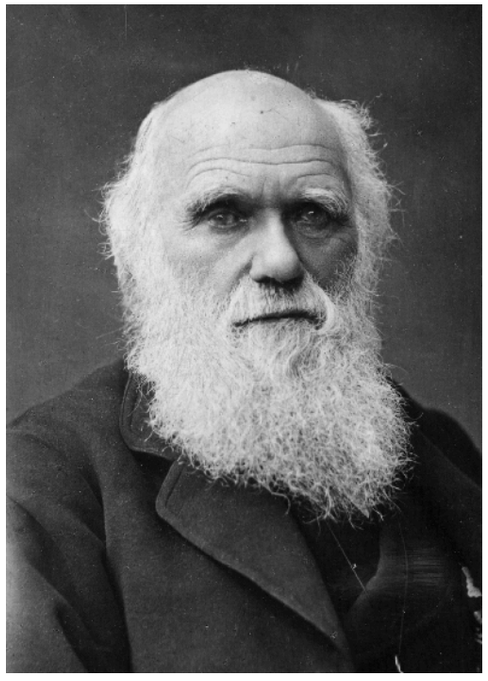
2: Evolution

- Macroscopic and microscopic views of evolution
- Darwin's theory of evolution
- Mendelian heredity
- DNA and modern genetics
- Lamarckian inheritance
- Baldwin effect
- Textbook Chapter 2.3

EC design principles

- Evolutionary computing uses the principles of
  - Darwinian evolution (macroscopic view) - survival of the fittest
  - Mendelian genetics (microscopic view) - heredity



Charles Darwin (1809-1882)

Gregor Mendel (1822-1884)

Darwinian Evolution: survival of the fittest

- All environments have finite resources
- Lifeforms have basic instinct / lifecycles geared towards reproduction
- Evolution is due to a "force" called natural selection which "selects" the individuals best adapted to the environment
- Those individuals that compete for the resources most effectively have increased chance of reproduction
- Constant vs. varying environment

Evolution of digital organisms at high mutation rates leads to survival of the flattest

Claus O. Wilke*, Jia Lan Wang*, Charles Ofria†, Richard E. Lenski† & Christoph Adami*‡

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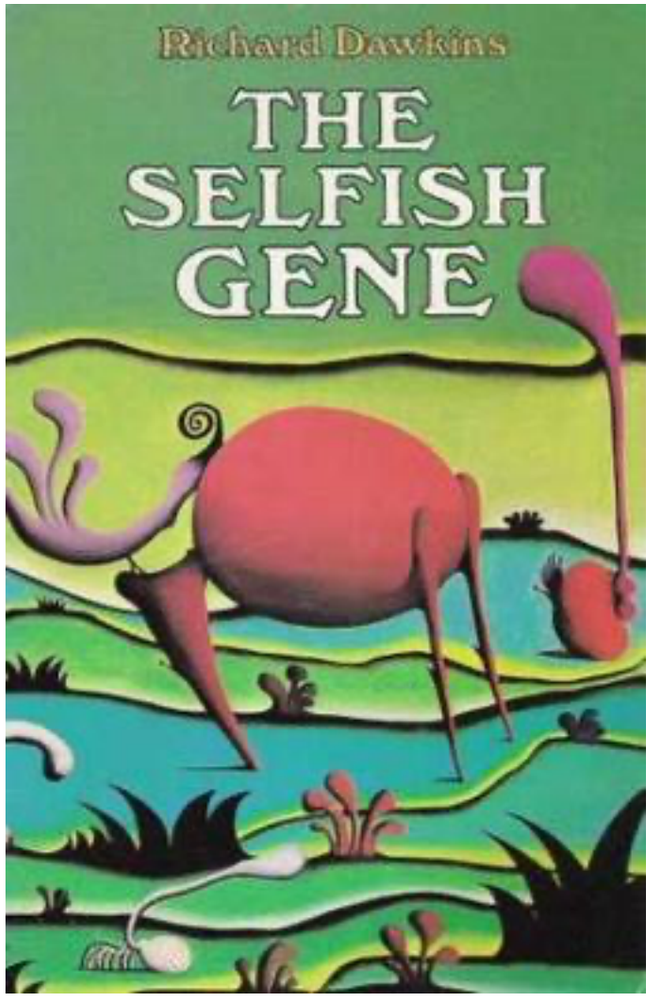
Darwinian Evolution: diversity drives change

