Computational Intelligence (CI)

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Introduction to Evolutionary Computation (I)

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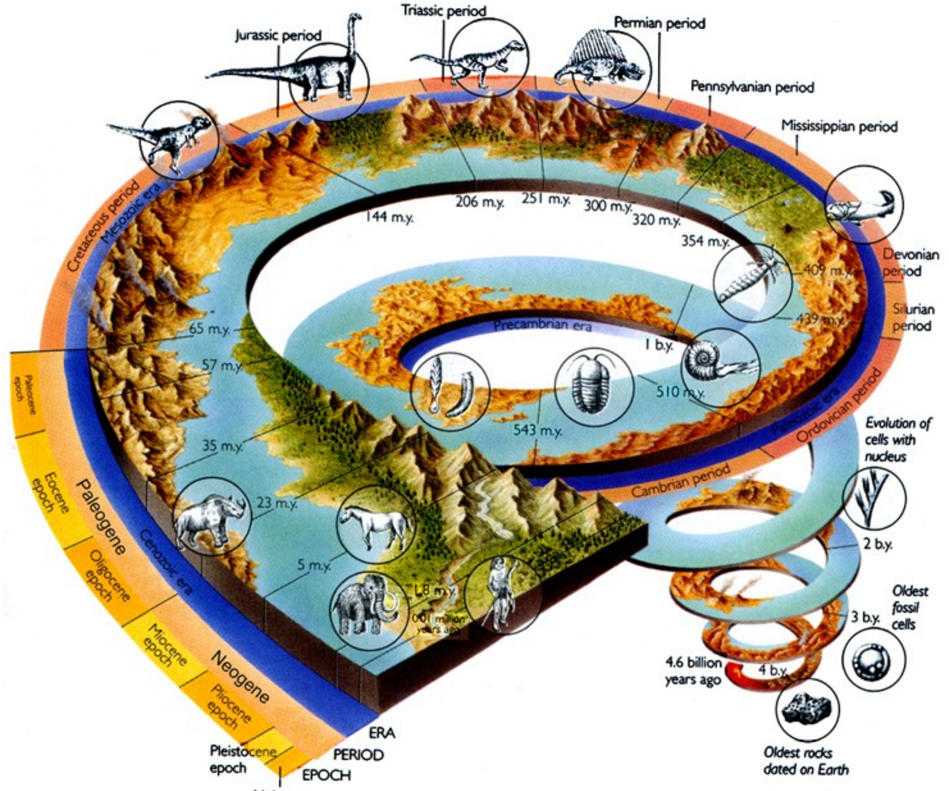
It's a long and winding road ...

History of life

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

These **processes** are:

- Reproduction
- Mutation
- Competition
- Selection



Adapted from Press & Siever, 2000, Understanding Earth

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

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 are 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 (and posterior), it is very difficult to tell 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 <u>plausible mechanism</u> and to present an <u>overwhelming case</u> 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)*

How does it work?

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?

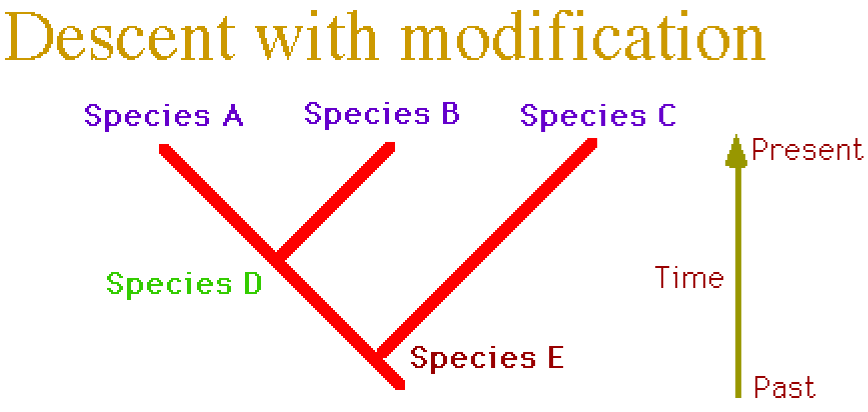
Mutation is not the only source of genetic variation. Other mechanisms (sometimes interacting) are **genetic drift**, **gene flow**, and **symbiosis:**

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

So 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?

