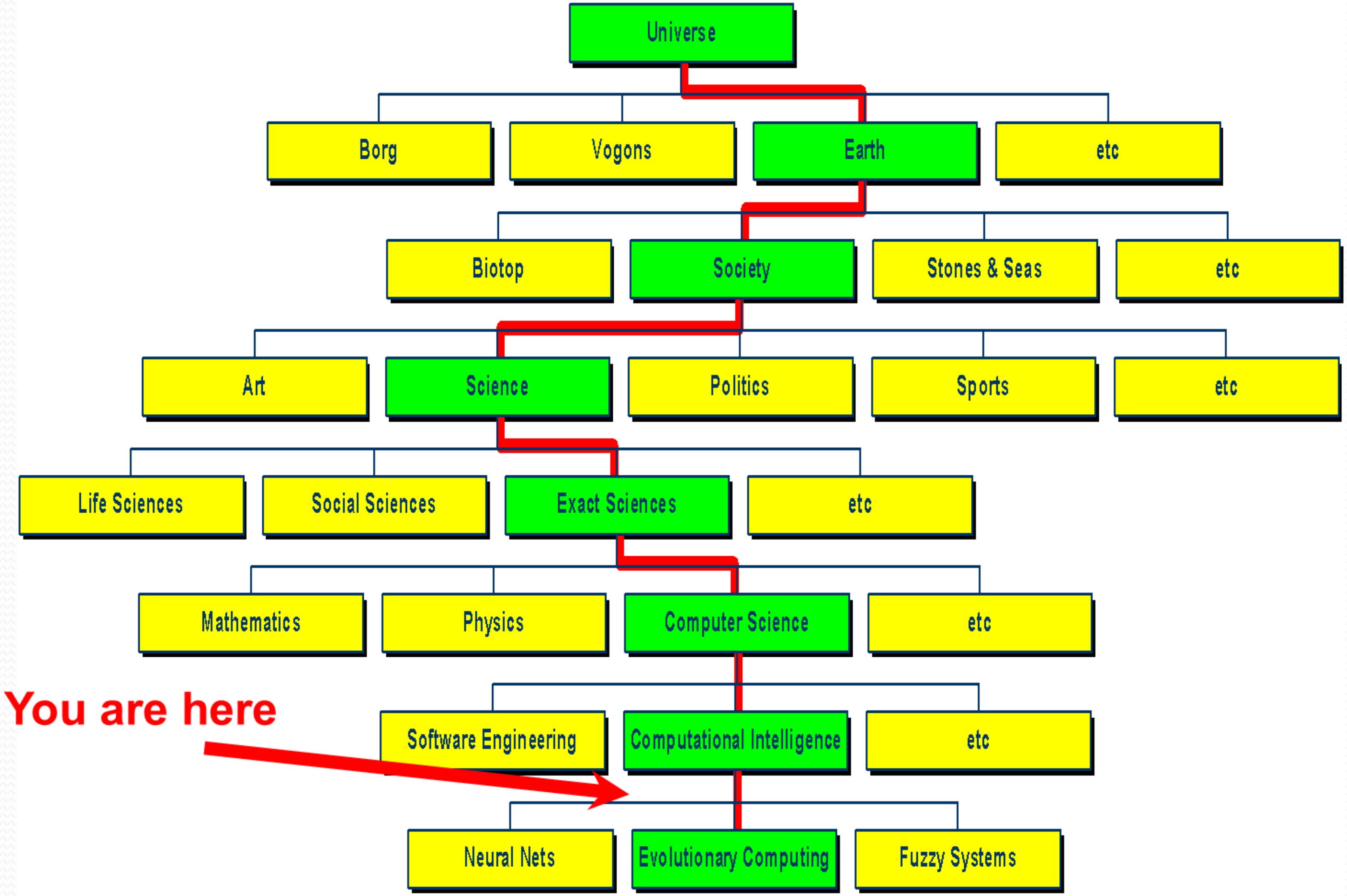
Introduction

Chapter 1

Contents

- 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

Positioning of EC



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

The Main EC Metaphor

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

Fitness $\rightarrow$ chances for survival and reproduction

Quality $\rightarrow$ chance for seeding new solutionsCV

Fitness in nature: observed, 2ndary, EC: primary

Brief EC history

- 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

Brief EC history 2

- 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
- 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: 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: 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"

