國立臺灣師範大學
National Taiwan Normal University

速度之謎
- 科學家發現運動員耐力基因

「自然遺傳學」期刊 (Nature Genetics Journal)

- 「速度基因」ACTN3能破解決定新陳代謝的蛋白質，肌肉纖維在迅速拉扯之下，產生高速行動的力量
- 需要爆發力的優秀短跑選手(sprinter)，比較可能帶有ACTN3的功能性變異基因。
- 演化專家稱之為正面選擇的跡象，有助生存的基因，可以持久地併入人類基因組，而拖累生存的基因則遭淘汰。
- 跑長途的能力，是一種經選擇後，進入智人基因組的特色。

ACTN3 : a gene for speed

Over the last couple of decades, research has focused on attempting to understand the genetic influence on sports performance. This has led to the identification of a number of candidate genes which may help differentiate between elite and non-elite athletes. One of the most promising genes in that regard is *ACTN3*, which has commonly been referred to as "a gene for speed". Recent research has examined the influence of this gene on other performance phenotypes, including exercise adaptation, exercise recovery, and sporting injury risk.

研究：基因變化影響 每人嗅覺反應不同

由紐約洛克斐勒大學所做的一項「嗅覺調查」報告，把數十種味道強烈而且會讓人感到快樂的氣味，其中包括只有在男性的尿液(urine)或汗水(sweat)中才有的睪丸酮（又稱男性荷爾蒙）讓受試者分辨。

根據這篇刊登在英國「自然」科學期刊的報告，大部分的受試者都反應聞起來「像一股尿騷味」(urine smell)，但也有不少的人，大約是百分之二十，認為味道很好聞，認為和香草(vanilla)或蜂蜜的味道很像。另一個由北卡羅萊納州杜克大學所做的實驗，發現男性荷爾蒙是由專門掌管味道的基因OR7D4所轉換的。

人體中有數百種專門接收不同味道的基因，但在鼻內的嗅覺神經元一次卻只能讓一種接收基因產生作用和表示味道。在共同合作下，兩個研究小組利用DNA進行測驗，找出OR7D4基因。

科學家在一些實驗中發現，這種**基因會進行輕微的多樣性變化**，稱為單核甘酸多樣性 (SNPs)，形成兩種不同的OR7D4。當他們根據「嗅覺調查」結果排列出兩種不同的基因分析後，發現，**認為男性荷爾蒙味道很像尿騷味的一組，和認為像香草的一組，體內掌管嗅覺的基因不一樣，才會造成不同的反應**。

Human olfactory perception

Human olfactory (嗅覺) perception differs enormously between individuals, with large reported perceptual variations in the intensity and pleasantness of a given odour. For instance, androstenone(雄烯酮), an odorous steroid (有氣味的類固醇), is variously perceived by different individuals as offensive ("sweaty, urinous"), pleasant ("sweet, floral") or odourless.

人類勇氣 來自基因突變

雖然歷史與文學中不乏英雄視死如歸的英勇故事，但英國「皇家學會學報」公布的研究指出，勇氣這回事既傷身又危險，原本不應該演化成人類的特質，只是因為古代部族戰事頻繁，勇敢的戰士不僅可攻城掠地，更可輕易抱得美人歸，開枝散葉的結果，才會讓這種特質代代相傳。

勇氣常被視為軍事策略的最大資產，但生物學家指出，人類原本不應該演化出英雄特質，因為逞英雄對生命與肌肉的傷害非常巨大。

贏得美人，讓勇士視死如歸。既然如此，人類為什麼又會發展出這樣的特質呢？美國史丹福大學的萊曼與費德曼解開了這個謎團，他們指出，原因是越勇敢的士兵最終可贏得較多性伴侶，因此傳播基因的機會也較多，打仗死亡的風險，與逞英雄的好處相比之下就顯得微不足道。

這份研究指出，如果發揮勇氣，即使是小部族也可以打勝仗，擁有勇敢基因的人可能會因為逞英雄而死，但也有可能打敗敵族、將敵人的妻小納為己有、掠奪可種植或採集更多食物的土地，勇敢的戰士可擁有更多傳承他們基因的子嗣。