All individuals 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.



If true, we should find **evidence** of this.

Evidence for descent with modification

Biogeography

Functional morphology

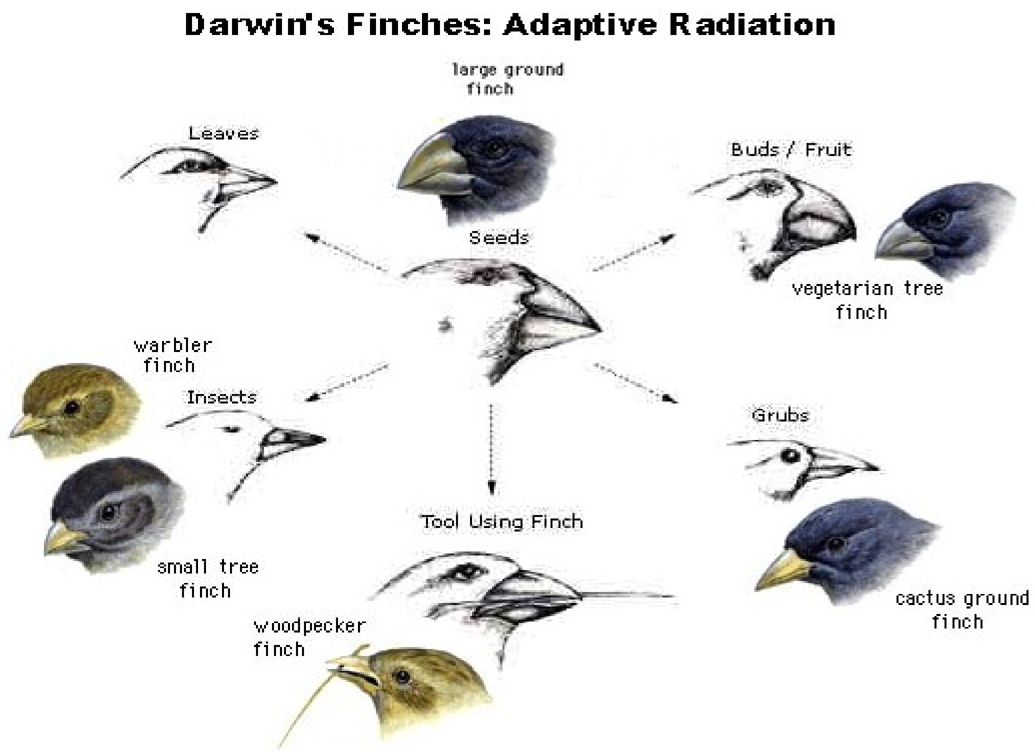
Paleontology

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

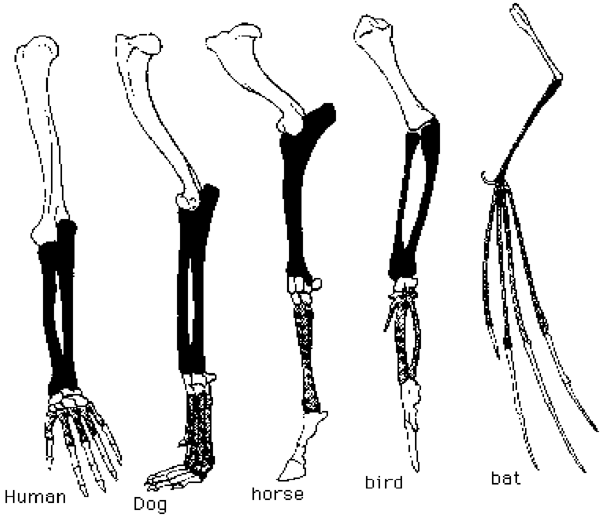
The finch has adapted to take advantage of feeding in different ecological niches

