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Evolutionary Computing

Lecture 2
(Introduction)

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History

- First Generation EC
  - Evolutionary Programming (Fogel)
  - Genetic Algorithms (Holland)
  - Evolution Strategies (Rechenberg, Schwefel)

- Second Generation EC
  - Genetic Evolution of Data Structures (Michalewicz)
  - Genetic Evolution of Programs (Koza)
  - Hybrid Genetic Search (Davis)
  - Tabu Search (Glover)

History

Third Generation EC

- Artificial Immune Systems (Forrest)
- Cultural Algorithms (Reynolds)
- DNA Computing (Adleman)
- Ant Colony Optimization (Dorigo)
- Particle Swarm Optimization (Kennedy & Eberhart)
- Memetic Algorithms
- Estimation of Distribution Algorithms

History

- 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

EC in the early 21st Century

- 3 major EC conferences, about 10 small related ones
- 3 scientific core EC journals
- 750-1000 papers published in 2003 (estimate)
- EvoNet has over 150 member institutes
- numerous applications
- numerous consultancy and R&D firms

Applications

Evolutionary Computation has been successfully applied to a wide range of problems including:

- Aircraft Design,
- Routing in Communications Networks,
- Tracking Game Playing (Checkers [Fogel])
- Robotics,
- Air Traffic Control,
- Design,
- Scheduling,
- Machine Learning,
- Pattern Recognition,
- Job Shop Scheduling,
- VLSI Circuit Layout,
- Design of Filters and Barriers,
- Data-Mining,
- User-Mining,
- Resource Allocation,
- Path Planning,

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:

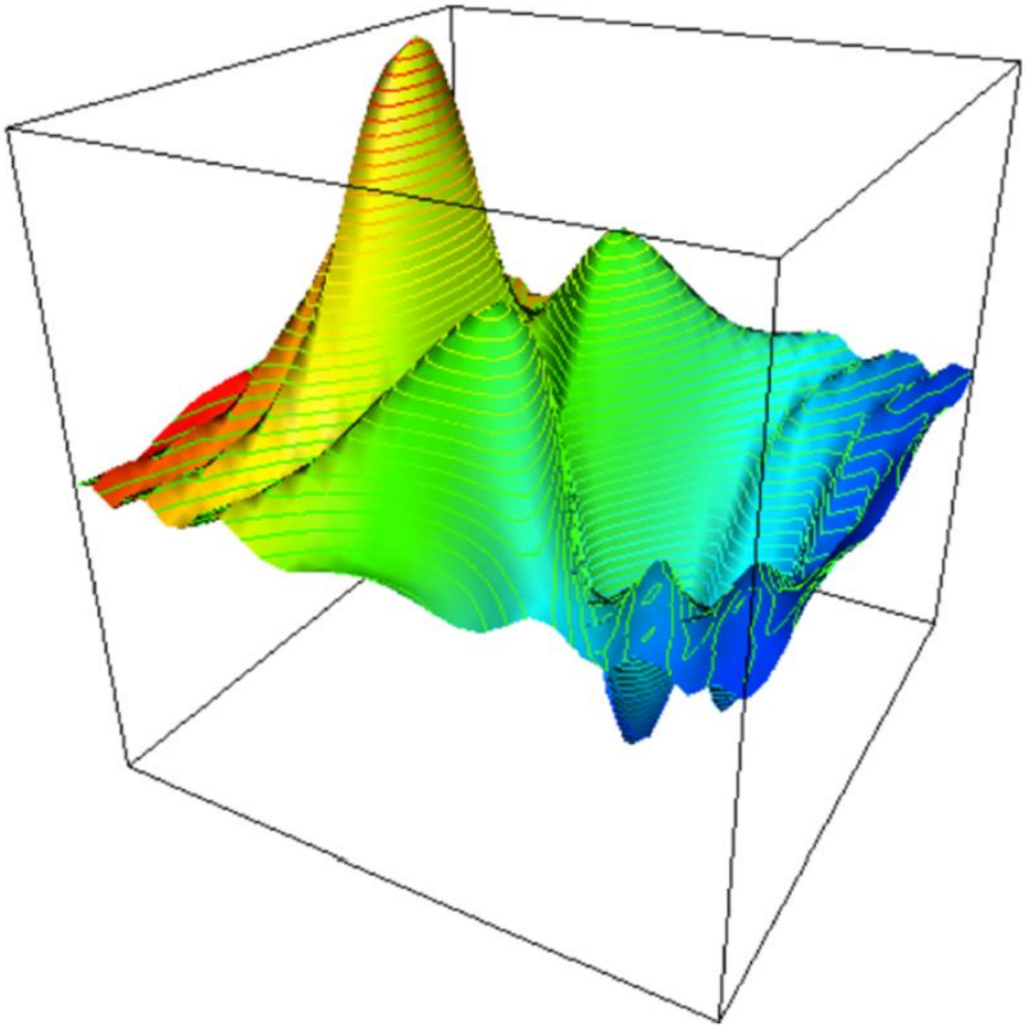
Population is the “unit of evolution”

