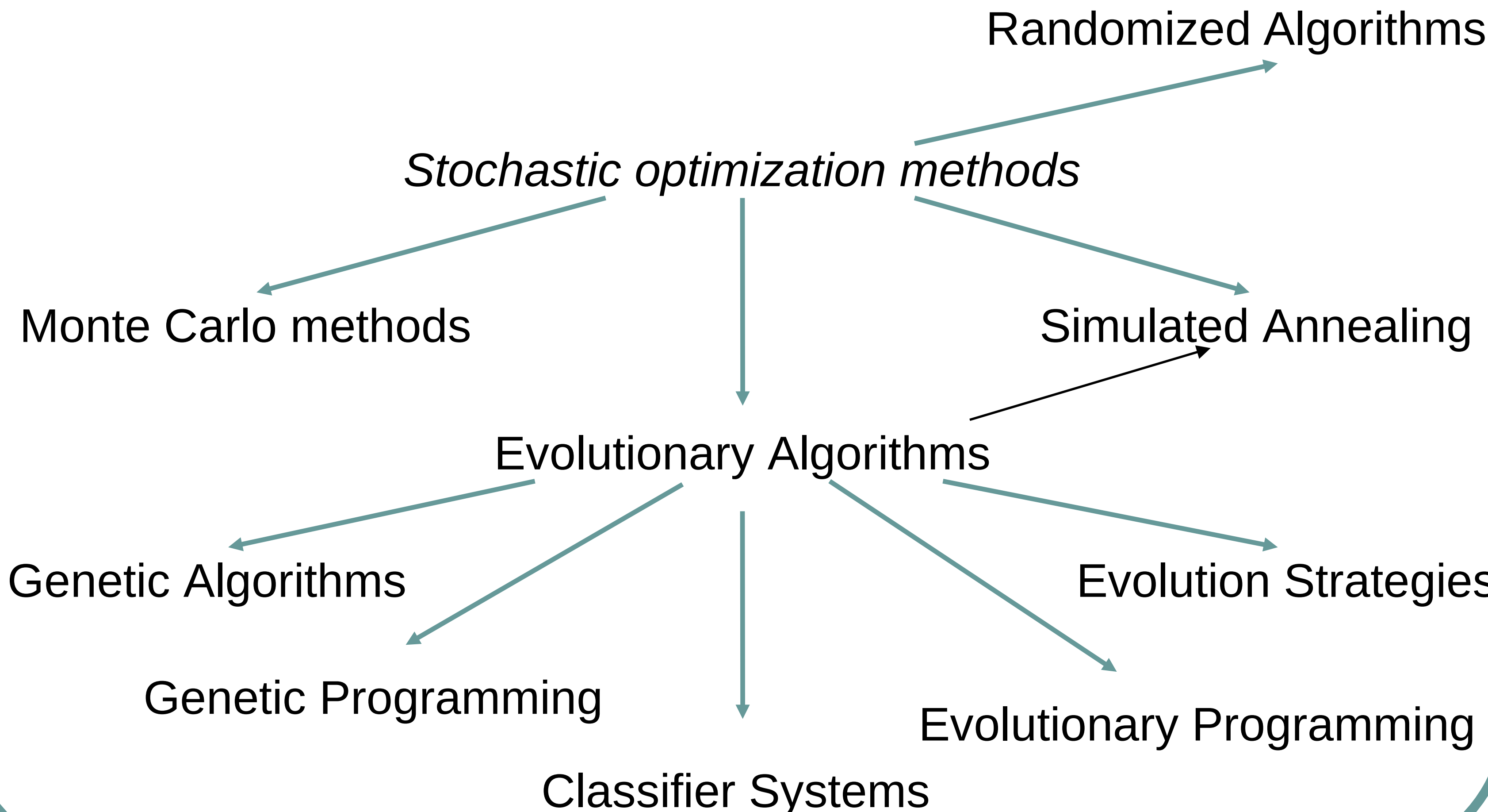
Two **strategies**:

- $(\mu + \lambda)$ - strategy
- $(\mu , \lambda)$ – strategy, $\lambda \geq \mu$