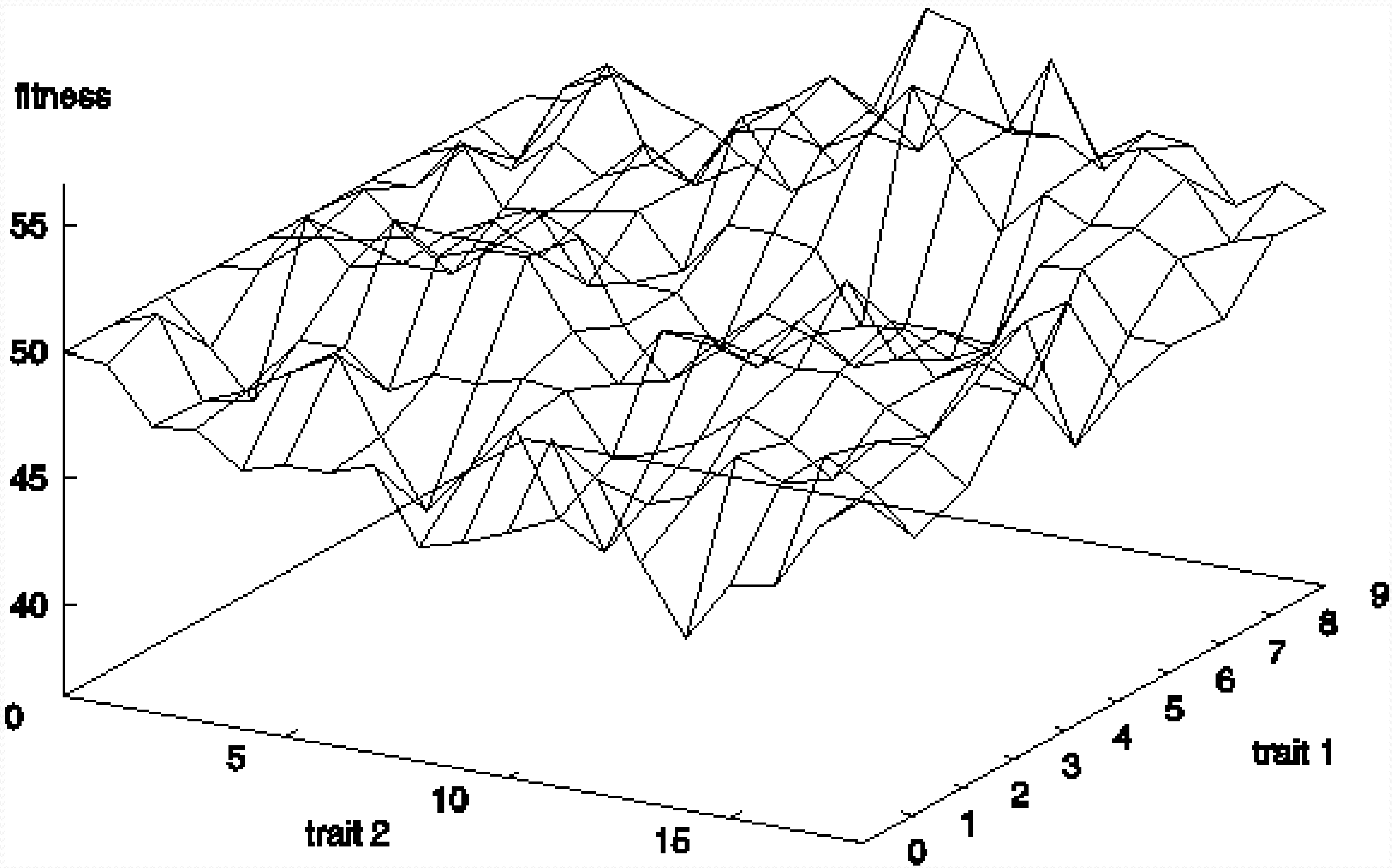
- Variations occur through random changes yielding constant source of diversity, coupled with selection means that:

Population is the "unit of evolution"