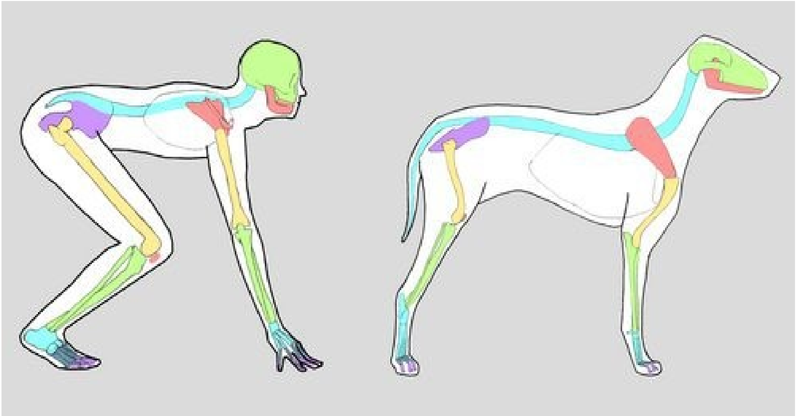
For example, the finches who eat grubs have a thin extended beak to poke into holes in the ground and extract the grubs

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.

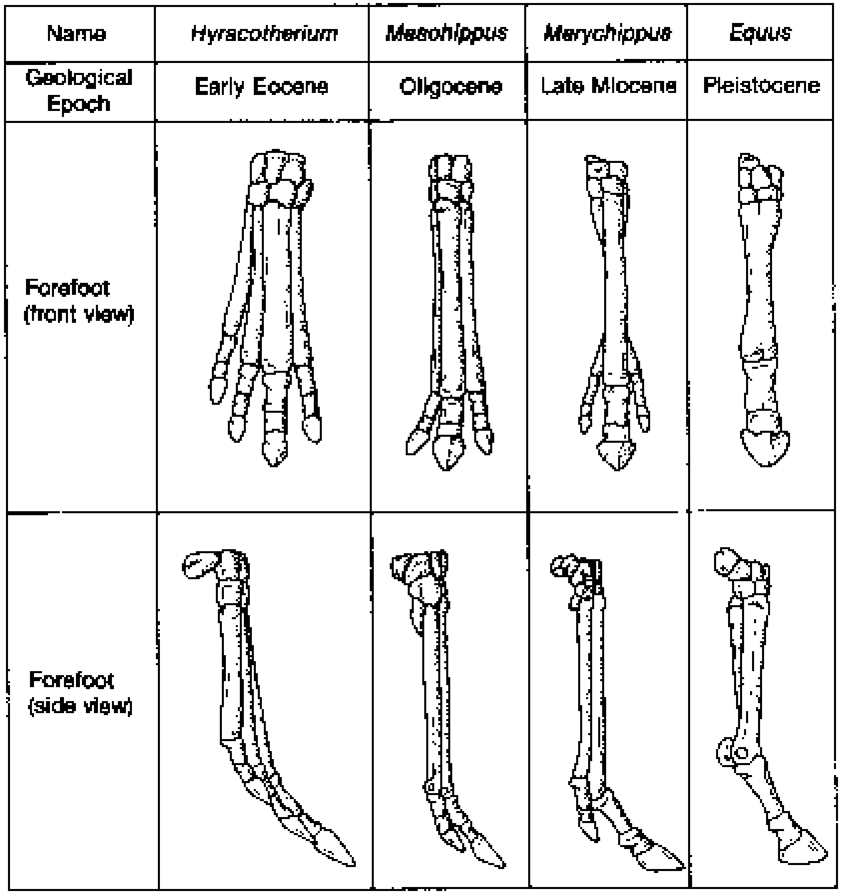
Evidence from **functional morphology**: an example





