Introduction to EC

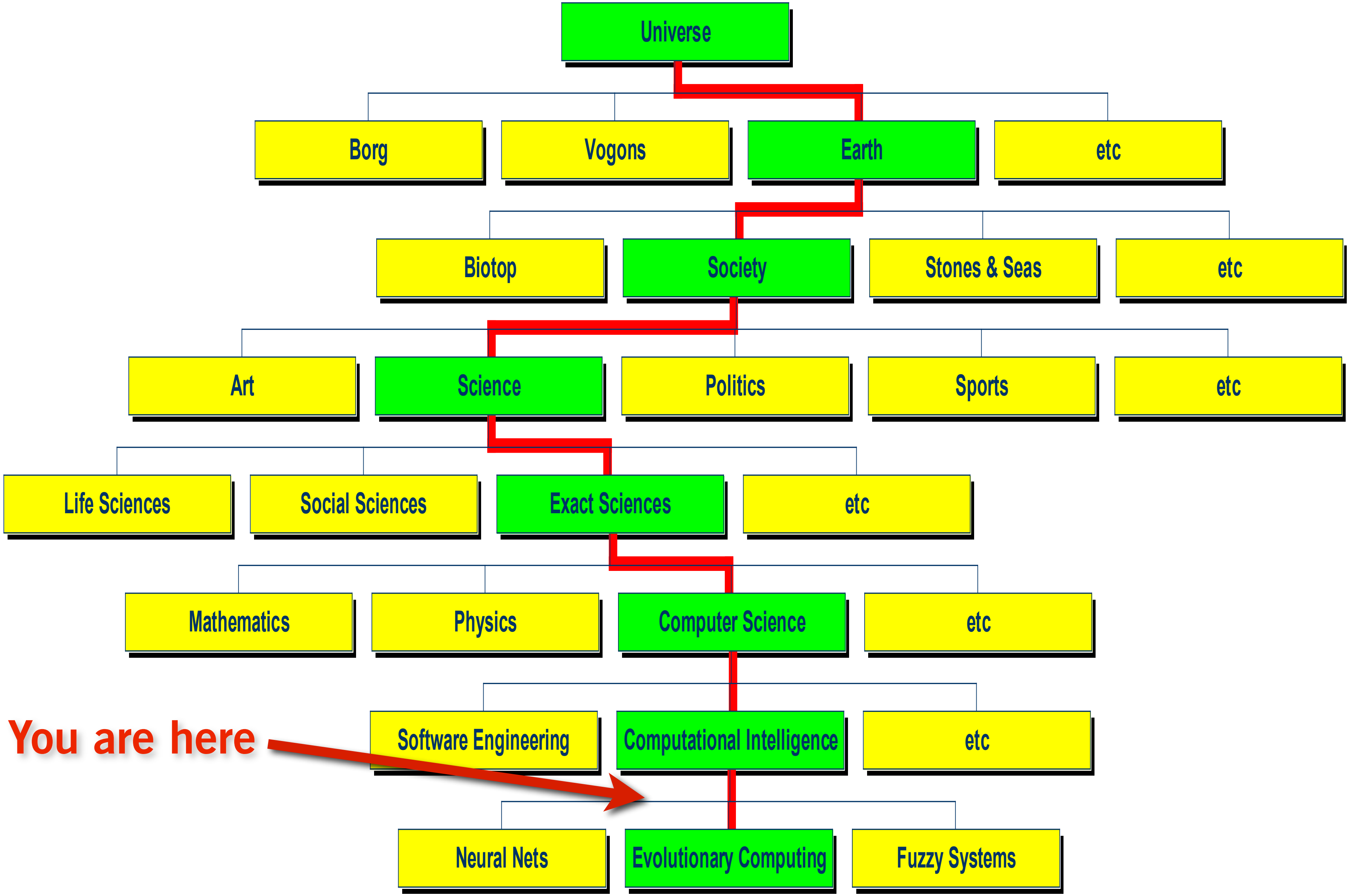
Lecture 1

MONASH UNIVERSITY CLAYTON'S SCHOOL OF INFORMATION TECHNOLOGY

Summary

Reading: Eiben& Smith Chapter 1

- Positioning of EC and the basic EC metaphor
- Historical perspective
- Biological inspiration:
  - Darwinian evolution theory (simplified!)
  - Genetics (simplified!)
- Motivation for EC
- What can EC do: examples of application areas
- Demo: evolutionary magic square solver



Universe
Borg
Vogons
Earth
etc
Biotop
Society
Stones & Seas
etc
Art
Science
Politics
Sports
etc
Life Sciences
Social Sciences
Exact Sciences
etc
Mathematics
Physics
Computer Science
etc
You are here
Software Engineering
Computational Intelligence
etc
Neural Nets
Evolutionary Computing
Fuzzy Systems

Positioning of EC

- EC is part of computer science
- EC is not part of life sciences/biology
- Biology delivered inspiration and terminology
- EC can be applied in biological research

Simulation and Synthesis

- Simulation: an *imitation* of some device, state or process
- Closely related to modelling
- Often used as an alternative when closed form analytic solutions fail
- Synthesis: the integration of two or more existing elements to produce a *new* creation
- Related to (various) concepts of *emergence* (Physics, Philosophy, Chemistry, Neuroscience, etc.)
- DNA is a powerful example of a natural synthesis process

The Main Evolutionary Computing Metaphor

EVOLUTION		PROBLEM SOLVING
Environment	⟷	Problem
Individual	⟷	Candidate Solution
Fitness	⟷	Quality

- Fitness → chances for survival and reproduction
- Quality → chance for seeding new solutions

Brief History 1: Pioneers

- 1948, Turing
  proposes "genetical or evolutionary search"
- 1962, Bremermann
  optimisation 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

Brief History 2: The rise of EC

- 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

Brief History: Alife and SAB

- 1987: First Artificial Life conference: Los Alamos (International Conference on the Synthesis and Simulation of Living Systems – Artificial Life I)
- 1991: First European Conference on Artificial Life held in Paris
- 1990: SAB (Simulation of Adaptive Behaviour, Animals to Animats).
- All conferences still going (strong-ish) today!

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
- uncountable (meaning: many) applications
- uncountable (meaning: ?) consultancy and R&D firms

"The entire modern deification of survival, per se, survival returning to its self, survival naked and abstract with the denial of any subsequent excellence in what survives except the capacity for more survival still, is surely the strangest intellectual stopping place ever proposed by one man to another."

