# Evolutionary Computing

Chapter 2

# Chapter 2:
# Evolutionary Computing: the Origins

- Historical perspective
- Biological inspiration:
  - Darwinian evolution theory (simplified!)
  - Genetics (simplified!)
- Motivation for EC

# Historical perspective (1/3)

- 1948, Turing:
  proposes "genetical or evolutionary search"
- 1962, Bremermann:
  optimization through evolution and recombination
- 1964, Rechenberg:
  introduces evolution strategies
- 1965, L. Fogel, Owens and Walsh:
  introduce evolutionary programming
- 1975, Holland:
  introduces genetic algorithms
- 1992, Koza:
  introduces genetic programming

# Historical perspective (2/3)

- 1985: first international conference (ICGA)
- 1990: first international conference in Europe (PPSN)
- 1993: first scientific EC journal (MIT Press)
- 1997: launch of European EC Research Network EvoNet

# Historical perspective (3/3)

EC in the early 21st Century:

- 3 major EC conferences, about 10 small related ones
- 4 scientific core EC journals
- 1000+ EC-related papers published last year(estimate)
- uncountable (meaning: many) applications
- uncountable (meaning: ?) consultancy and R&D firms
- part of many university curricula

# Darwinian Evolution (1/3): Survival of the fittest

- All environments have finite resources

  (i.e., can only support a limited number of individuals)
- Life forms have basic instinct/ lifecycles geared towards reproduction
- Therefore some kind of selection is inevitable
- Those individuals that compete for the resources most effectively have increased chance of reproduction
- Note: fitness in natural evolution is a derived, secondary measure, i.e., we (humans) assign a high fitness to individuals with many offspring

# Darwinian Evolution (2/3): Diversity drives change

- Phenotypic traits:
  - Behaviour / 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 phenotypic traits:
  - Lead to higher chances of reproduction
  - Can be inherited

  then they will tend to increase in subsequent generations, leading to new combinations of traits …

# Darwinian Evolution (3/3): Summary

- Population consists of diverse set of individuals
- Combinations of traits that are better adapted tend to increase representation in population

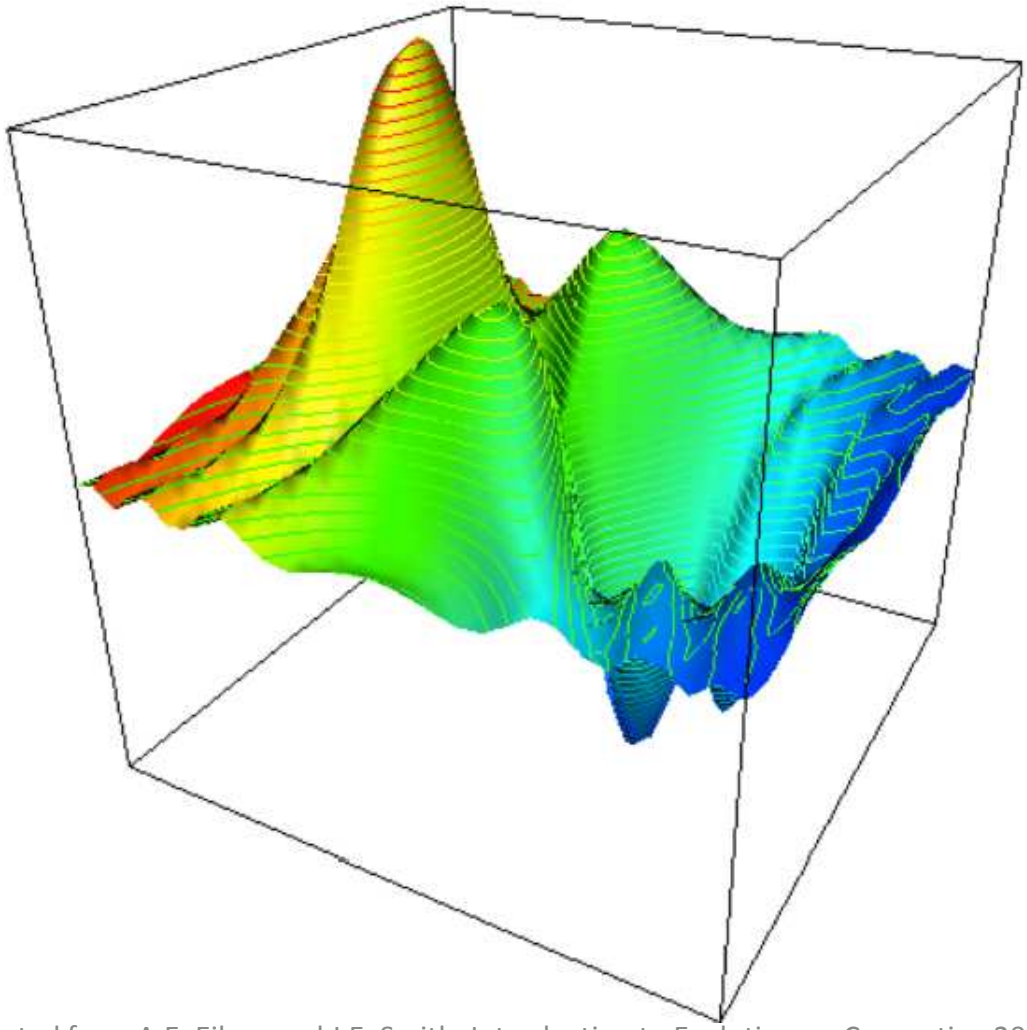
  Individuals are “units of selection”
- Variations occur through random changes yielding constant source of diversity, coupled with selection means that:

  Population is the “unit of evolution”
- Note the absence of “guiding force”

# Adaptive landscape metaphor (Wright, 1932)

- Can envisage 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 (Wright, 1932)



# Adaptive landscape metaphor (cont'd)

- Selection "pushes" population up the landscape
- Genetic drift:
  - random variations in feature distribution
  - (+ or -) arising from sampling error
  - can cause the population "melt down" hills, thus crossing valleys and leaving local optima

# Genetics: Natural

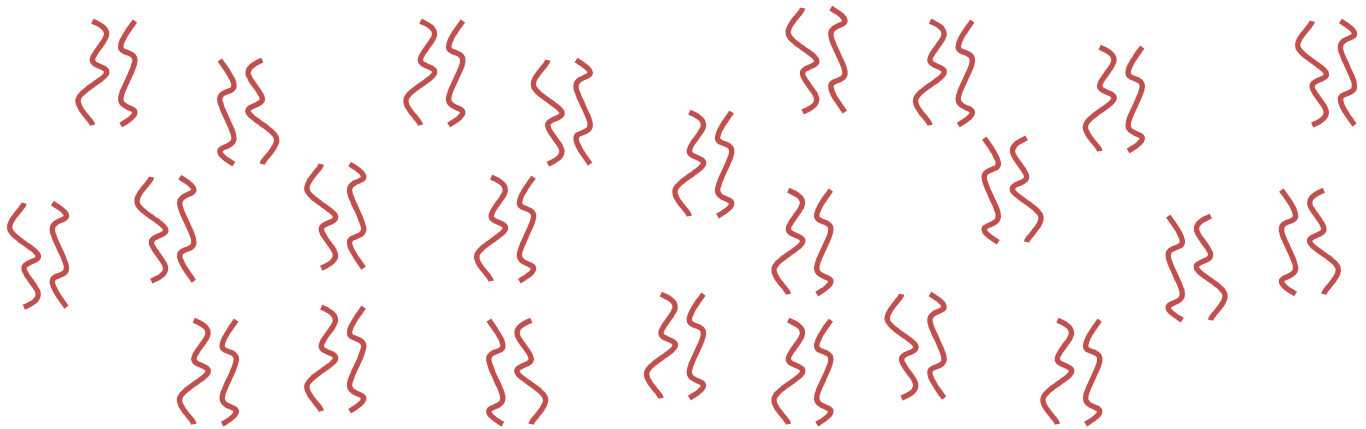
- The information required to build a living organism is coded in the DNA of that organism
- Genotype (DNA inside) determines phenotype
- Genes → phenotypic traits is a complex mapping
  - One gene may affect many traits (pleiotropy)
  - Many genes may affect one trait (polygeny)
- Small changes in the genotype lead to small changes in the organism (e.g., height, hair colour)

# Genetics:
# Genes and the Genome

- Genes are encoded in strands of DNA called chromosomes
- In most cells, there are two copies of each chromosome (diploidy)
- The complete genetic material in an individual's genotype is called the Genome
- Within a species, most of the genetic material is the same