# The story so far



# Taxonomy of methods



# Outline of various techniques

- **Genetic Algorithms (GA)** model standard genetic evolution
- **Genetic Programming (GP)**, based on genetic algorithms, but individuals are computer programs
- **Evolutionary Programming (EP)**, derived from the simulation of adaptive behavior in evolution (i.e. phenotypic evolution).
- **Evolution Strategies (ES)**, geared toward modeling the strategic parameters that control evolution itself (“evolution of evolution”)
- **Classifier Systems (CS)** aim at knowledge representation
- **Differential Evolution (DE)**, similar to genetic algorithms, differing only in the reproduction mechanism used
- **Neuro Evolution (NE)**, specifically aiming at evolving neural networks
- and many many others ...

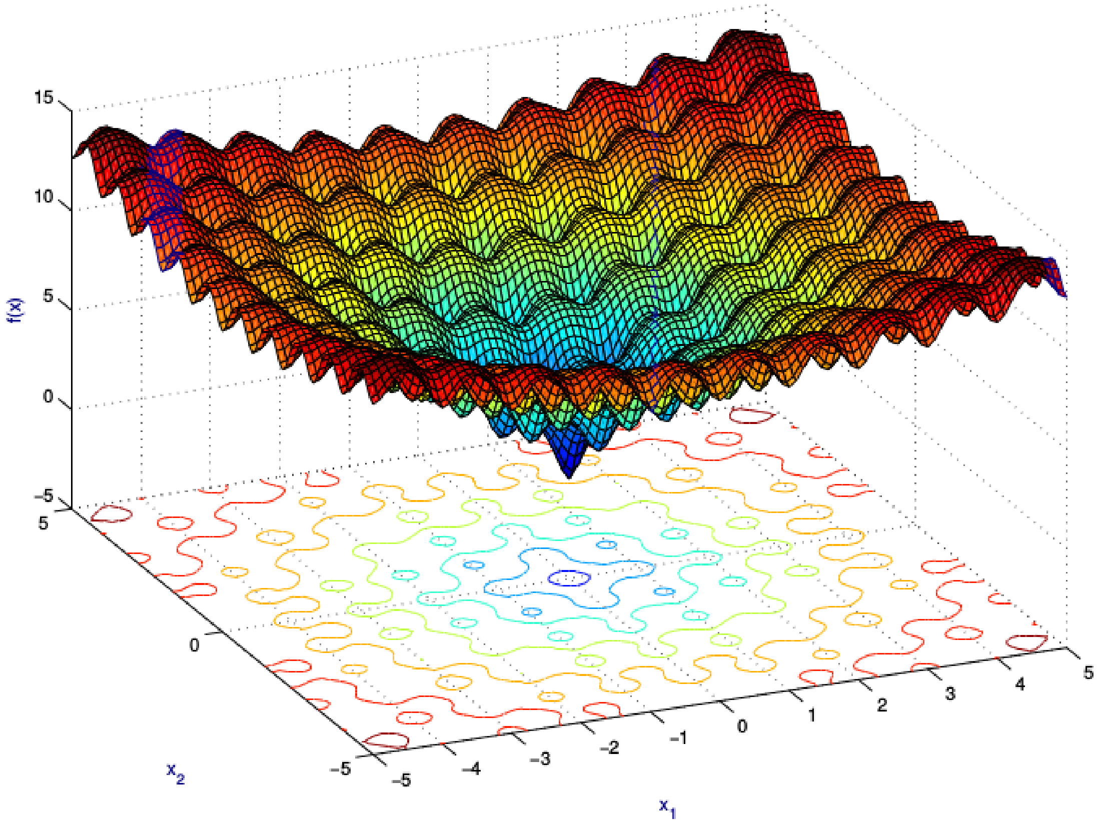
# A fundamental difference

- Genetic Algorithms (bitstrings)
- Evolutionary Programming (finite-state automata)
- Evolution Strategies (real-valued vectors)
- Genetic Programming (computer programs)
- Neuro Evolution (neural networks)
- Classifier Systems (if-then rules)