Attributed to William James

Photo: A. Dorin

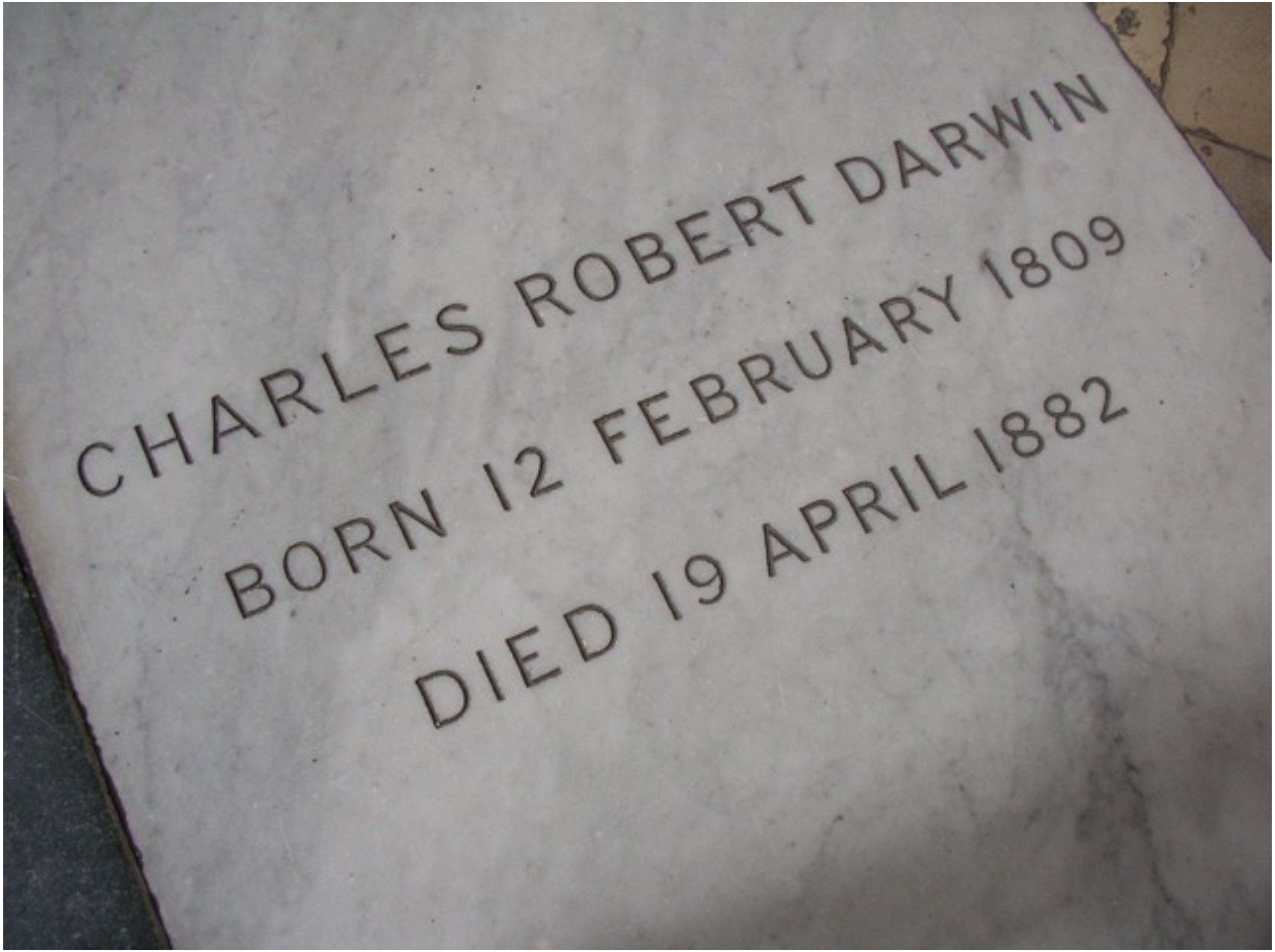


Photo: A. Dorin

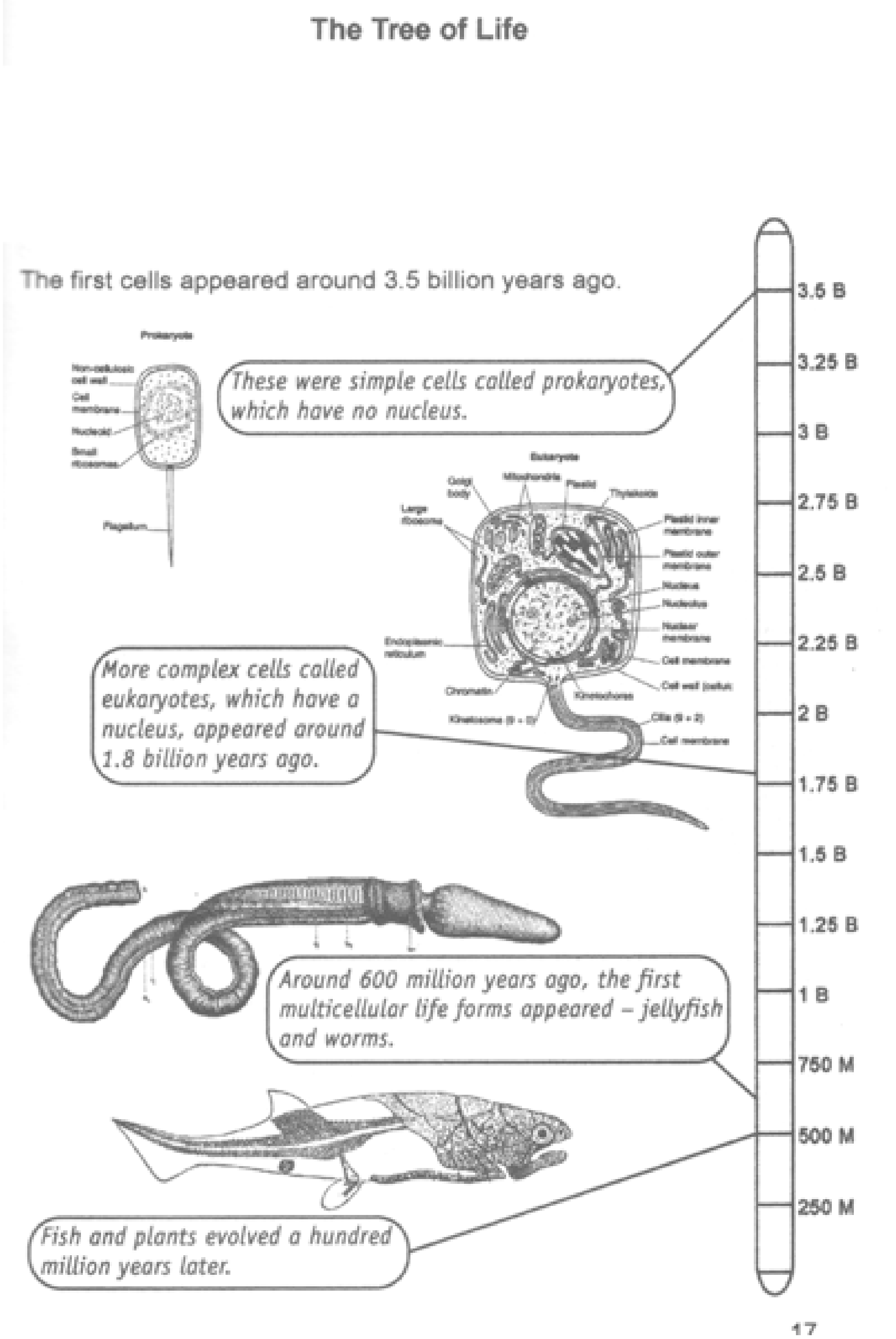
Photo: A. Dorin

What is Evolution?

- The theory that species can *change*. One species gives rise to another.
- Ultimately, every species on Earth is descended from a single, common ancestor, like branches on a tree spring from a single trunk.
- The fossil record of species that no longer exist shows *patterns*, where it appears that groups of fossils follow a developmental sequence. Hence species are related to each other in some way.
- Carbon dating confirms a temporal sequence of change.
- Evolution is not just a theoretical possibility. It is a concrete *fact*.

The Tree of Life

- All life descended from a common ancestor that lived around 4 billion years ago.
- Around 370 million years ago, animals began to colonise the land
- Primates appeared around 35 million years ago
- Modern humans (*Homo sapiens sapiens*) around 100k years ago



Evolution by Natural Selection

- The theory of *natural selection* explains **how** evolution occurred on Earth
- Proposed by Charles Darwin and Alfred Russel Wallace in 1858