- Note the absence of "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


fitness
55
50
45
40
0
5
10
15
trait 2
0
1
2
3
4
5
6
7
8
9
trait 1

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

Natural Genetics

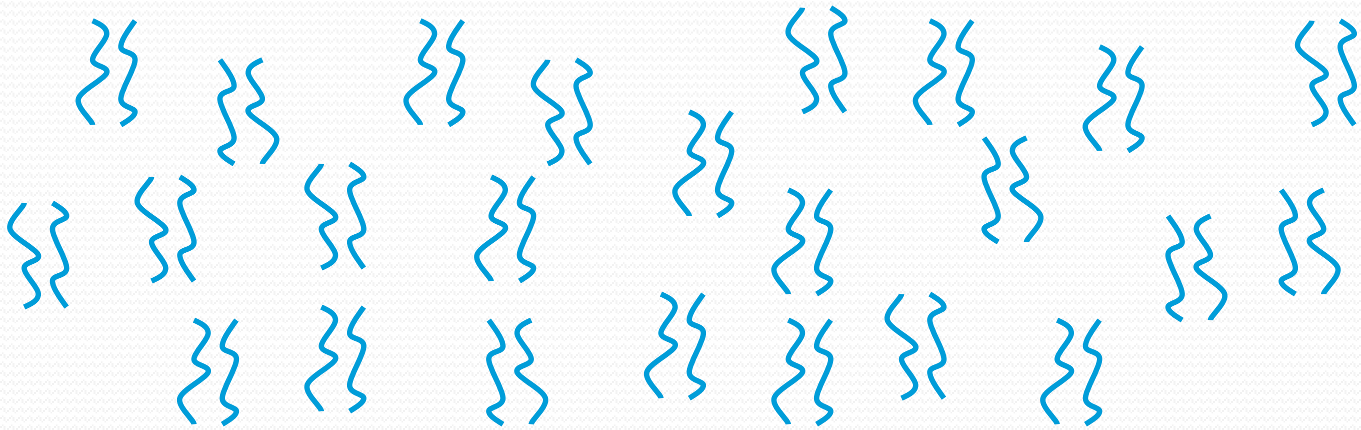
- The information required to build a living organism is coded in the DNA of that organism
- Genotype (DNA inside) determines phenotype
- Genes → phenotypic traits is a complex mapping
  - One gene may affect many traits (pleiotropy)
  - Many genes may affect one trait (polygeny)
- Small changes in the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