- Phenotypic traits:
  - Behavior / physical differences that affect response to environment
  - Partly determined by inheritance, partly by factors during development
  - Unique to each individual, partly as a result of random changes
- If a phenotypic trait evaluates favorably
  - Lead to higher chances of reproduction
  - Propagate via the individual's offspring
- Random variations during reproduction lead to new combinations of traits

Darwinian Evolution: population vs. individual

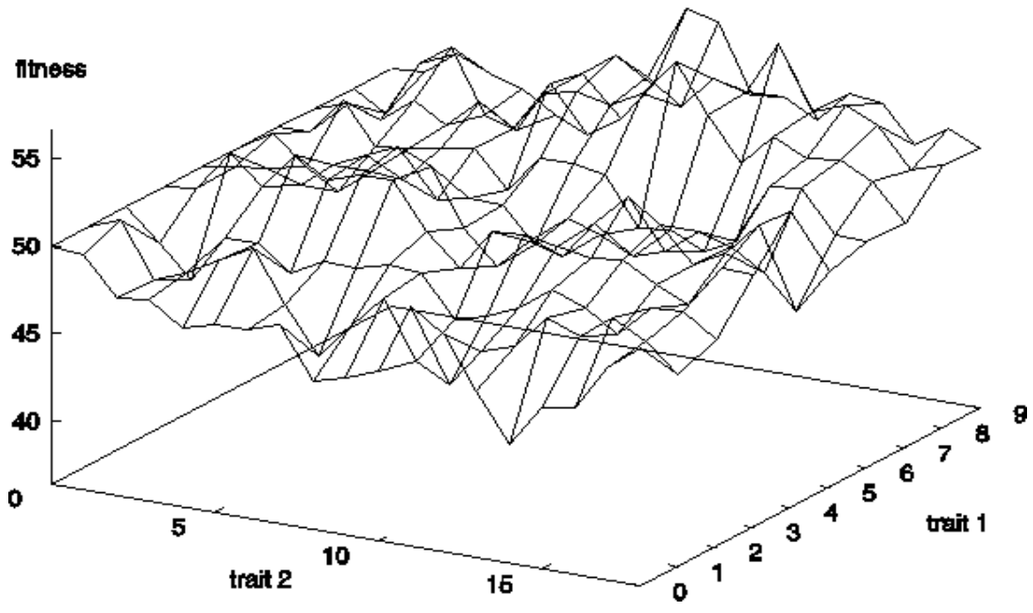
- Population consists of diverse set of individuals
- Combinations of traits that are better adapted tend to increase reproduction in population
    - Individuals are "unit of selection"
- Variations occur through random changes yielding constant source of diversity, coupled with selection means that
    - Population is the "unit of evolution"