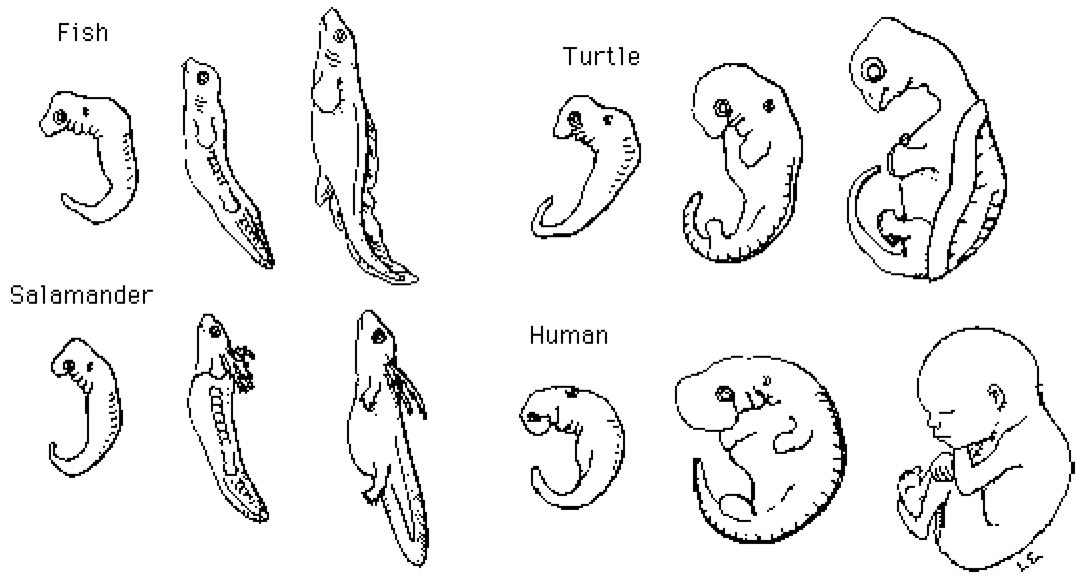
Homologous structures are anatomical resemblances that represent variations on a structural theme present in a common ancestor

Evidence from **paleontology**: an example



Evolution of the hoof

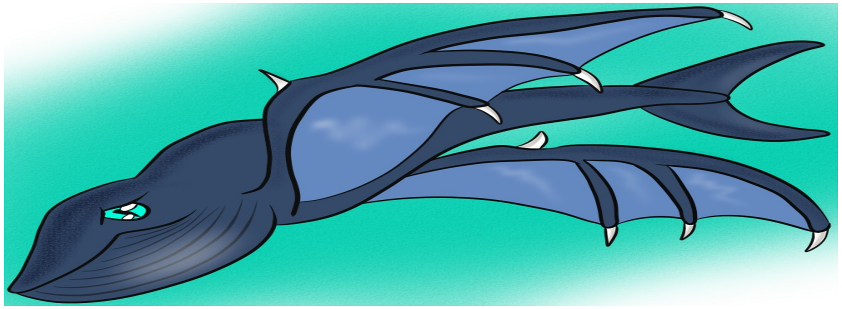
Evidence from **comparative embryology**: an example



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



Paternity testing: how do you tell who's dad?

DNA profiling (aka genetic fingerprinting) can determine whether two individuals are biologically parent and child. The tests can also determine the likelihood of someone being a biological grandparent to a grandchild

Modern example of natural selection “in action”

Rabbits and myxomatosis

In 1859, 12 cute and cuddly rabbits brought to Australia.

By 1886, the army of rabbits was advancing at over 66 miles a year, smashing through rabbit-proof barriers. They spanned Australia by 1907.

Myxomatosis introduced in 1950, with an initial mortality rate of 99.9%. Mortality rate today is about 40%

Modern example of natural selection “in action”

The peppered moth and industrial melanism

Dark (melanic) forms of the peppered moth increased in frequency in Southern England as air pollution (soot) darkened trees.

As pollution controls were put in place, the light form of the moth increased in frequency.

To think about ...