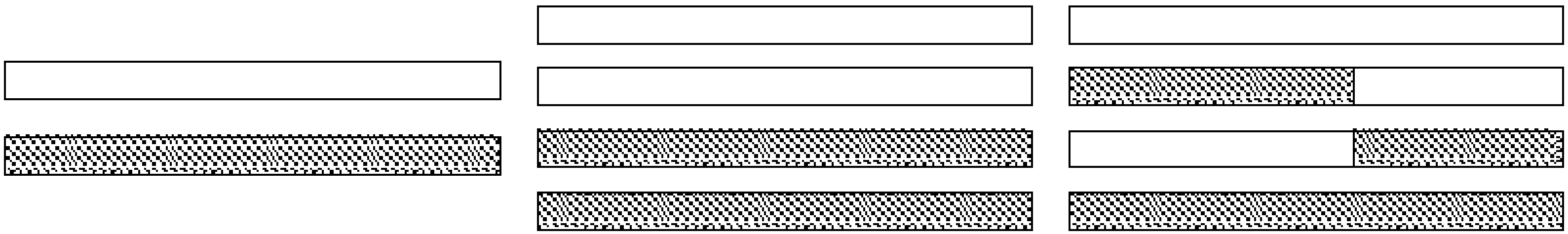


Reproductive Cells

- 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*

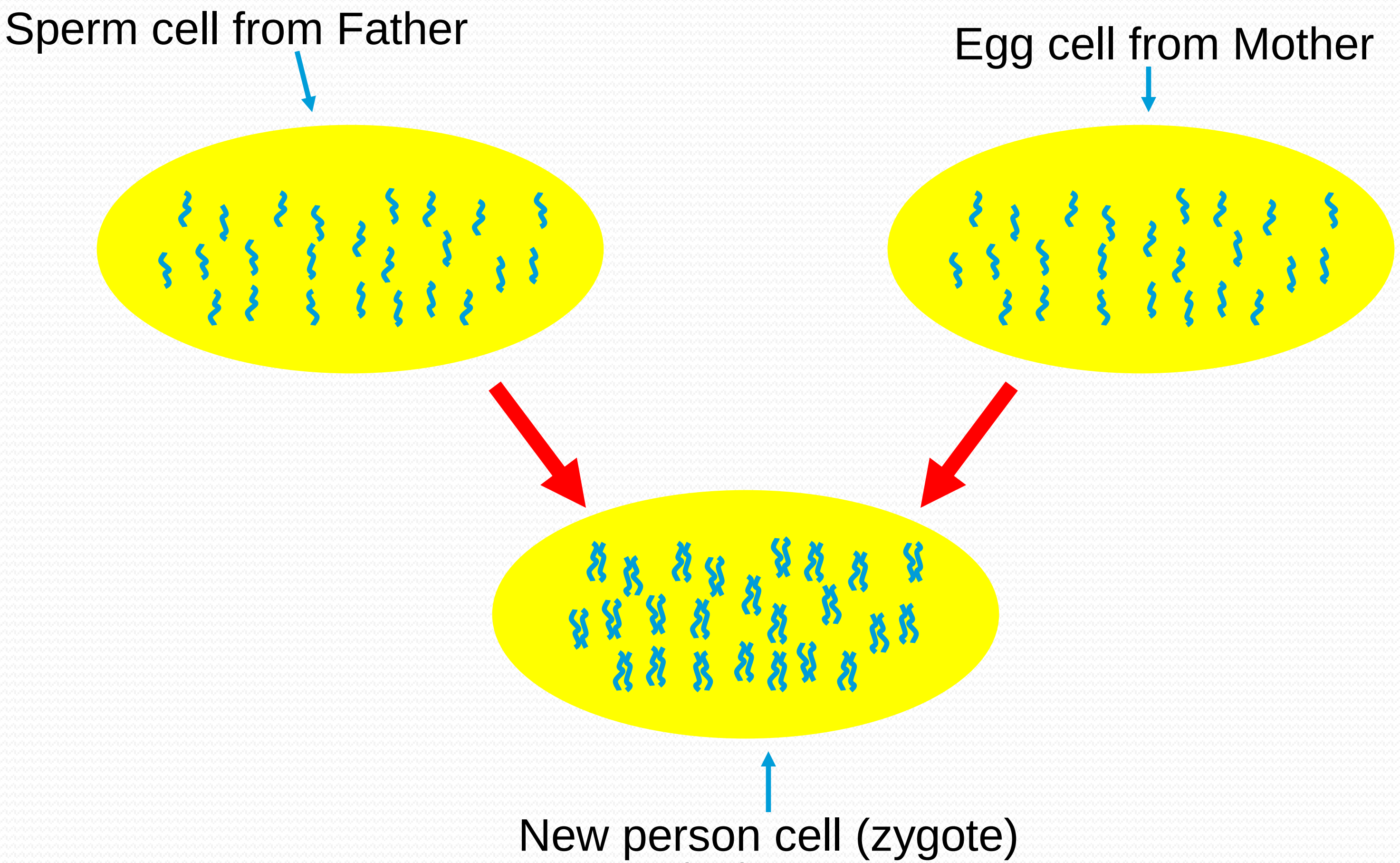
Crossing-over during meiosis

- 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



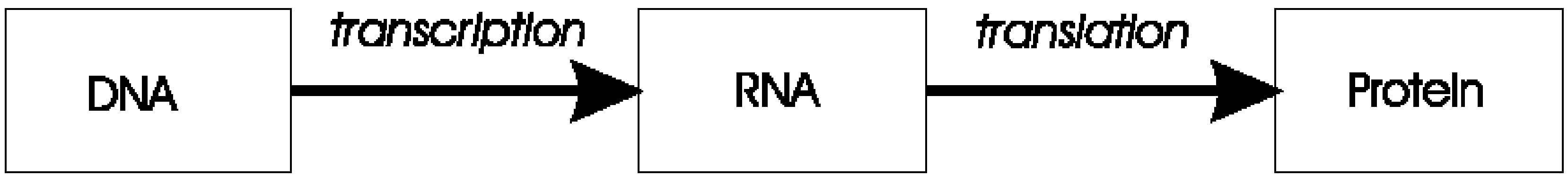
After fertilisation

- 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
  - 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 !**

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

Motivations for EC 1

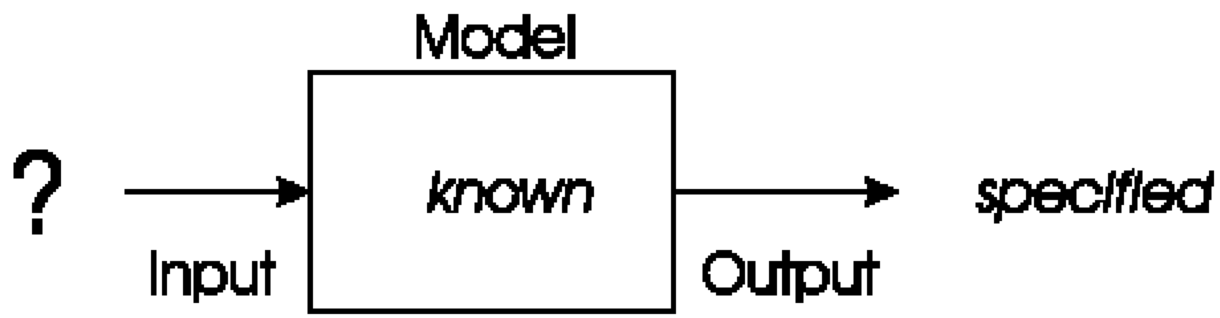
- Nature has always served as a source of inspiration for engineers and scientists
- The best problem solver known in nature is:
  - the (human) brain that created "the wheel, New York, wars and so on" (after Douglas Adams' Hitch-Hikers Guide)
  - the evolution mechanism that created the human brain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