The Selfish Genes



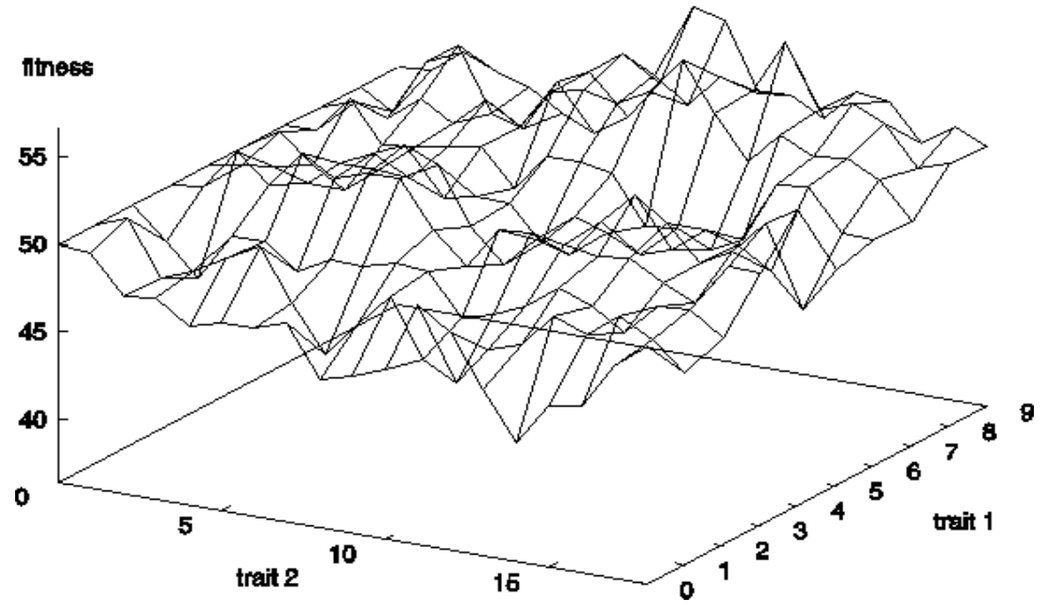
- Richard Dawkins
- Gene-centered view of evolution
- A lineage evolves to maximize the number of copies of it genes passed on globally
- Organisms are fundamentally simple survival machines
- Meme - an idea that spreads by imitation from person to person within a culture

Adaptive landscape metaphor (Wright, 1932)



- Population with `n` traits as existing in a `n+1` dimensional space (landscape) with height corresponding to fitness
- Each different individual (phenotype) represents a single point on the landscape
- Population is therefore a "cloud" of points, moving on the landscape over time as it evolves - adaptation

Adaptive landscape metaphor



- Selection “pushes” population up the landscape
- Genetic drift:
  - random variations in feature distribution arising from sampling error
  - can cause the population “melt down” hills, thus crossing valleys and leaving local optima
  - highly fit individuals may be lost from the population
- Unimodal and multimodal problems