萊曼與費德曼在研究中，著重於兩個可能影響社會生產力與作戰才能的特點：勇敢與好戰性。

他們認為，好鬥男性多的部族，比較可能攻擊敵對部族；勇敢男性多的部族，比較可能贏得戰役，但這兩個特徵都會增加死亡的機率。

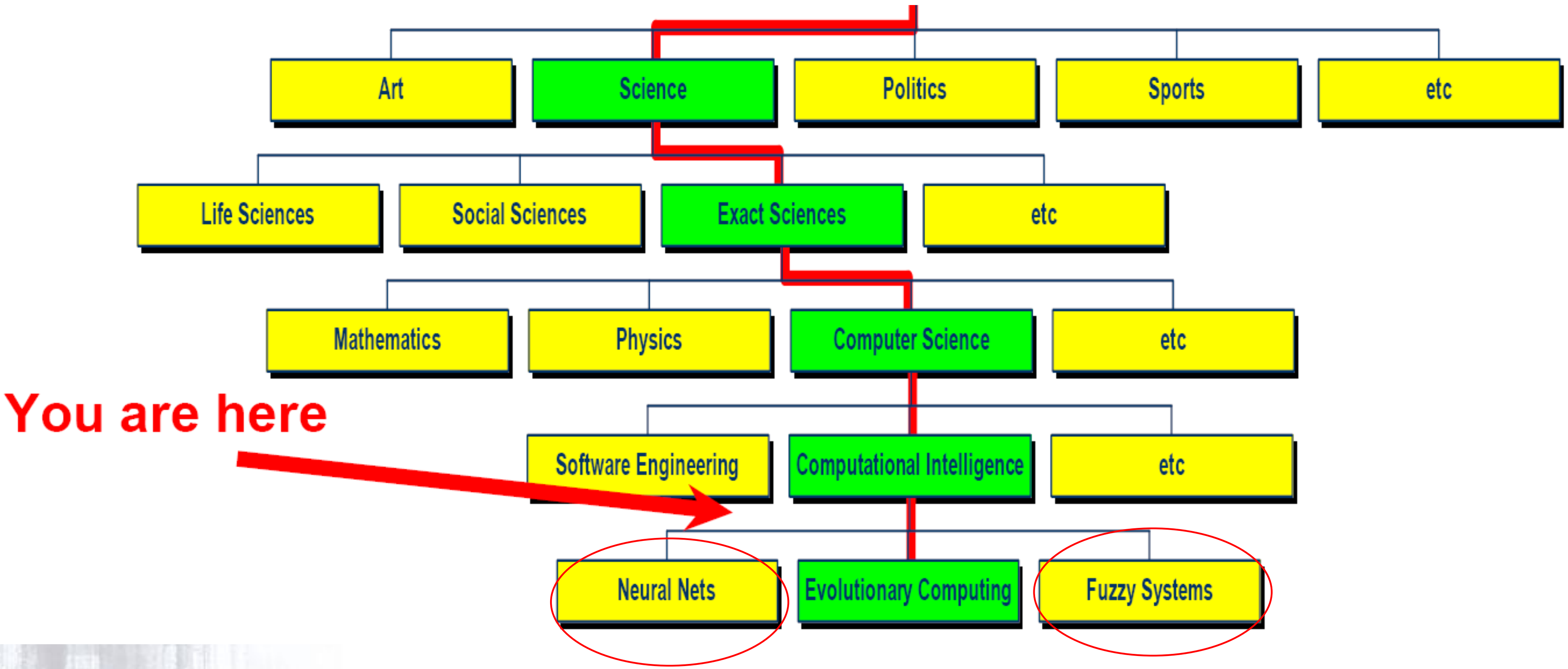
雖然這些特質並非由單一基因控制，但科學家猜測，單一基因變異的出現，促使其中一種特徵的產生，多個影響勇氣或好鬥的**基因**，應該就是以類似的方式演化。

Chapter 1

Introduction to Evolutionary Computation (EC)

Contents

- Positioning of EC and the basic EC metaphor (隱喻)
- 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


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
靈感
- Draw inspiration from the process of natural evolution
- EC can be applied in biological research