Motivations for EC 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

Problem type 1 : Optimisation

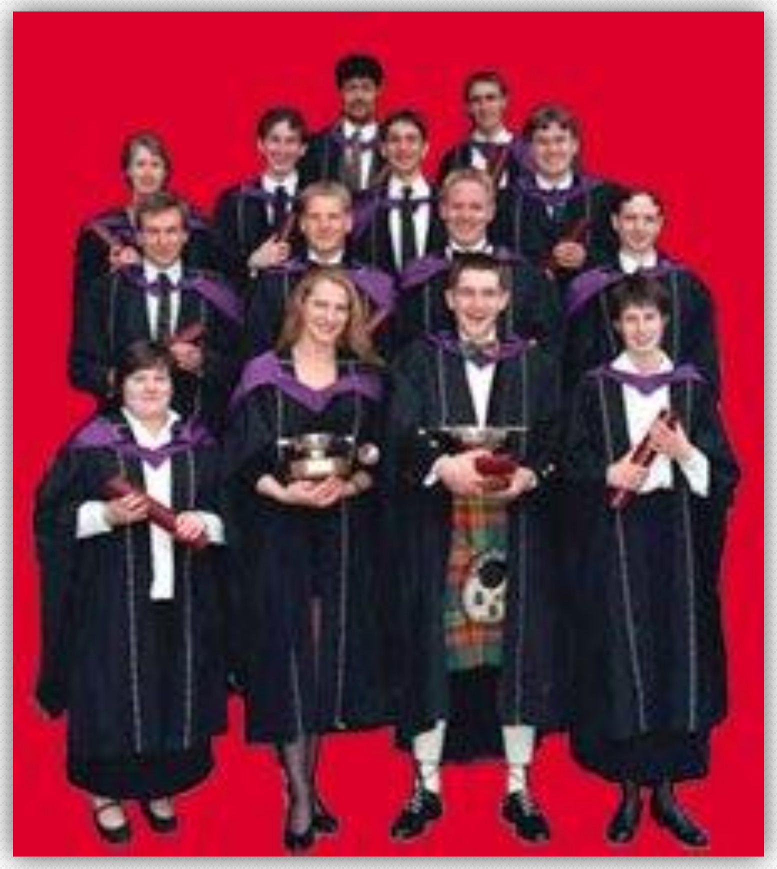
- We have a model of our system and seek inputs that give us a specified goal