# Genetics:
# Example: Homo Sapiens

- Human DNA is organised into chromosomes
- Human body cells contains 23 pairs of chromosomes which together define the physical attributes of the individual:

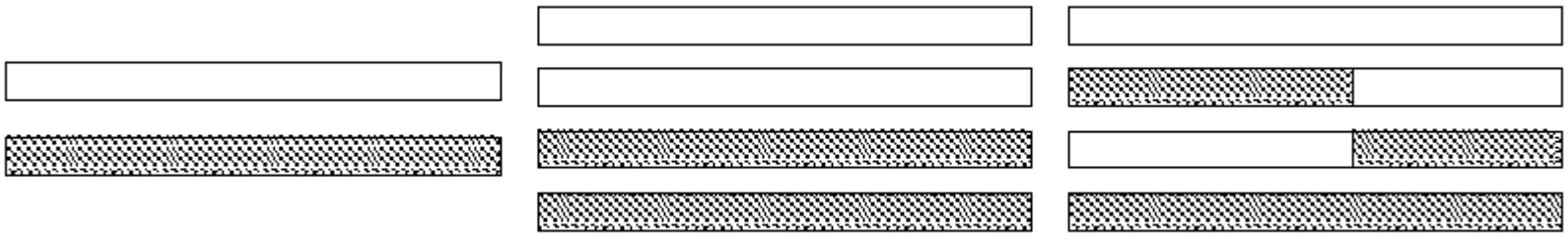


# Genetics: Reproductive Cells

- Gametes (sperm and egg cells) contain 23 individual chromosomes rather than 23 pairs
- Cells with only one copy of each chromosome are called haploid
- Gametes are formed by a special form of cell splitting called meiosis
- During meiosis the pairs of chromosome undergo an operation called *crossing-over*

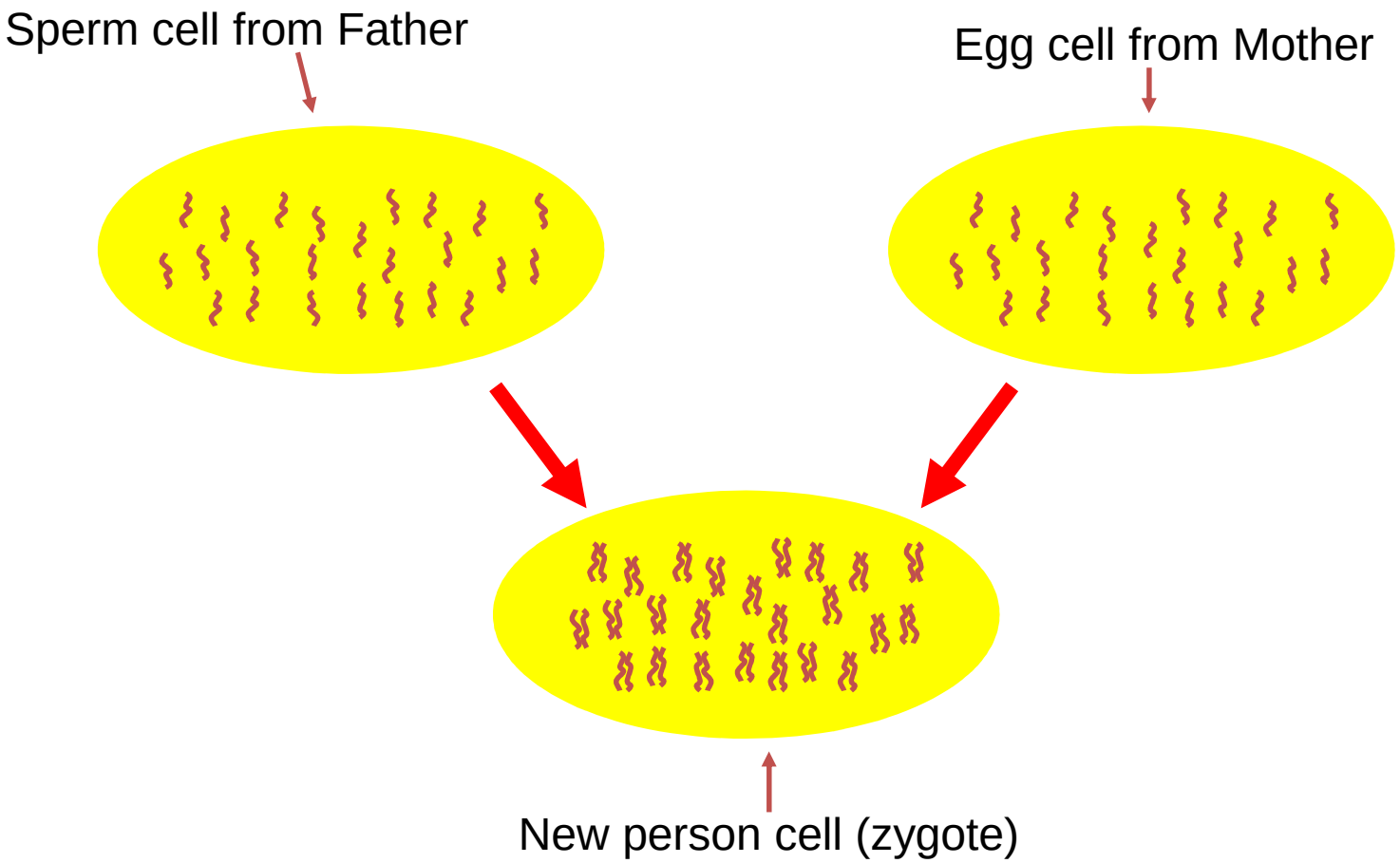
# Genetics:
# Crossing-over during meiosis