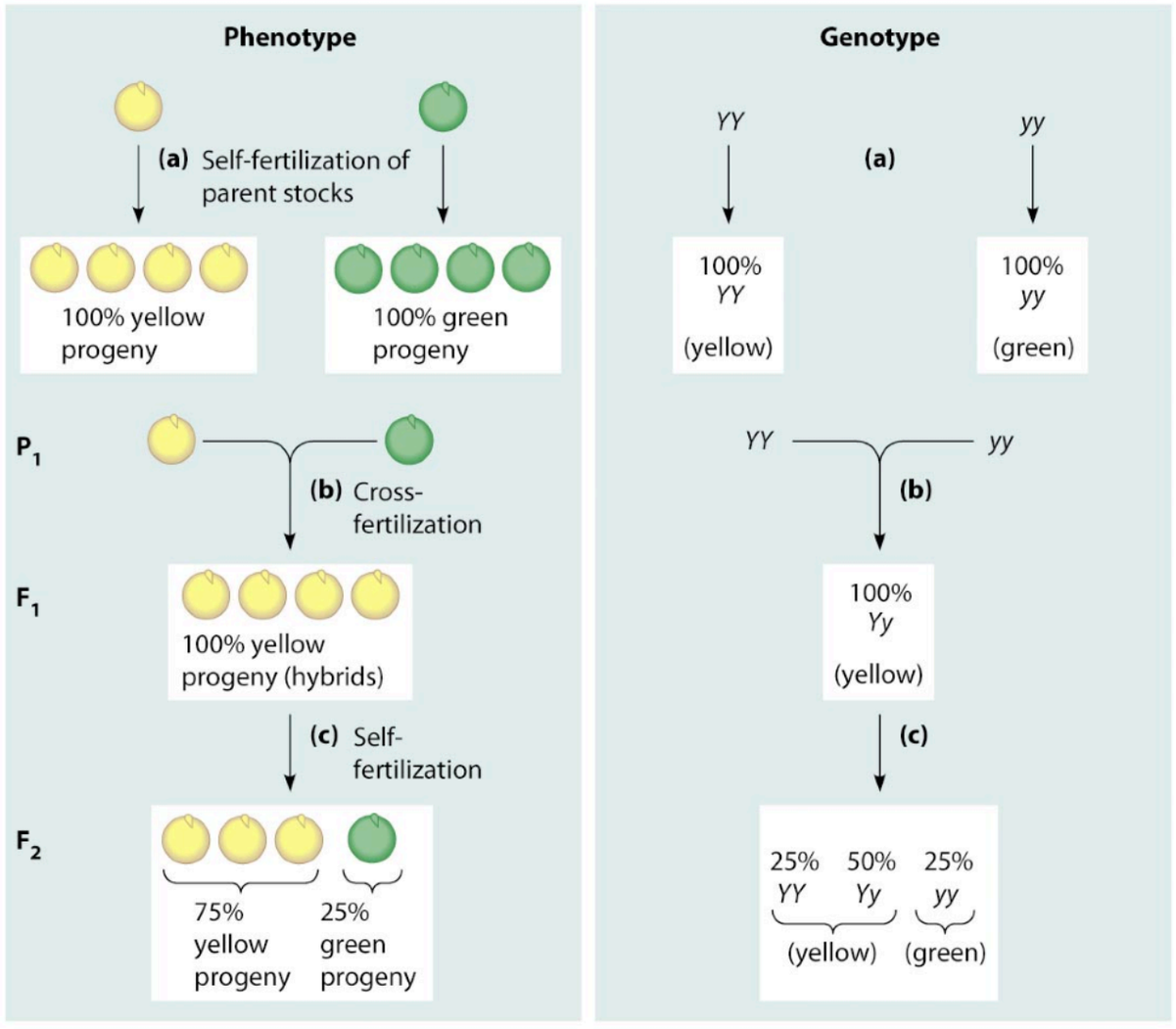
Mendelian Genetics

Gregor Mendel (1822-1884)

- Followed the inheritance of traits from pea plants (wrinkled vs. smooth)
- Postulated that the plants passed on traits to their offspring and described some of the characteristics (dominant vs. recessive)
- Had no concept of DNA
- Was ignored in his lifetime

Mendel's Laws

- Law of Segregation
  - plants possess pair of alleles (genes or group)
  - only one pair is passed on (randomly)
- Law of Independent Assortment
  - separate genes (separate traits) passed on independently



Crick and Watson

- Discovered the existence of DNA in 1953 and the pairing of bases to form genes

Francis Crick (1916 - 2004) James Watson (1928 -)

Genetics

- The information required to build a living organism is coded in the DNA of that organism
- Genotype (DNA inside) determines phenotype
- Genotype to phenotypic traits is a complex mapping
  - One gene may affect many traits (pleiotropy)
  - Many genes may affect one trait (polygeny)
  - Mendelian traits (e.g., ear wax, albinism)
- Changes in the genotype may lead to changes in the organisms (e.g., height, hair color)