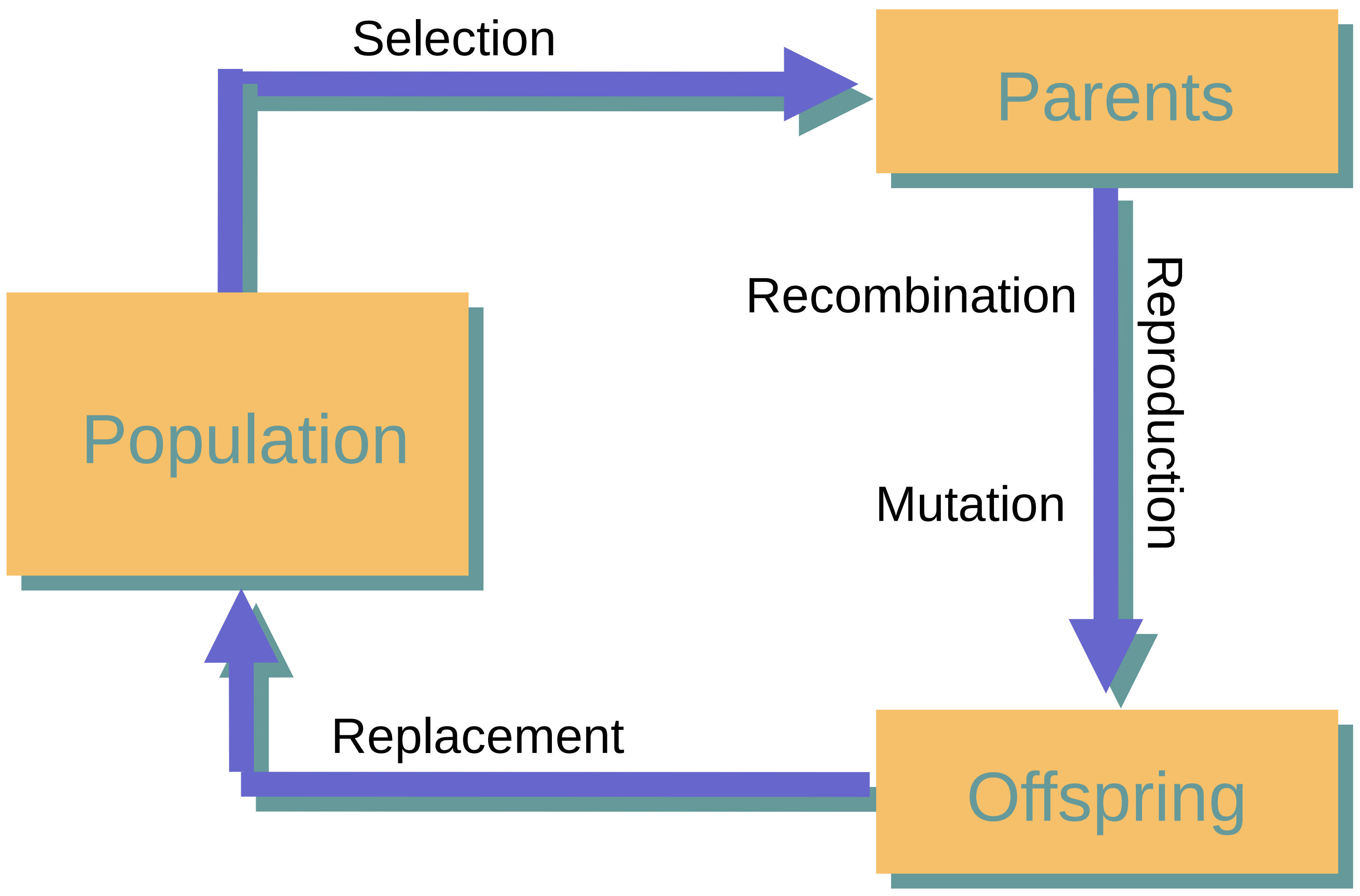
“However many ways there may be of being alive, it is certain there are vastly more ways of being dead, or rather not alive.”

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*

The evolutionary cycle in Nature



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)

Main Components of an EA

- a **coding function** to represent potential solutions as valid chromosomes
- a **fitness function** to evaluate the goodness of individuals
- an **initialization method** to create the initial population
- a **selection operator** to determine which individuals will undergo variation
- a set of **genetic variation operators** (mutation, recombination) to perform the variation
- a **termination criterion** to stop the process

Some 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)