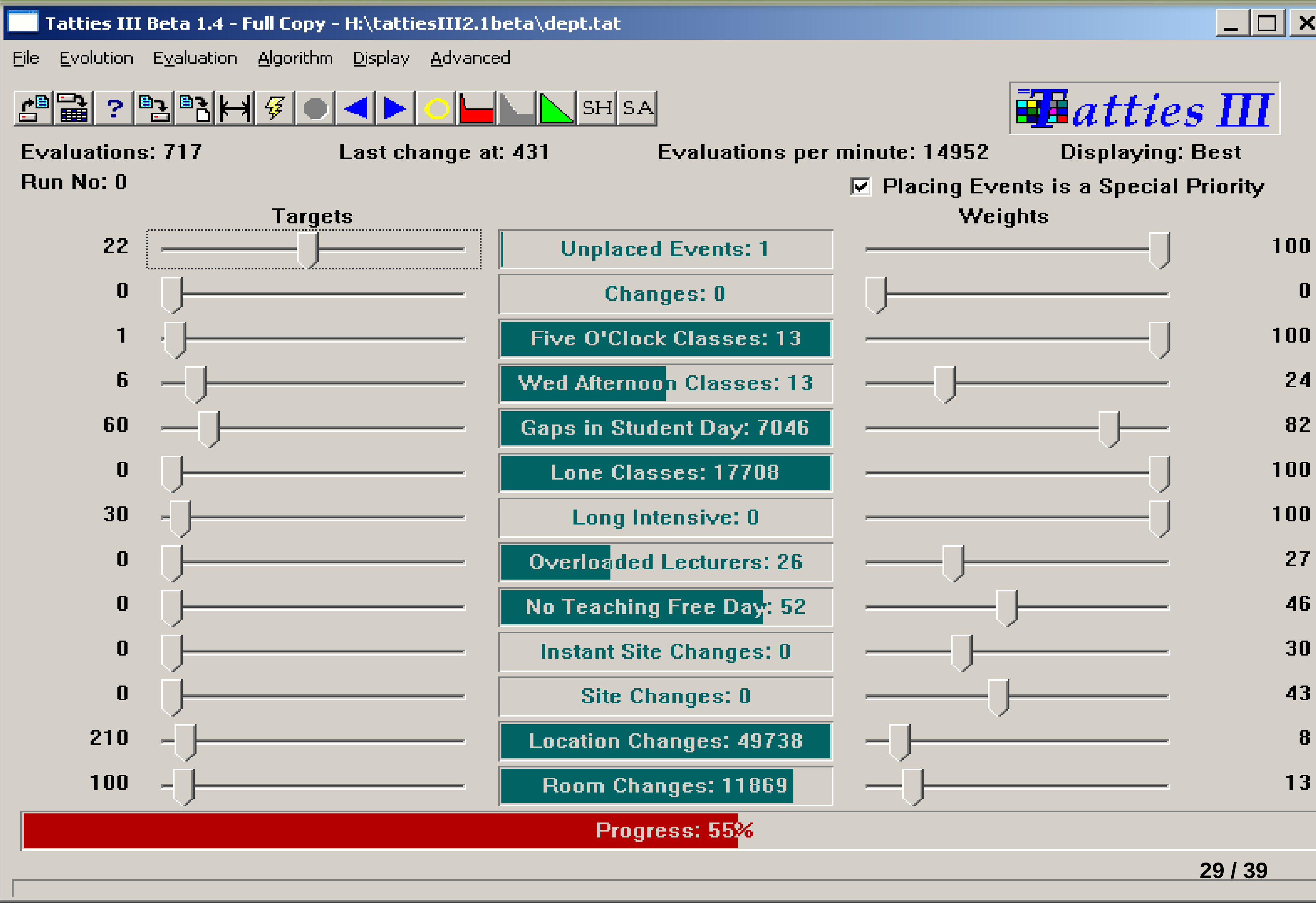


- e.g.
  - time tables for university, call center, or hospital
  - design specifications, etc etc