- Chromosome pairs align and duplicate
- Inner pairs link at a *centromere* and swap parts of themselves



- Outcome is one copy of maternal/paternal chromosome plus two entirely new combinations
- After crossing-over one of each pair goes into each gamete

# Genetics: Fertilisation



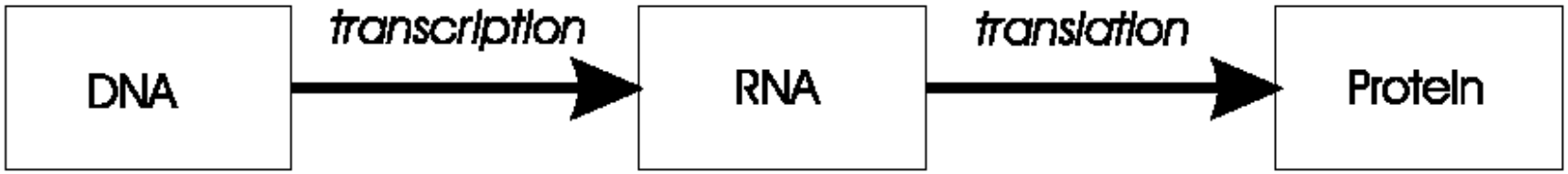
# Genetics:
# After fertilisation

- New zygote rapidly divides etc creating many cells all with the same genetic contents
- Although all cells contain the same genes, depending on, for example where they are in the organism, they will behave differently
- This process of differential behaviour during development is called ontogenesis
- All of this uses, and is controlled by, the same mechanism for decoding the genes in DNA

# Genetics:
# 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 from *codons*, each of which codes for a specific amino acid
- Much redundancy:
  - purines complement pyrimidines
  - the DNA contains much rubbish
  - $4^3$=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 !

# Genetics:
# Transcription, translation




A central claim in molecular genetics: only one way flow

Genotype → Phenotype

Genotype ↛ Phenotype

Lamarckism (saying that acquired features can be inherited) is thus wrong!

# Genetics: 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 in 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

# Motivation for evolutionary computing (1/2)

- Nature has always served as a source of inspiration for engineers and scientists
- The best problem solver known in nature is:
  - the (human) brain that created “the wheel, New York, wars and so on” (after Douglas Adams’ Hitch-Hikers Guide)
  - the evolution mechanism that created the human brain (after Darwin’s Origin of Species)
- Answer 1 → neurocomputing
- Answer 2 → evolutionary computing

# Motivation for evolutionary computing (2/2)

- Developing, analyzing, applying problem solving methods a.k.a. algorithms is a central theme in mathematics and computer science
- Time for thorough problem analysis decreases
- Complexity of problems to be solved increases
- Consequence: ROBUST PROBLEM SOLVING technology needed