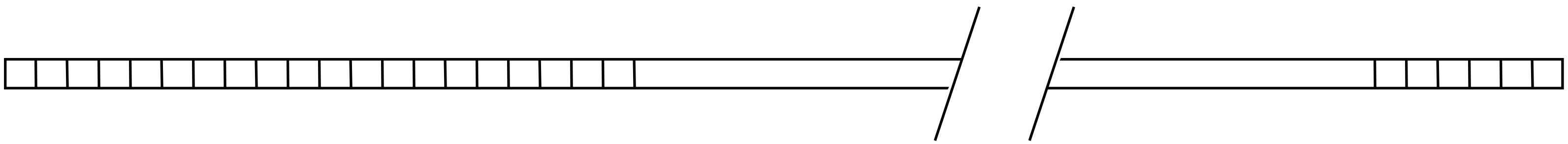
- **Genotype**: the genetic composition of an individual
- **Phenotype**: the expressed behavioral traits of an individual in a specific environment

Evolutionary Mechanisms

- Selection and differential reproduction
  - **DECREASE** diversity in population
- Genetic operators (mutation, recombination)
  - **INCREASE** diversity of population

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.

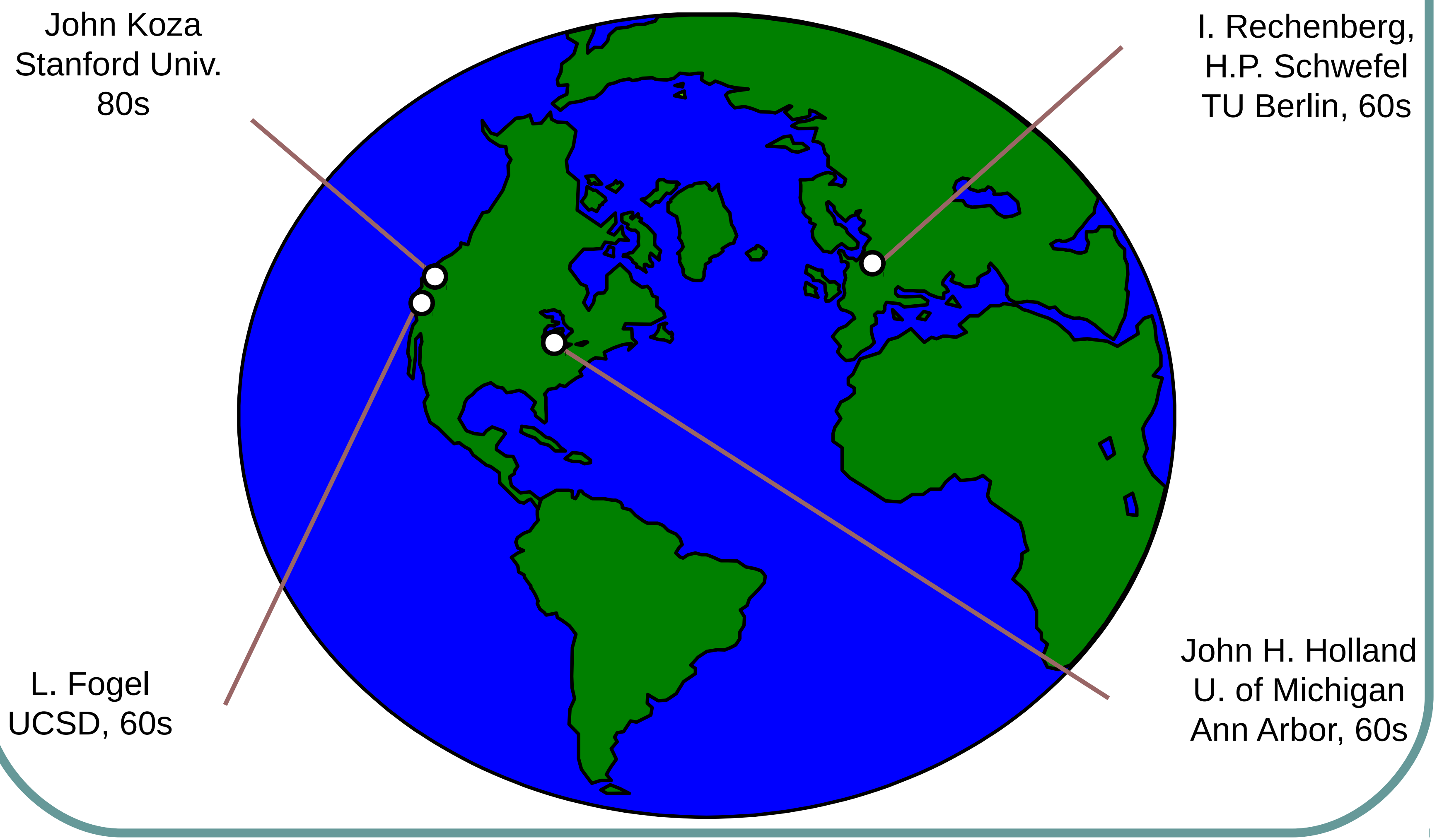
Families of Algorithms

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

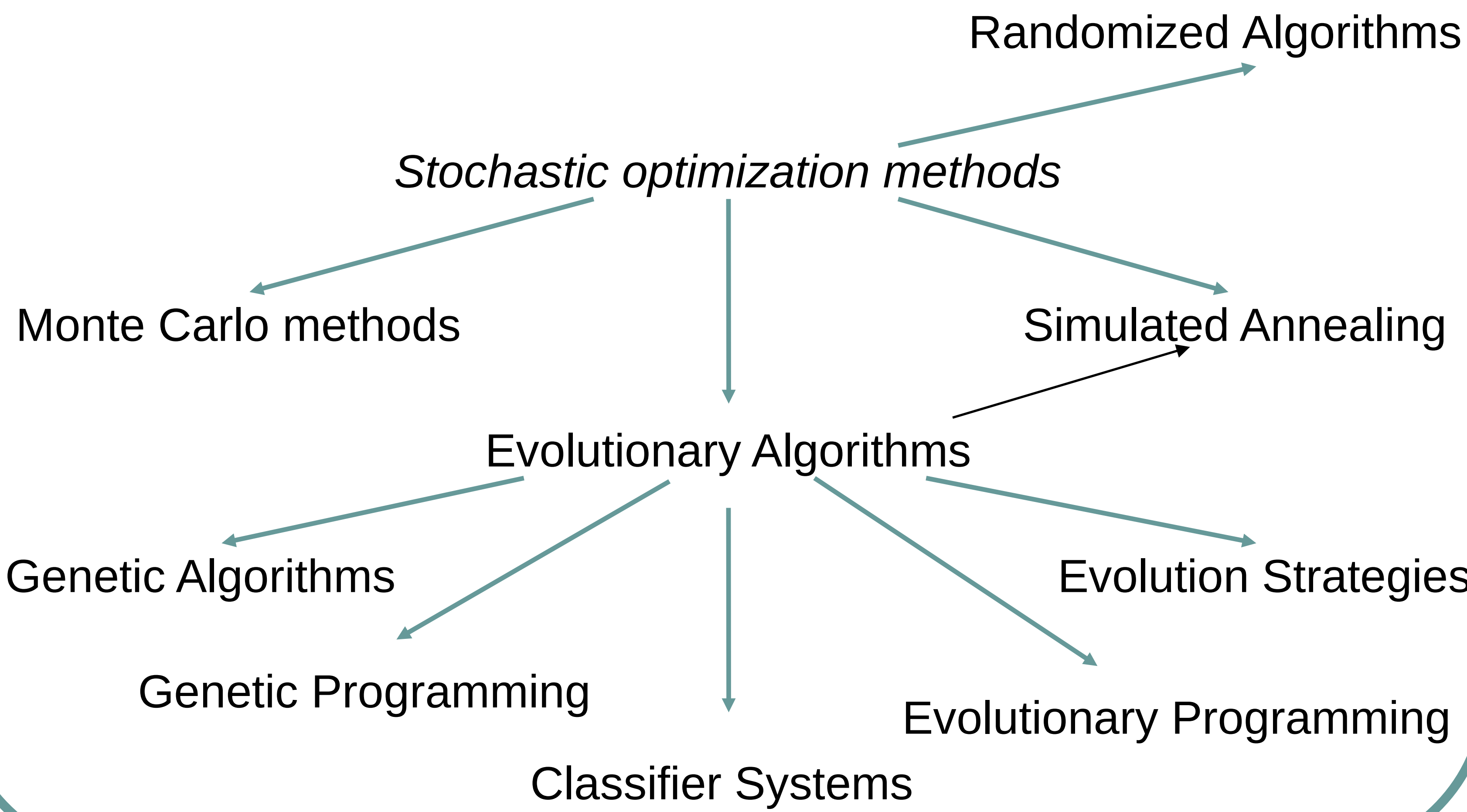
Two strategies:

- $(\mu + \lambda)$ - strategy, $\lambda \geq \mu$
- (μ , λ) - strategy

The story so far



Taxonomy


Randomized Algorithms
Stochastic optimization methods
Monte Carlo methods
Simulated Annealing
Evolutionary Algorithms
Genetic Algorithms
Evolution Strategies
Genetic Programming
Evolutionary Programming
Classifier Systems

Outline of various techniques (I)

- **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 GAs, differing in the reproduction mechanism used
- **Cultural evolution (CE)**, which models the evolution of culture
- And many others ...

Outline of various techniques (II)

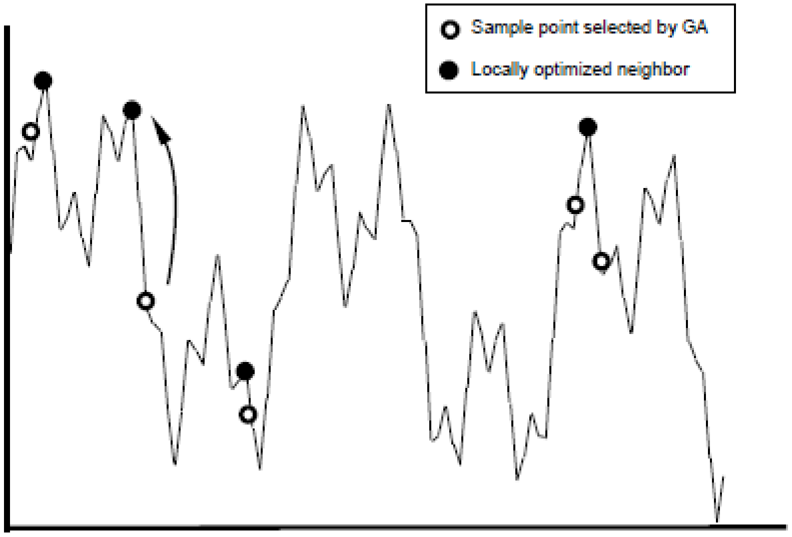
- Genetic Algorithms (bitstrings)
- Evolutionary Programming (finite-state automata)
- Evolution Strategies (real-valued vectors)
- Genetic Programming (computer programs)
- Neuroevolution (neural networks)
- Classifier Systems (rules)

EA vs derivative-based methods

- EAs can be much slower (but they are *any-time* algorithms)
- EAs are less dependent on initial conditions (still be 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)

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)

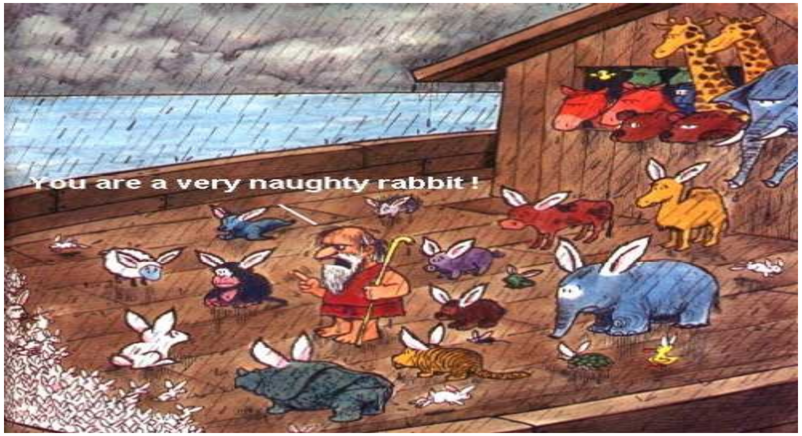


(from Belew, McInerney & Schraudolf: Evolving Networks)

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,
The Twilight of the Idols



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