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





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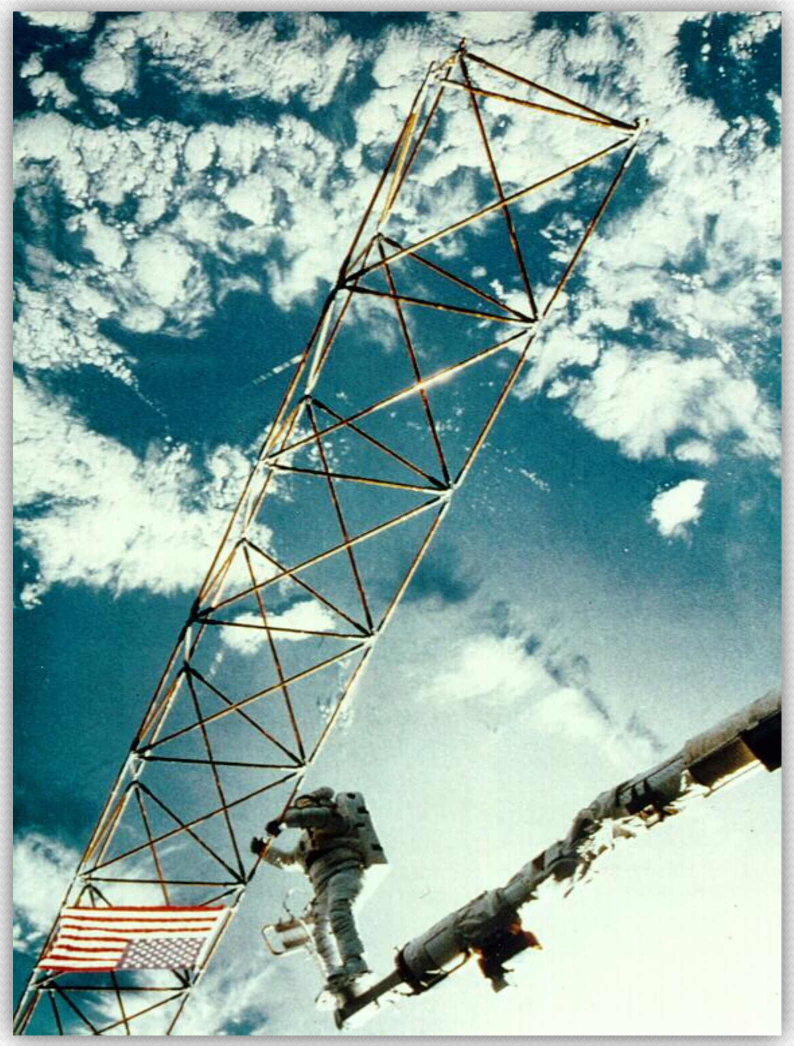
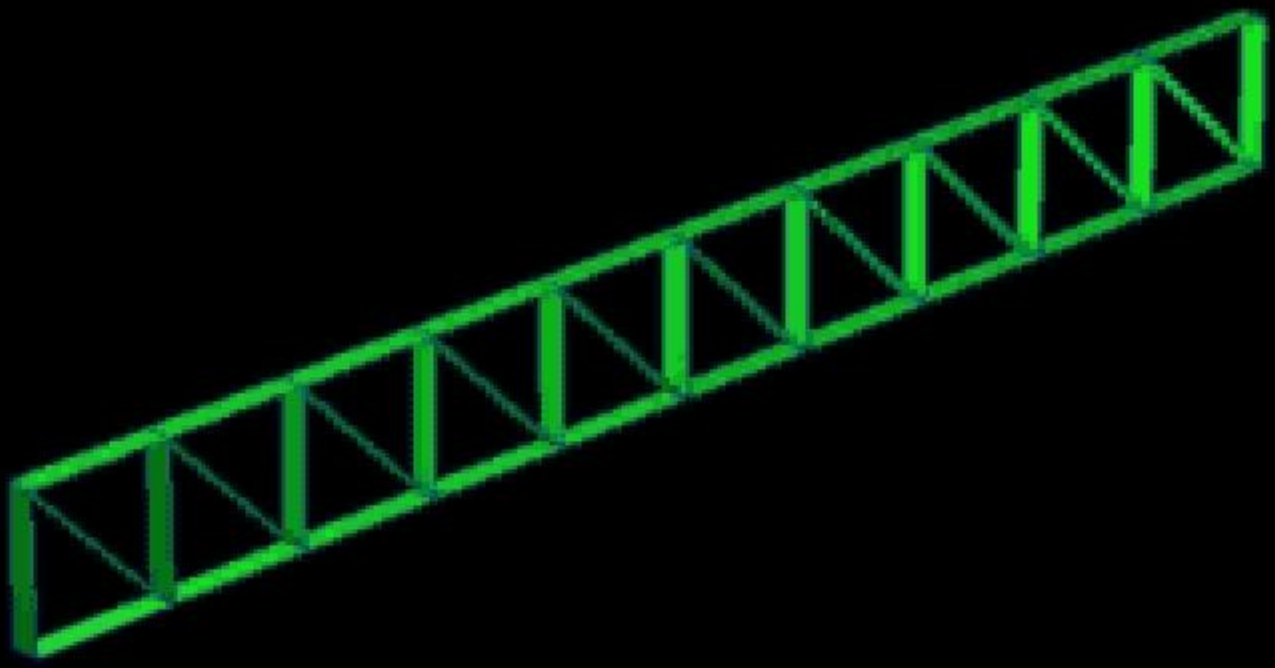
File Evolution Evaluation Algorithm Display Advanced
SH SA
Tatties III
Evaluations: 717
Last change at: 431
Evaluations per minute: 14952
Displaying: Best
Run No: 0
Placing Events is a Special Priority
Targets
Weights
22 Unplaced Events: 1 100
0 Changes: 0 0
1 Five O'Clock Classes: 13 100
6 Wed Afternoon Classes: 13 24
60 Gaps in Student Day: 7046 82
0 Lone Classes: 17708 100
30 Long Intensive: 0 100
0 Overloaded Lecturers: 26 27
0 No Teaching Free Day: 52 46
0 Instant Site Changes: 0 30
0 Site Changes: 0 43
210 Location Changes: 49738 8
100 Room Changes: 11869 13
Progress: 55%