- The theory of evolution states that one species can change into another, but it does not say **how** this happens
- Natural selection provides a mechanism by which things can change their design **without any outside help**
- This is the 'universal acid' (Dennett)

Natural Selection

1. There is a population of things that make copies of themselves
2. The copying process is not perfect – errors or changes are introduced
3. The copying errors lead to differences in the ability of offspring to survive and make copies of themselves

Darwinian Evolution 1: Survival of the fittest

- All environments have finite resources (i.e., can only support a limited number of individuals)
- Lifeforms 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: 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 …

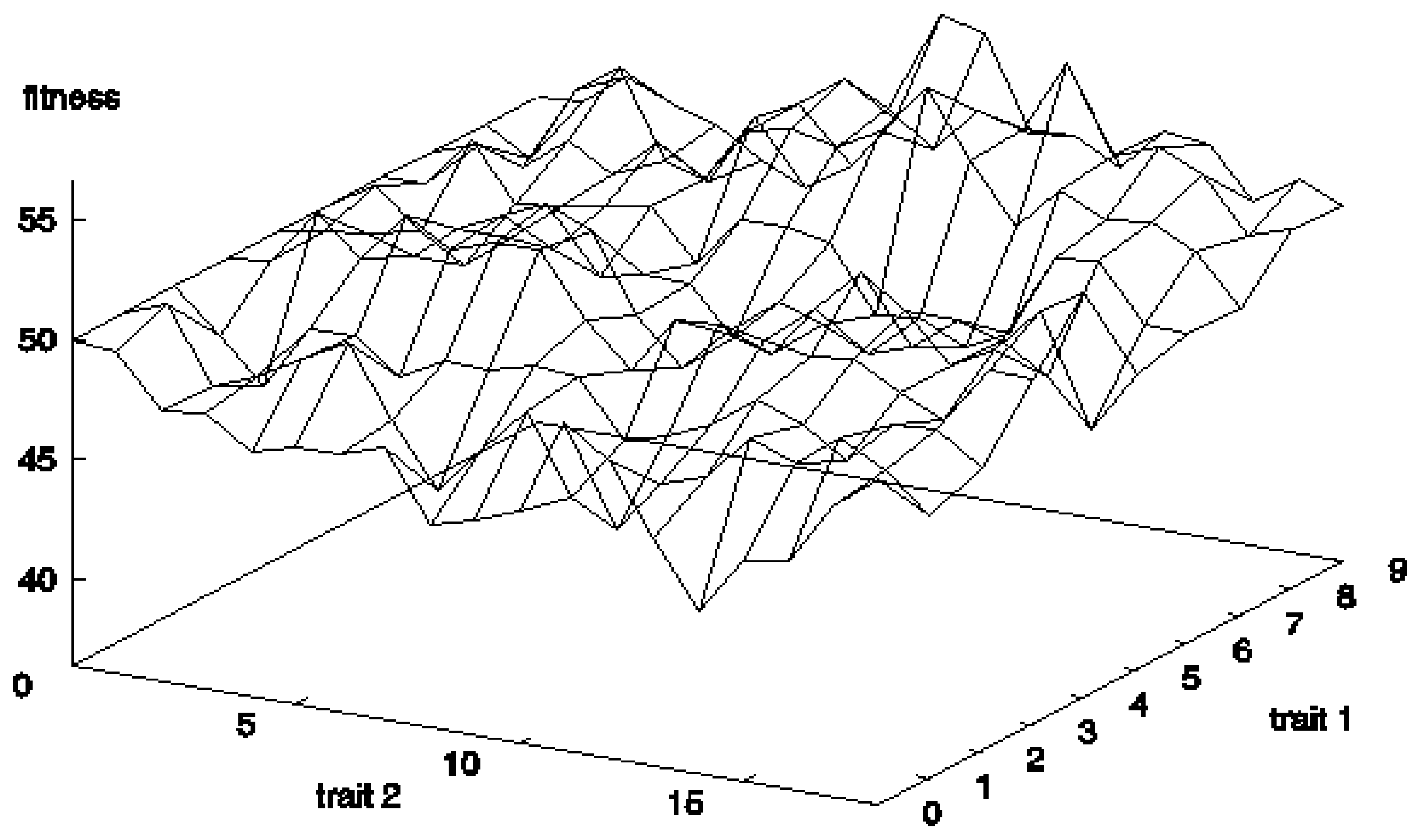
Darwinian Evolution: Summary

- 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 a "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

Example with 2 traits



Adaptive Landscape Metaphor

- 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

Natural Genetics

- 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)