→ **Biological processes** serve as inspiration that provides a rich source of ideas and metaphors.
隱喻

The Main Evolutionary Computing Metaphor

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

Fitness: How well they **adapt to** the environment?
→ chances for survival and reproduction

Quality: How well they **solve** the problem?
→ chance for seeding new solutions

Brief History 1: the ancestors

- 1948, Turing:
  - ✓ proposes "genetical or evolutionary search" by applying Darwinian principles to automated problem solving
  - ✓ long before the breakthrough of computers
- 1962, Bremermann
  optimization through evolution and recombination
- 1964, Rechenberg (Germany)
  introduces **evolution strategies**
- 1965, L. Fogel, Owens and Walsh (US)
  introduce **evolutionary programming**
- **1975, Holland (US)**
  introduces **genetic algorithms**
- 1992, Koza (US)
  introduces **genetic programming**

- The whole field: evolutionary computing or evolutionary computation
- (roughly) 4 dialects (sub-areas, variants):

evolution strategies, evolutionary programming, genetic algorithms, genetic programming

- algorithm involved: evolutionary algorithms

Brief History 2: The rise of EC

- 1985: first international conference (ICGA)
  International conference on genetic algorithms (ICGA)
- 1990: first international conference in Europe (PPSN)
  Parallel Problem Solving from Nature (PPSN)
- 1993: first scientific EC journal:
  Evolutionary Computation (MIT Press)
- 1997: launch of European EC Research Network EvoNet

EC in the early 21st Century

• 3 major EC conferences: CEC (Congress on Evolutionary Computation), GECOCO, PPSN

• many related conferences

• Core EC journals: *Evolutionary Computation*, *IEEE Transactions on Evolutionary Computation*, *Genetic Programming and Evolvable Machines*

•*Other Journals*: *Applied Soft Computing, Soft Computing, Swarm and Evolutionary Computation, Neurocomputing*

• 750-1000 papers published in 2003 (estimate)→2100 journal papers in 2023 (excluding conference papers)

•Journal publications:

http://www.macs.hw.ac.uk/~ml355/journals.htm

Evolutionary Computing

Evolutionary Computation MIT Press, 1993-Present, Impact factor 3.600 REF →

IEEE Transactions on Evolutionary Computation IEEE Press, 1997-Present, Impact factor 5.908 REF →

Genetic Programming and Evolvable Machines Springer, 2000-Present, Impact factor 1.143 REF →

Swarm Intelligence Springer, 2007-Present, Impact factor 2.577 REF →

Evolutionary Intelligence Springer, 2008-Present REF →

Journal of Artificial Evolution and Applications Hindawi, 2008-2010 REF →

Memetic Computing Springer, 2009-Present, Impact factor 0.900 REF →

International Journal of Applied Evolutionary Computation IGI Global, 2010-Present

Swarm and Evolutionary Computation Elsevier, 2011-Present, Impact factor 2.963 REF →

International Journal of Swarm Intelligence and Evolutionary Computation OMICS group, 2012-Present

- EvoNet has over 150 member institutes
- uncountable (meaning: many) applications
- uncountable (meaning: ?) consultancy and R&D firms
- Closely related with natural computing, soft computing, or computational intelligence

Biological inspiration
Darwinian Evolution 1: Survival of the fittest

- All environments have finite resources
  - (i.e., can only support a limited number of individuals)
- Lifeforms (生命體) have basic instinct / lifecycles geared towards reproduction (praying mantis?螳螂)

➔ Therefore some kind of selection is inevitable

- Those individuals that compete for the resources most effectively have increased chance of reproduction

i.e., adapted or fit to the environment best.

➔ **Survival of the fittest**

LABORATORY EVOLUTIONARY CONTROL

- Evolutionary process:
  - Competition-based selection
  - Phenotypic variations/traits (外顯特徵變化) among members of population (giraffe?) that directly affect the responses to the environment
- Each individual represents a unique combination of phenotypic traits that is evaluated by the environment.
- Fitness in natural evolution is a derived, secondary measure, i.e., we (humans) assign a high fitness to individuals who survive better with many offspring

Darwinian Evolution 2:
Diversity (多樣性) drives change

- Phenotypic traits (Phenotypic character, 性狀，外顯性特徵)
  - Behaviour / physical features of an individual that affect its response to the environment
  - Each individual is a unique combination of phenotypic traits that is evaluated by the environment
  - evaluated by the environment (Kenya, Jamaica athletes)
  - determining fitness
- If phenotypic traits lead to higher chances of reproduction, then they will tend to increase in subsequent generations.