- 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

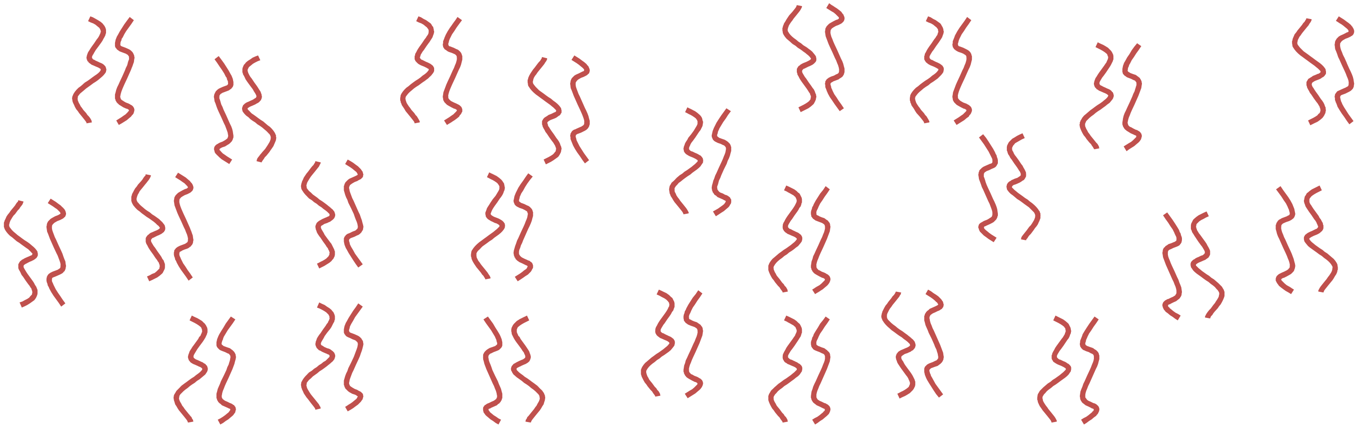
- The information required to build a living organism is coded in the DNA of that organism
- Genotype (DNA inside) determines phenotype
- Genes → phenotypic traits is a complex mapping
  - One gene may affect many traits (pleiotropy)
  - Many genes may affect one trait (polygeny)
- Small changes in the 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:

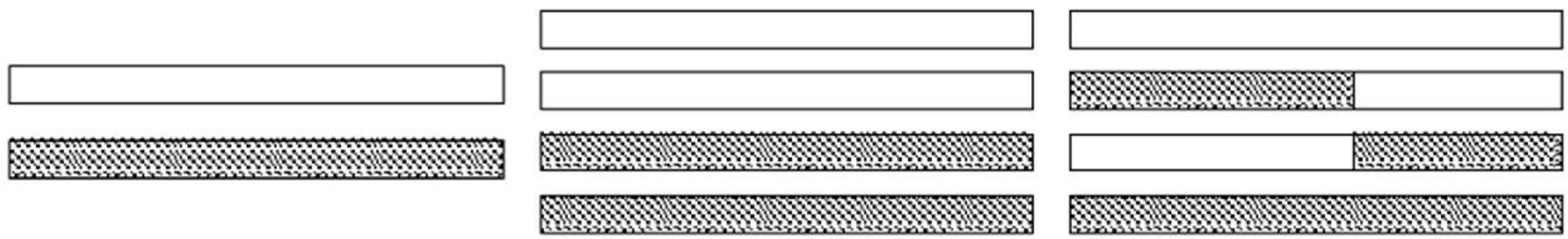


Genetics: Reproductive Cells

- 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*

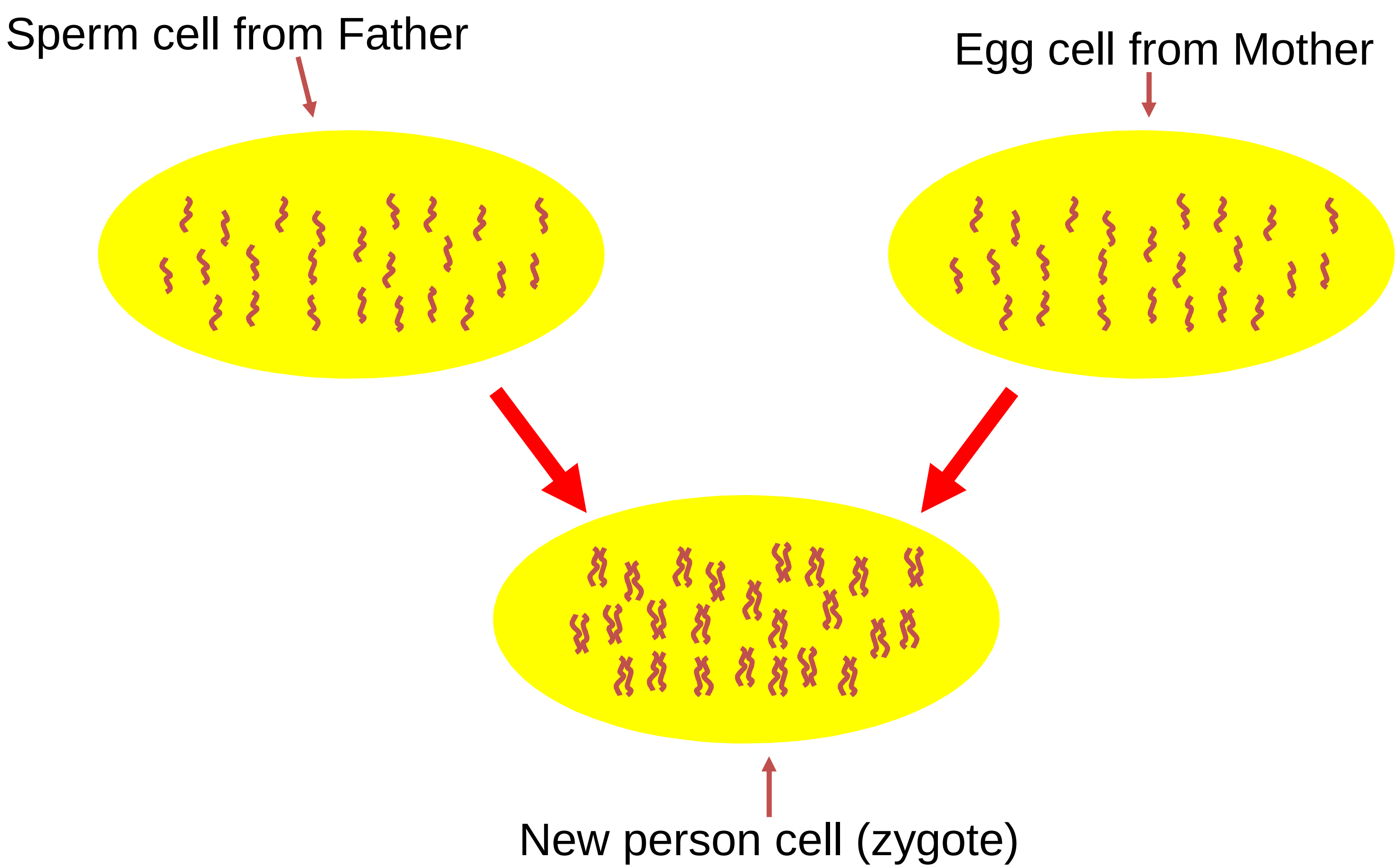
Genetics:
Crossing-over during meiosis

- 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



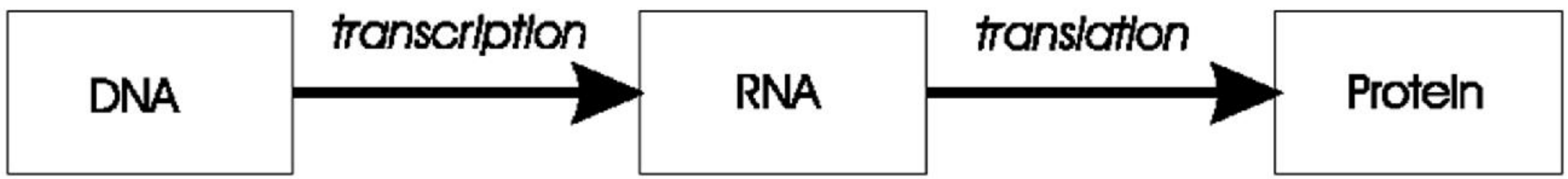
Genetics:
After fertilisation

- 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