Genes and the Genome

- Genes are encoded in strands of DNA called chromosomes

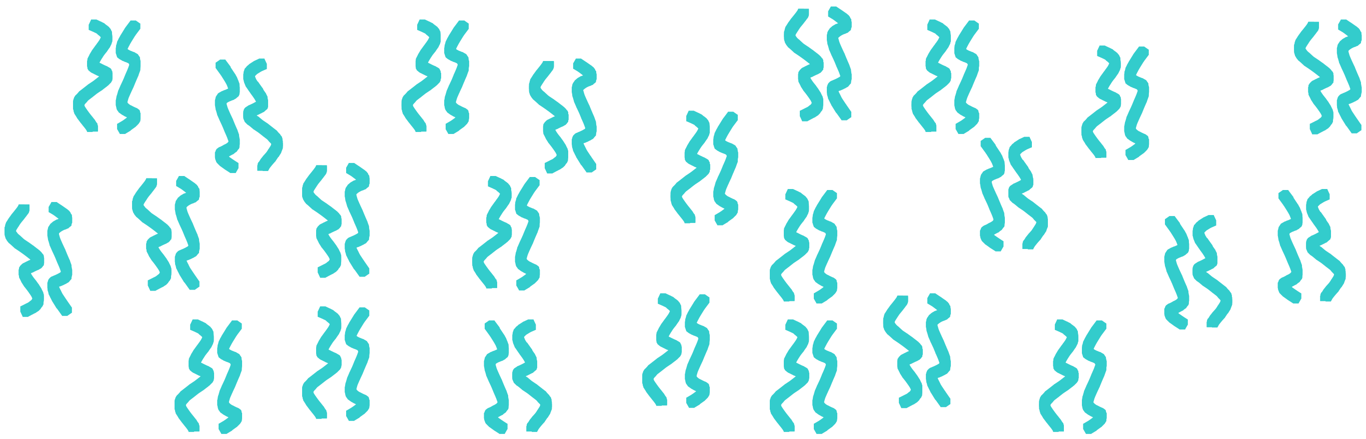
- In most cells, there are two copies of each chromosome (diploidy)

- The complete genetic material in an individual's genotype is called the Genome

- Within a species, most of the genetic material is the same

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:

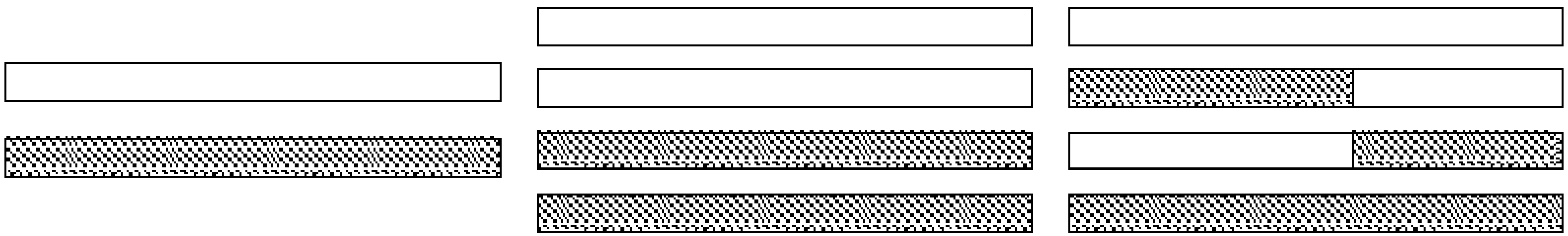


Reproductive Cells

- 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*

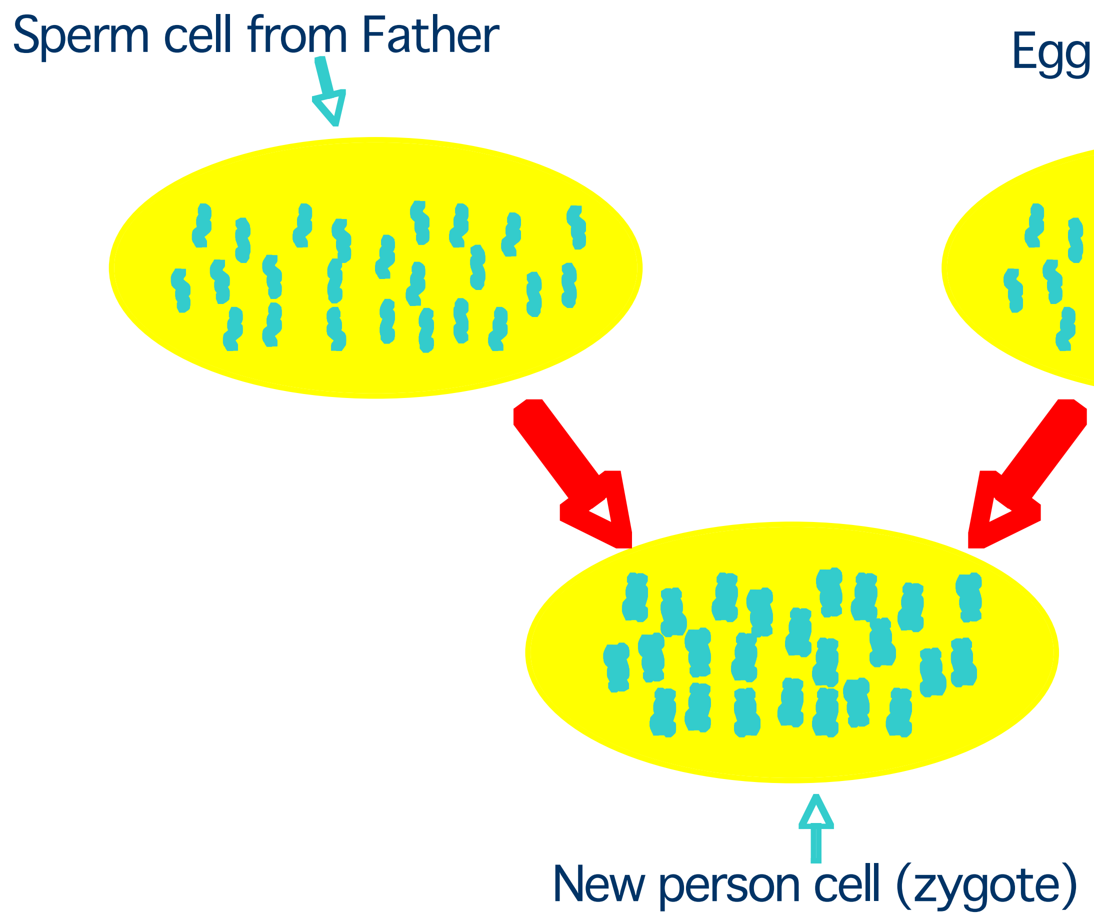
Crossing-over during Meiosis

- 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

Fertilisation



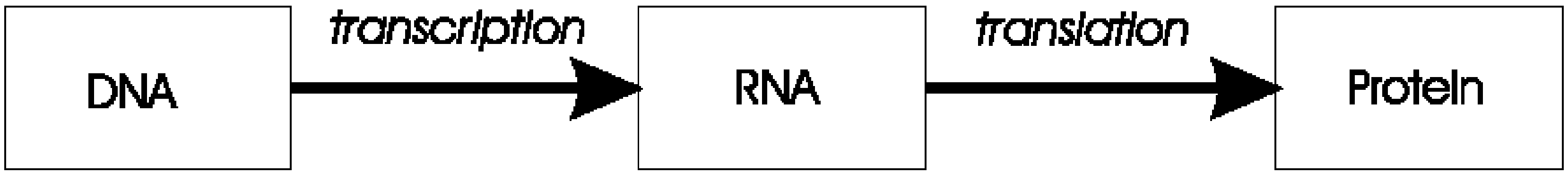
After Fertilisation

- 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

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
  - DNA contains a lot of 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 !

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!

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

Possible Approaches

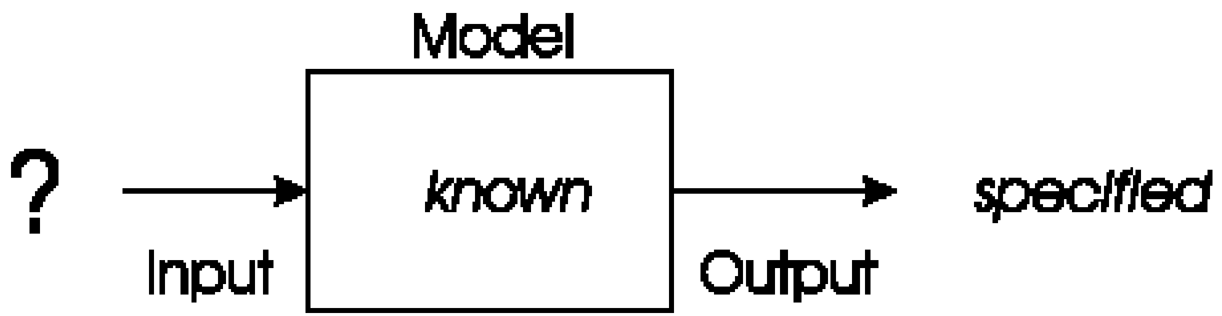
- Nature has always served as a source of inspiration for engineers and scientists
- The best problem solver known in nature is:
  - **the (human) brain** that created "the wheel, New York, wars and so on" (after Douglas Adams' *Hitch-Hikers Guide*)
  - **the evolution mechanism** that created the human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