• As the more successful individuals reproduce, small, random variations (mutation 突變) in phenotypic traits occur during reproduction from generation to generation, which gives rise to new individuals to be tested.

外顯の 特徵

➔ As time passes, there is a change in the constitution of the population, i.e., the population is the unit of evolution.

結構

• Reproductive success depends on how well they are adapted to their environment relative to the rest of the population.

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:

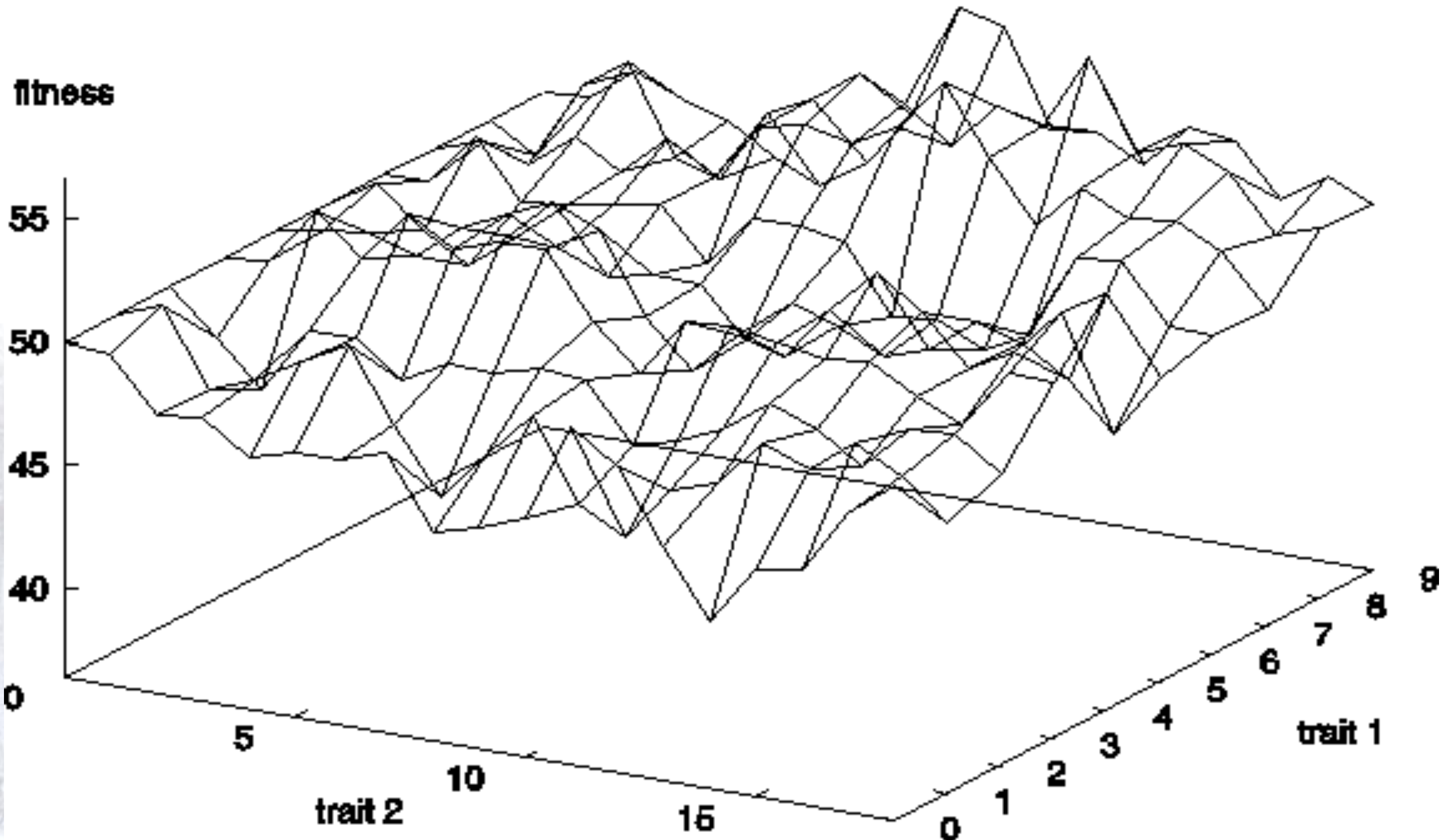
Population is the "unit of evolution"