# EA vs derivative-based methods

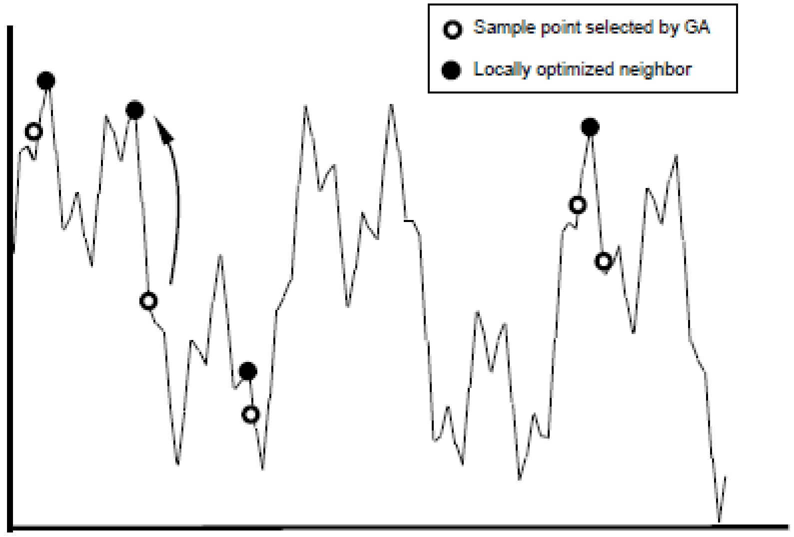
- EAs can be much slower (but they are *any-time* algorithms)
- EAs are less dependent on initial conditions (still we need several runs)
- EAs can use alternative error functions:
  - Not continuous or differentiable
  - Including structural terms
- EAs do not get easily stuck in local optima
- EAs are better “scouters” (global searchers)

# Example: Ackley’s function



# Hybrid algorithms (aka memetic)

- EAs + local tuner: the EA can be used to find a good set of initial solutions
- Hopefully a very good solution is on the basin of attraction of one of these points
- Iteration leads to Lamarckian evolution (and may be very slow)



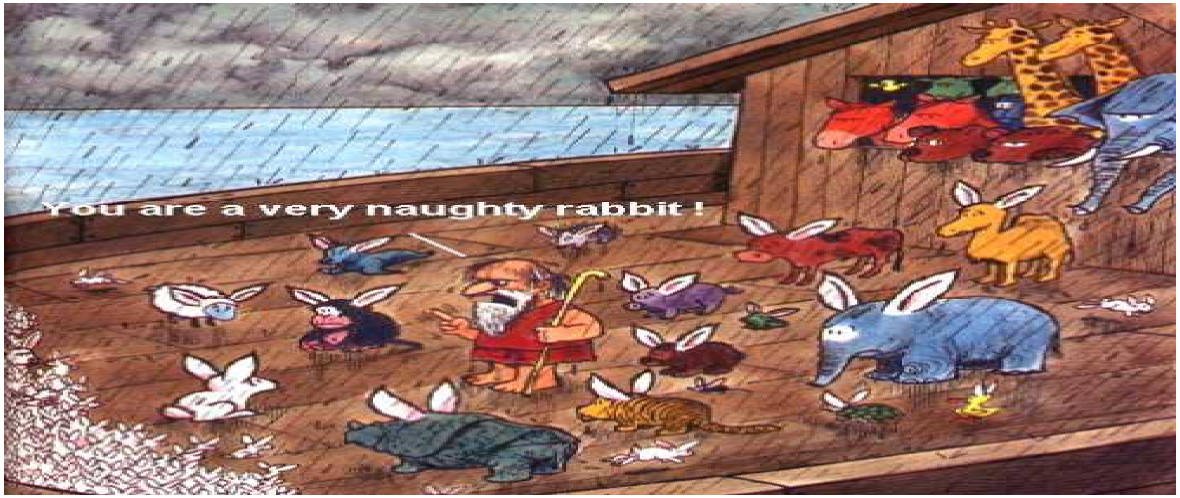

(from Belew, McInerney & Schraudolf: Evolving Networks)

# And the Oscar goes to …

"Species do not evolve to perfection, but quite the contrary. The weak, in fact, always prevail over the strong, not only because they are in the majority, but also because they are the more crafty."

Friedrich Nietzsche,

in *The Twilight of the Idols*



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