Motivations for EC

- 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

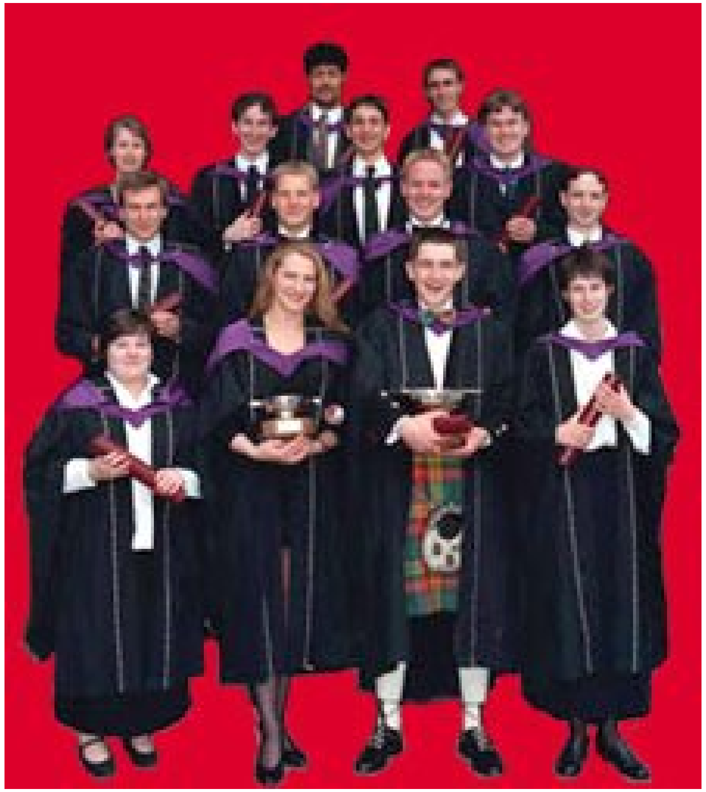
Problem Type 1: Optimisation

- We have a model of our system and seek inputs that give us a specified goal

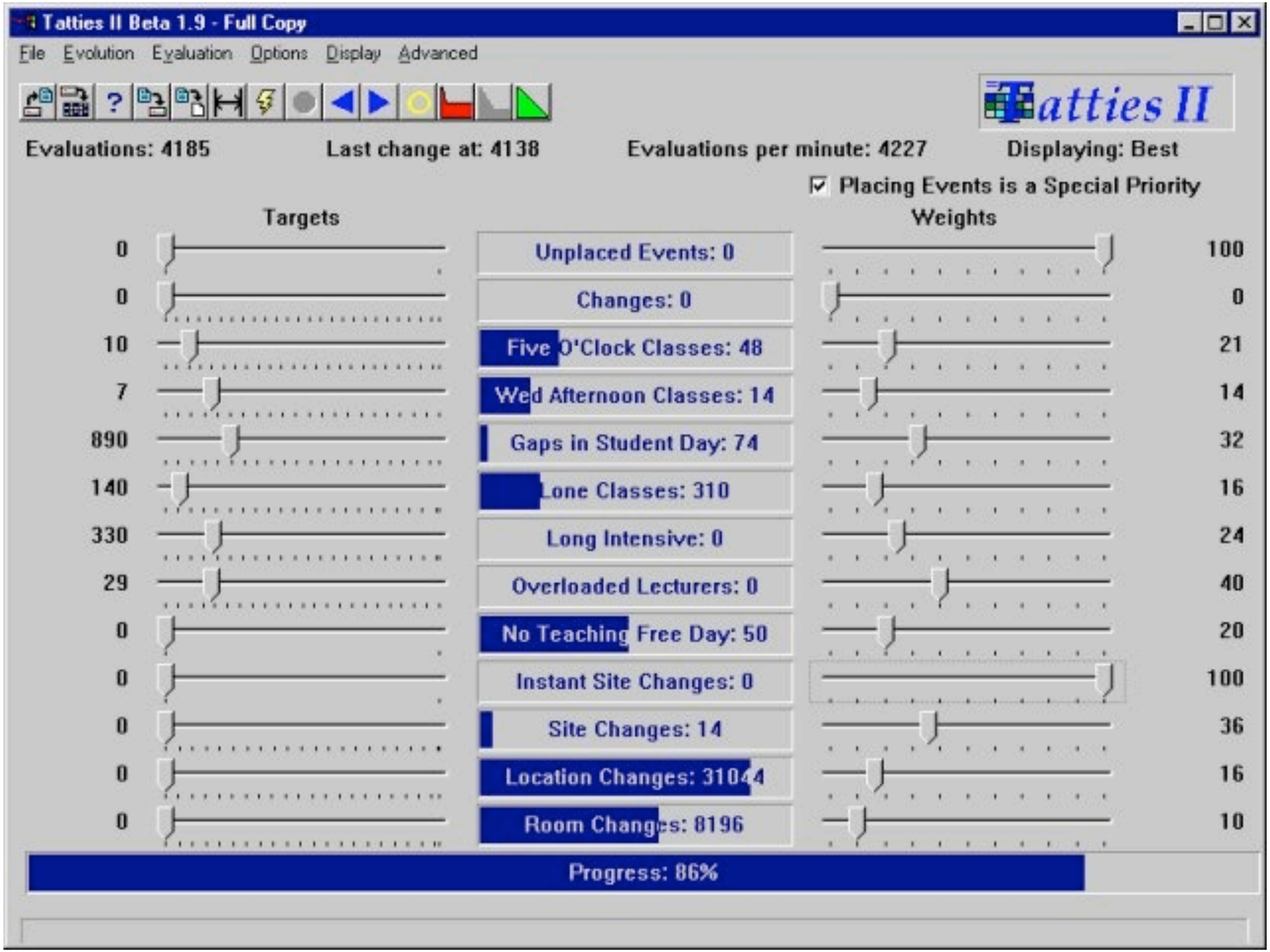


- e.g.
  - time tables for university, call centre, or hospital
  - design specifications, etc. etc.

Optimisation Example 1: University Timetabling



- Enormously big search space
- Timetables must be good
- "Good" is defined by a number of competing criteria
- Timetables must be feasible
- Vast majority of search space is infeasible