- Note the absence of "guiding force"

Adaptive landscape (surface) metaphor (Wright, 1932)

- A population with n traits as existing in a $(n+1)$ dimensional space (landscape) with height corresponding to fitness
- Each different individual (phenotype 表現型) represents a single point on the landscape
- Population is therefore a "cloud" of points, moving on the landscape over time as it evolves – adaptation
- **Evolution is the process of gradual advances of the population to high-altitude areas, powered by variation and natural selection.**

Example with two traits



Adaptive landscape metaphor (cont'd)

- Local optimum vs global optimum
- Unimodal vs multi-modal problems
- Selection "pushes" population up the landscape
- Genetic drift: random variations in feature distribution

➔ Highly fit individual may be lost from the population

➔Can cause the population "melt down" hills, thus crossing valleys and leaving local optima

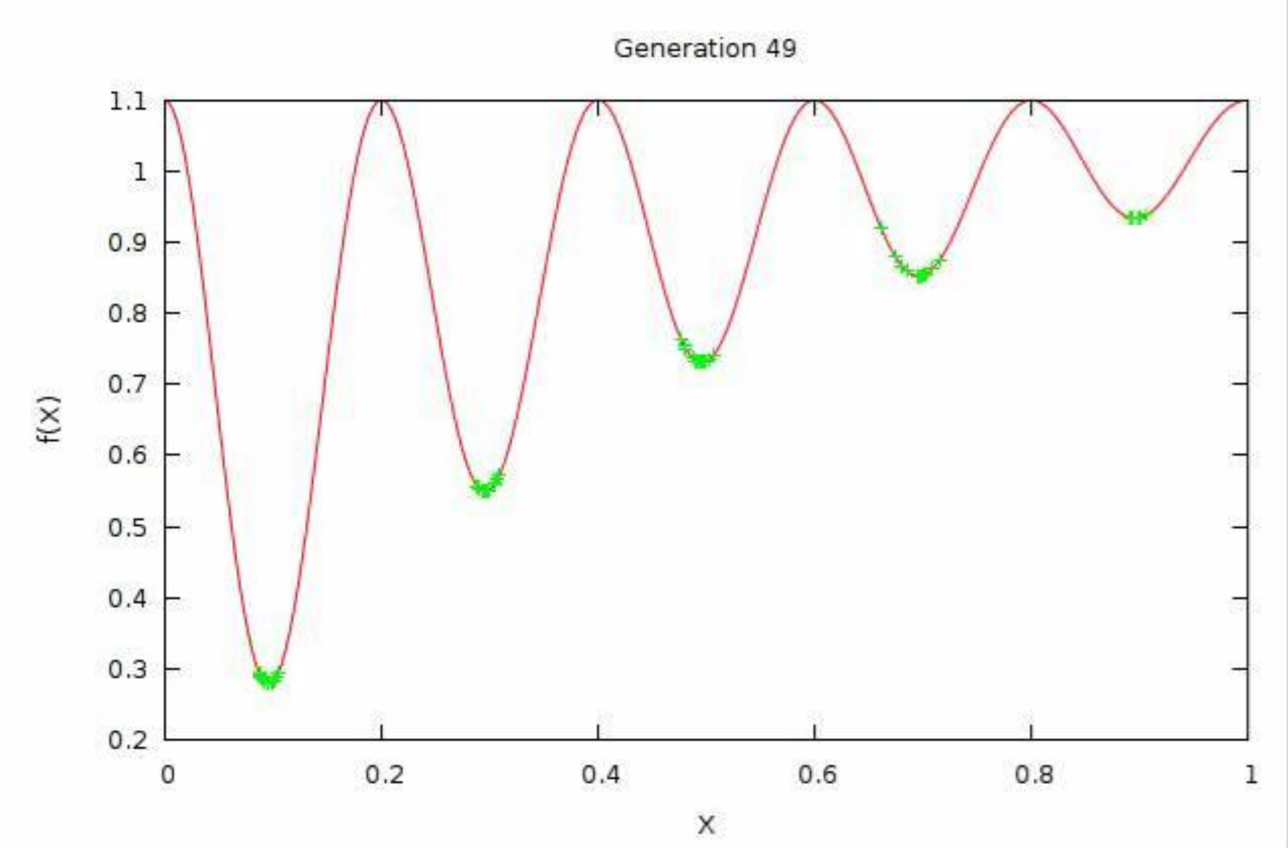
➔The combined global effects of drift and selection enable populations to move uphill and downhill.