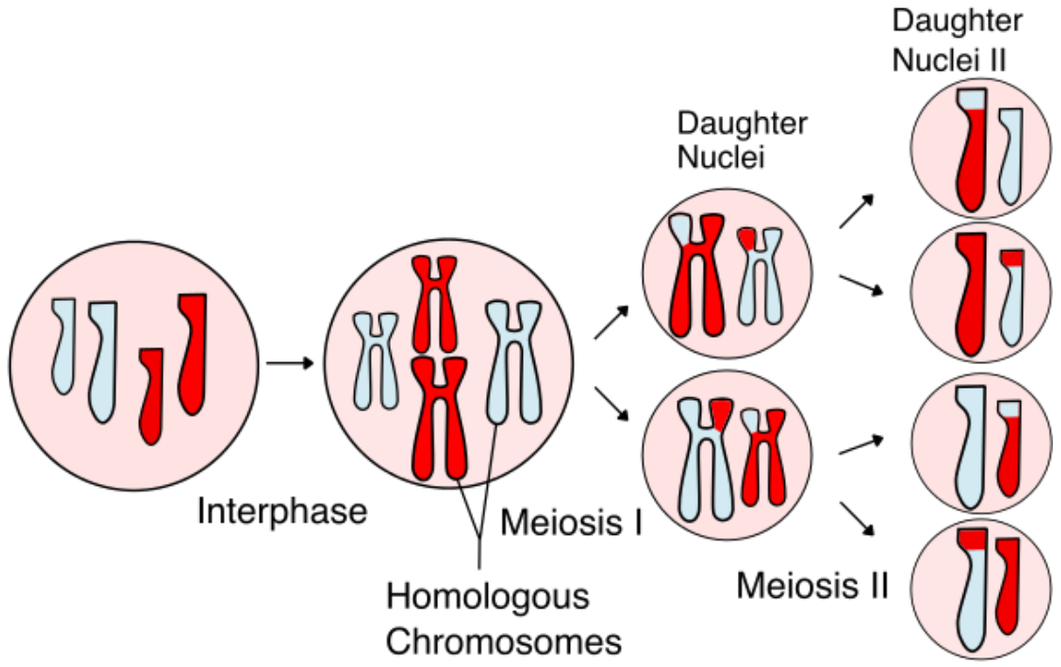
Genes and the genome

- Deoxyribonucleic acid (DNA) and nitrogenous bases
  - Adenine, Thymine, Cytosine, Guanine
  - 3 billion base pairs in humans
- **Genes** are functional unit of stretches of DNA on chromosomes (~20k in human genome)
- The complete genetic material in an individual's genotype is called the **Genome**

Genetic code

- All proteins in life on earth are composed of sequences built from 20 different amino acids
- DNA is built from four nucleotides in a double helix spiral: Purines A, G; Pyrimidines T, C
- Triplets of these form **codons**, each of which codes for a specific amino acid
- Much redundancy:
  - purines complement pyrimidines
  - the DNA contains much unknown regions
  - 4^3=64 codons code for 20 amino acids
  - genetic code = the mapping from codons to amino acids
- For all natural life on earth, the genetic code is the same!