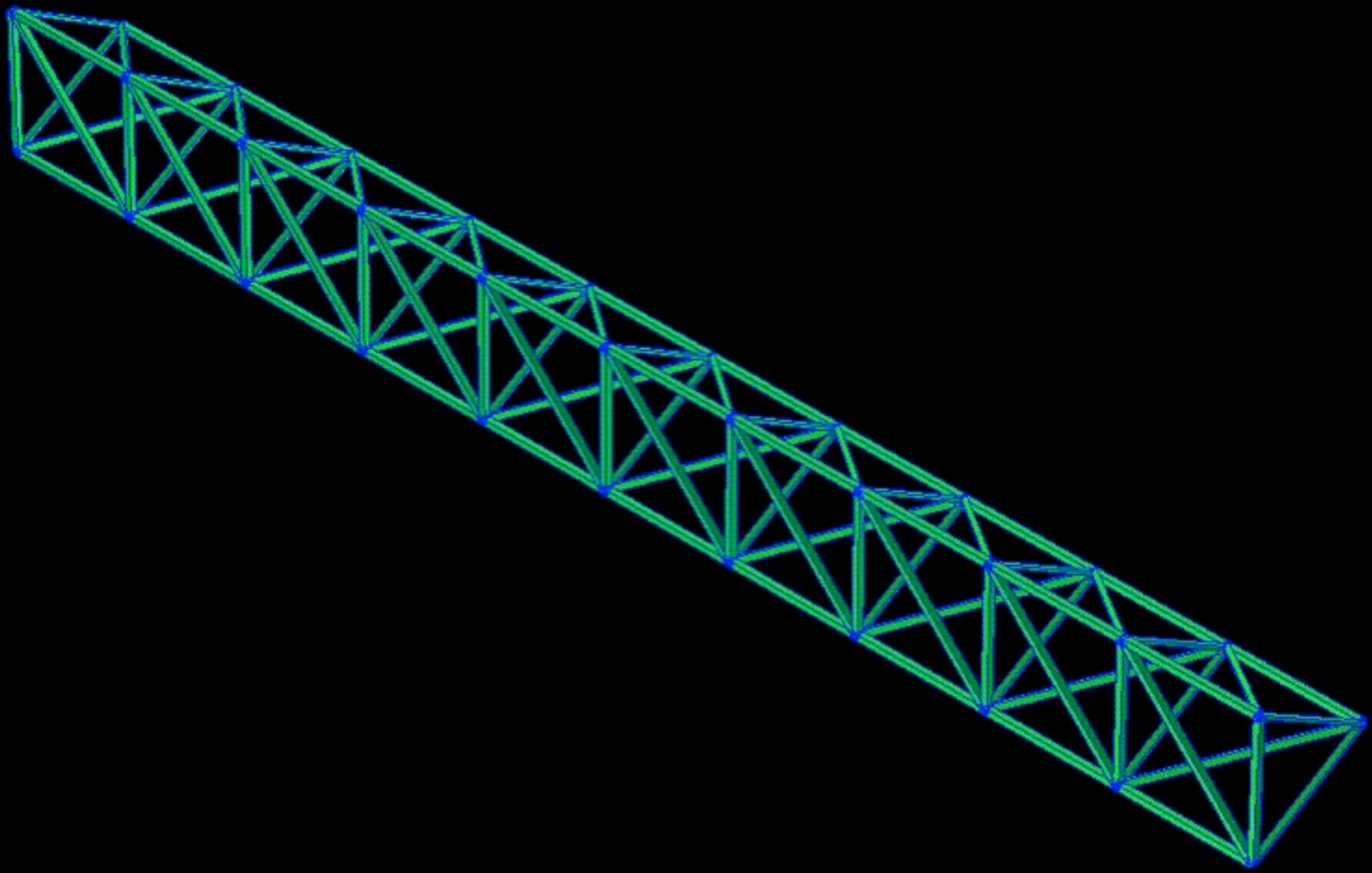


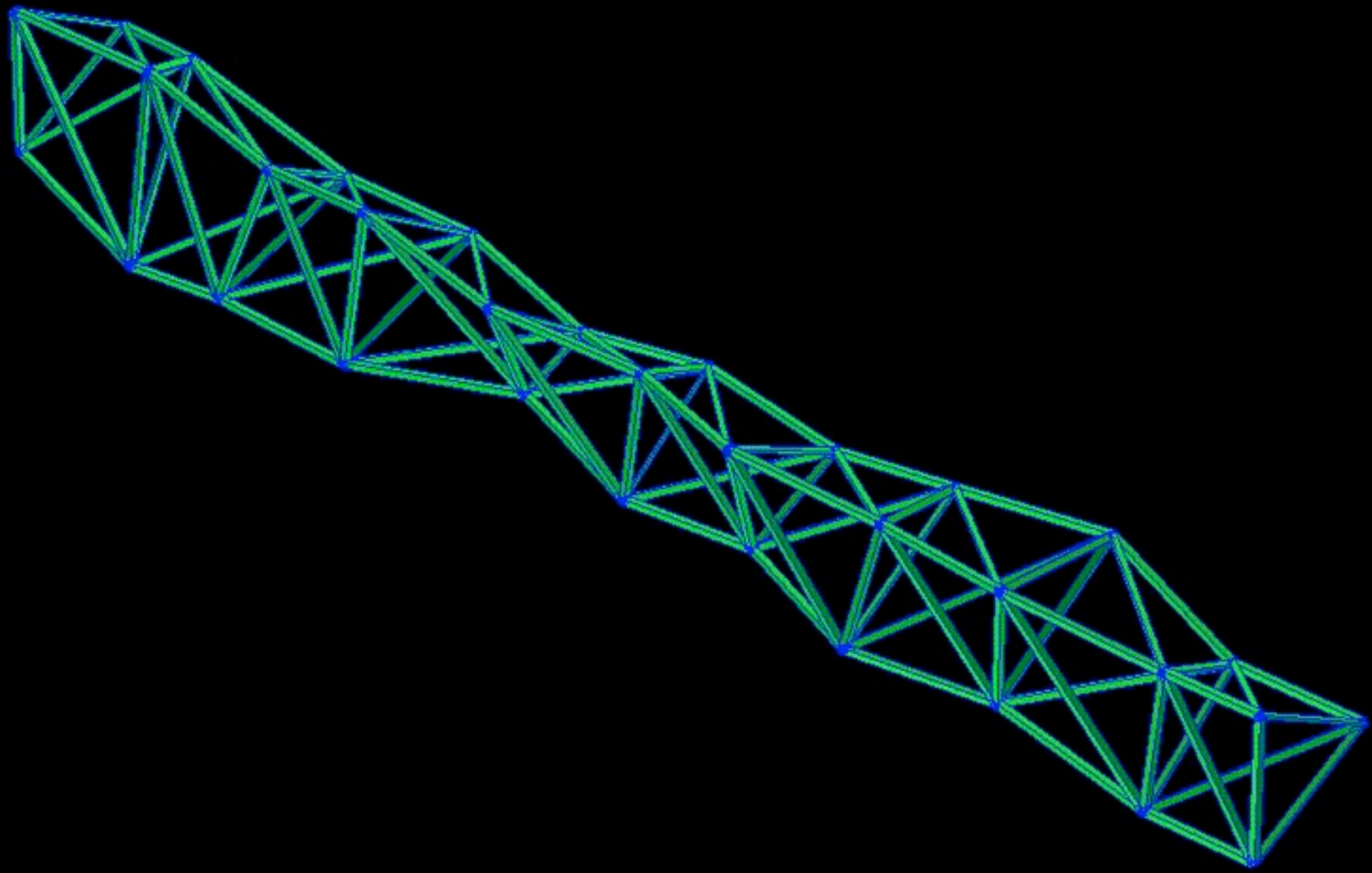
Tatties II Beta 1.9 - Full Copy
File Evolution Evaluation Options Display Advanced
Tatties II
Evaluations: 4185
Last change at: 4138
Evaluations per minute: 4227
Displaying: Best
Placing Events is a Special Priority
Targets
Weights
0 Unplaced Events: 0 100
0 Changes: 0 0
10 Five O'Clock Classes: 48 21
7 Wed Afternoon Classes: 14 14
890 Gaps in Student Day: 74 32
140 Lone Classes: 310 16
330 Long Intensive: 0 24
29 Overloaded Lecturers: 0 40
0 No Teaching Free Day: 50 20
0 Instant Site Changes: 0 100
0 Site Changes: 14 36
0 Location Changes: 31044 16
0 Room Changes: 8196 10
Progress: 86%

Optimisation Example 2: Satellite Structure

- Optimised satellite designs for NASA to maximise vibration isolation
- Evolving: design structures
- Fitness: vibration resistance
- Evolutionary "creativity"

http://www.soton.ac.uk/~ajk/BBeam.AVI

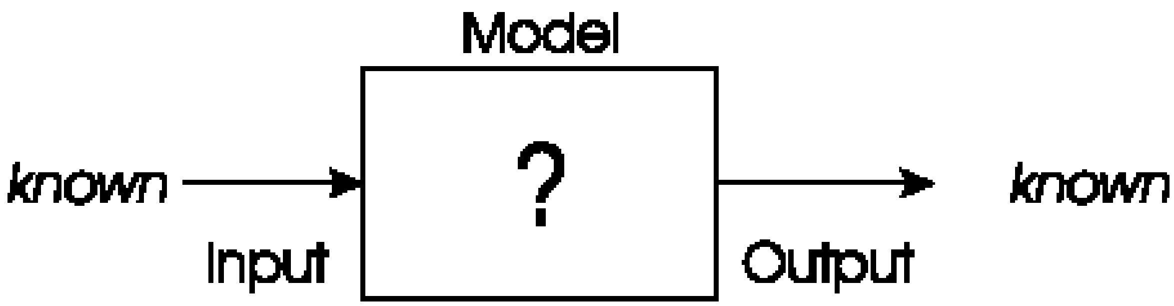





cnes
centre national d'études spati

Problem Types 2: Modelling

- We have corresponding sets of inputs & outputs and seek model that delivers correct output for every known



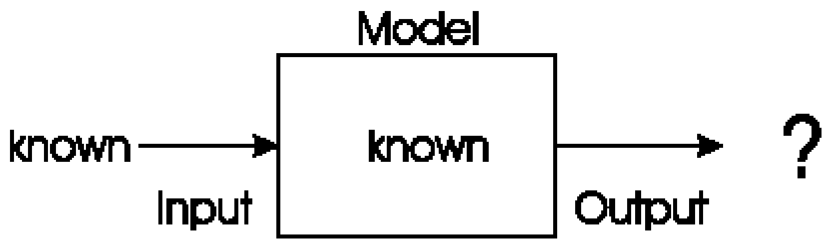
- Evolutionary Machine Learning

Modelling Example: Loan applicant credibility

- British bank evolved creditability model to predict loan paying behaviour of new applicants
- Evolving: prediction models
- Fitness: model accuracy on
- historical data