Optimisation example 2: satellite structure

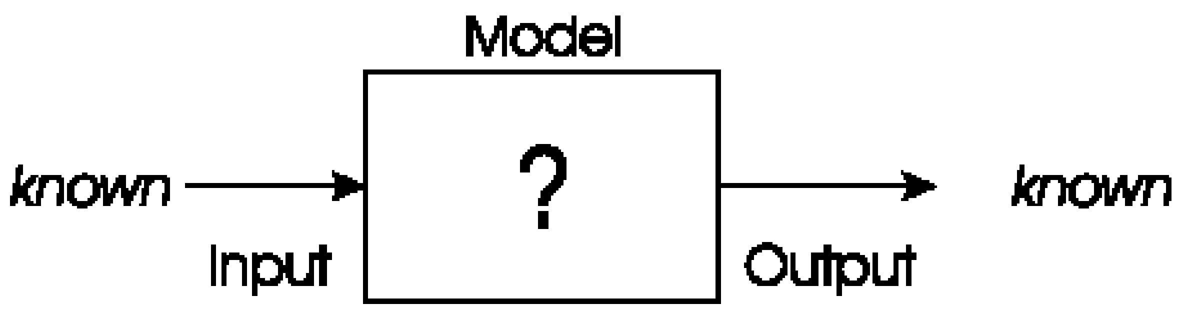
- Optimised satellite designs for NASA to maximize vibration isolation
- Evolving: design structures
- Fitness: vibration resistance
- Evolutionary "creativity"





Problem types 2: Modelling

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



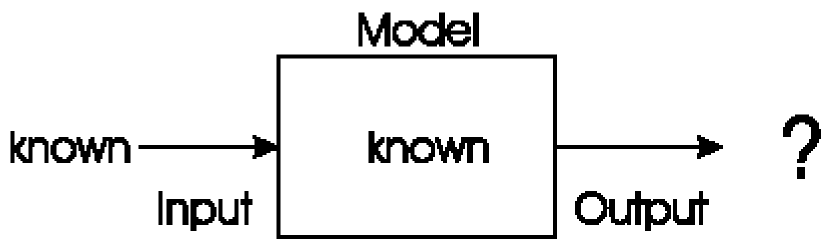
- Evolutionary machine learning

Modelling example: load applicant creditibility

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

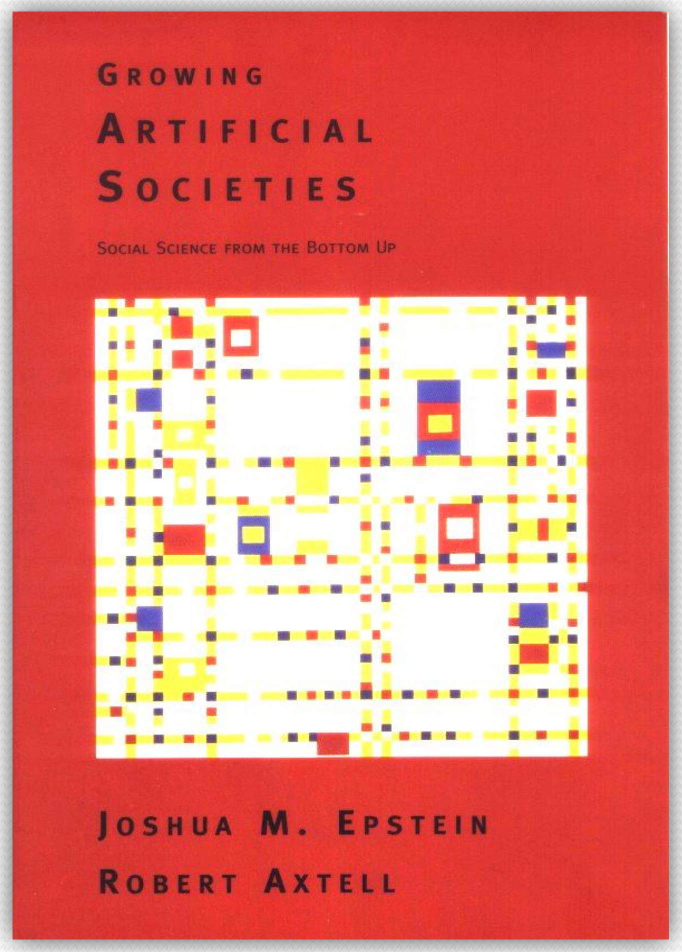
Problem type 3: Simulation

- 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

Picture censored

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

- 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

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

- 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)