Crossover during meiosis



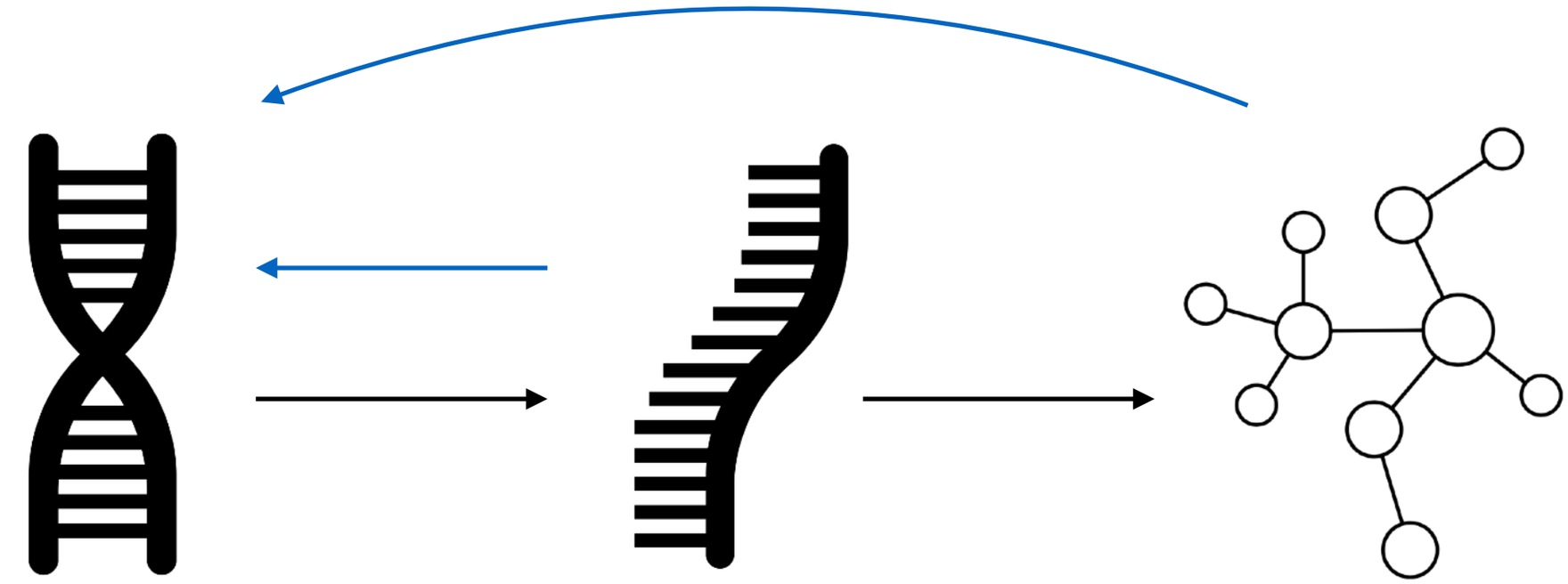
https://en.wikipedia.org/wiki/Meiosis

- Chromosome pairs align and duplicate
- Sister chromatids attach at centromere
- Homologous chromosome pairs swap genetic material - chromosomal crossover
- Homologous chromosomes are then pulled apart to form two new daughter cells
- These two cells will divide again
- Outcome is four new haploid gamete cells different from both original parent genomes

Mutation

- Occasionally some of the genetic material changes very slightly during this process (replication error)
- This means that the child might have genetic material information not inherited from either parent
- This can be
  - catastrophic: offspring is not viable (most likely)
  - neutral: new feature not influences fitness
  - advantageous: strong new feature occurs
- Redundancy in the genetic code forms a good way of error checking

Central Dogma of Molecular Biology

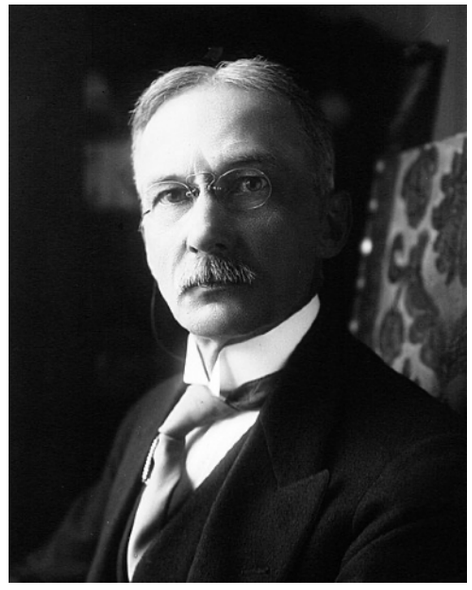


Lamarckian Inheritance

Jean-Baptiste Lamarck (1744 -1829)

- Inheritance of acquired characteristics
- Parent organism can pass onto its offspring physical characteristics acquired through use or disuse during its lifetime
- Has never been proven

Baldwin Effect



James Mark Baldwin (1861 -1934)

- Phenotype-first theory of evolution
- Organism's ability to learn new behaviours affects its reproductive success
- Therefore has an effect on the genetic makeup of its species through natural selection
- Learning can accelerate evolution

How Learning Can Guide Evolution

Geoffrey E. Hinton & Steven J. Nowlan

Originally published in 1987 in *Complex Systems*, 1, 495-502.

Natural selection

When learning guides evolution

John Maynard Smith

NATURE VOL. 329 29 OCTOBER 1987

Embodied Intelligence via Learning and Evolution

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Terminology

- Terms borrowed from biology
  - Genotype: underlying representation, that is manipulated by evolution
  - Phenotype: expressed behavior or solution, that is optimized by evolution
  - Genome (chromosome): string representing the genetic encoding for the problem solution
  - Gene: subpart of genome (chromosome) that maps to a particular feature/behavior in the phenotype
  - Allele: a particular feature value of the gene
  - Locus: position in the chromosome