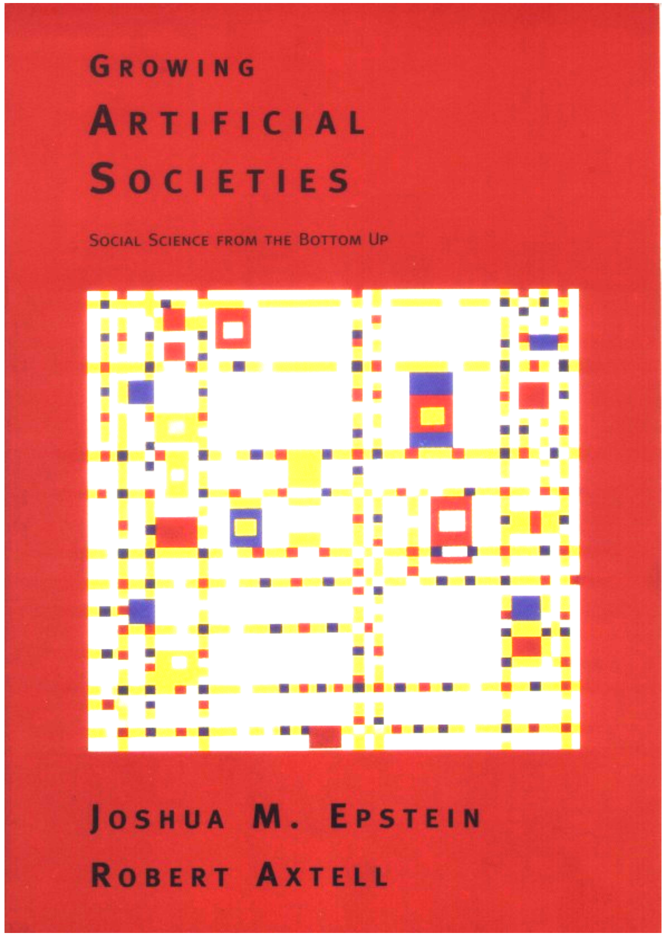
Problem Type 3: Simulation

- We have a given model and wish to know the outputs that arise under different input conditions



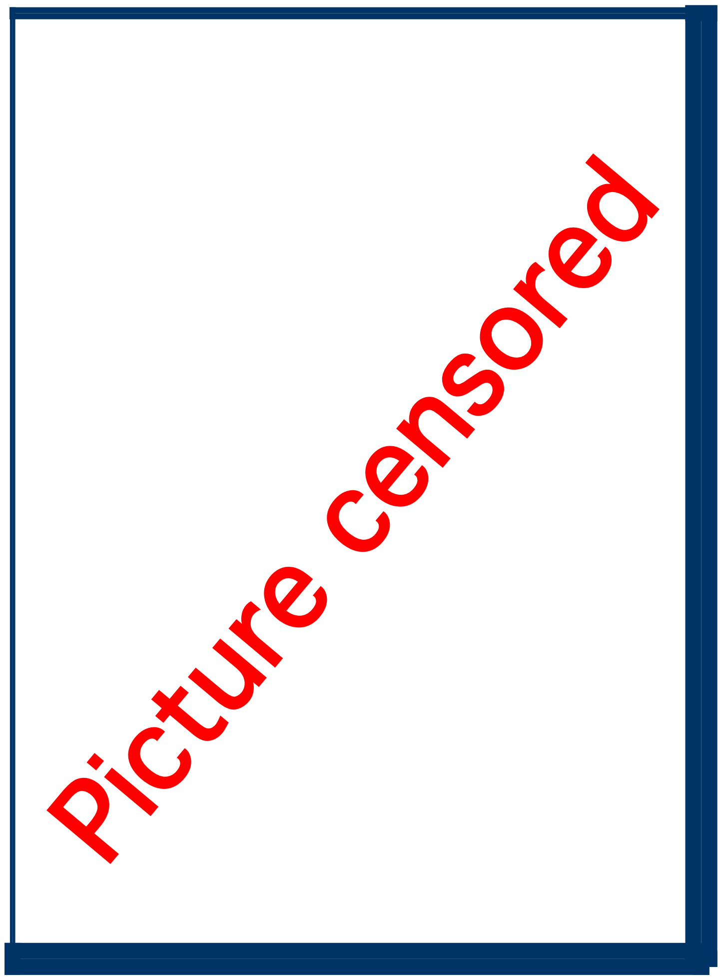
- Often used to answer "what-if" questions in evolving dynamic environments
- e.g. Evolutionary economics, Artificial Life

Simulation Example: evolving artificial societies



- Simulating trade, economic competition, etc. to calibrate models
- Use models to optimise strategies and policies
- Evolutionary economy
- Survival of the fittest is universal (big/small fish)

Simulation Example 2: biological interpretations



- Incest prevention keeps evolution from rapid degeneration
  (we knew this)
- Multi-parent reproduction, makes evolution more efficient
  (this does not exist on Earth in carbon)
- 2nd sample of Life

Demonstration: Magic Square

Evolutionary approach to solving this puzzle:

- Creating random begin arrangement
- Making N mutants of given arrangement
- Keeping the mutant (child) with the least error
- Stopping when error is zero

Demonstration: Magic Square

- Given a 10x10 grid with a small 3x3 square in it
- Problem: arrange the numbers 1-100 on the grid such that
  - all horizontal, vertical, diagonal sums are equal (505)
  - a small 3x3 square forms a solution for 1-9

Demonstration: Magic Square

- Software by M. Herdy, TU Berlin
- Interesting parameters:
  - Step1: small mutation, slow & hits the optimum
  - Step10: large mutation, fast & misses ("jumps over" optimum)
  - Mstep: mutation step size modified on-line, fast & hits optimum
- Start: double-click on icon below
- Exit: click on TUBerlin logo (top-right)

http://www.dcs.napier.ac.uk/~benp/summerschool/jdemos/herdy/magic_problem.html

Recommended Reading

- Recommended Reading for this lecture:
  - Eiben and Smith Chapter 1
  - Dylan Evans and Howard Selina, *Introducing Evolution.* Icon Books, 2001
  - Charles Darwin, *The Origin of Species.* John Murray 1859
  - Richard Dawkins, *The Selfish Gene* (30th anniversary edition). Oxford University Press, 2006
  - John Maynard-Smith & Szathmáry, Eörs, *The major transitions in evolution.* W.H. Freeman Spektrum, 1995.
  - D. B. Fogel, ed., *Evolutionary Computation: the Fossil Record.* IEEE Press, 1998.
  - Stuart Kauffman, *Origins of Order: Self-Organisation and Selection in Evolution.* Oxford University Press, 1993.