Multimodal functions

- Multimodal functions have more than one optima, but can either have a single or more than one global optima.
- In the first case, the problem that a optimization algorithm has to deal with is to avoid premature 过早の convergence to a local optimum.
- In the second, the presence 存在 of several solutions with equal optimum 最佳 fitness arises 表現 the issue of how an algorithm can locate all the global optima.

Also,

- A multimodal function is a function with many local maxima
- a function with several optima

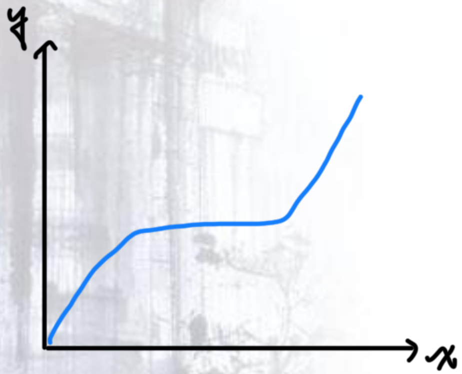


Finding multiple optima using Genetic Algorithms in a Multi-modal optimization task (The algorithm demonstrated in this demo is the one proposed by Deb in the multi-objective approach to multimodal optimization

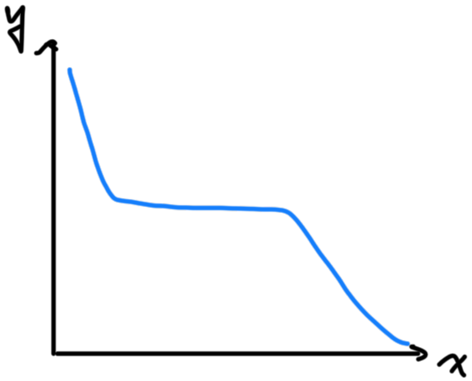
演示

Unimodal

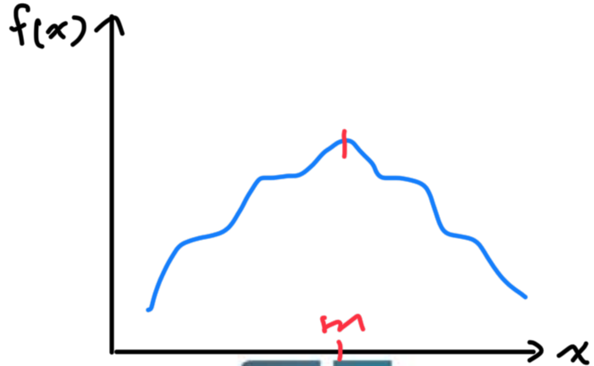
- a function $f(x)$ is a **unimodal function** if for some value m , it is monotonically increasing for $x \le m$ and monotonically decreasing for $x \ge m$. In that case, the maximum value of $f(x)$ is $f(m)$ and there are no other local maxima.



monotonically non-decreasing



monotonically non-increasing



Natural Genetics

- Molecular genetics (分子遺傳學)

  Each individual is a dual entity: phenotypic (表現型) properties (outside) are represented at a low genotypic (基因遺傳型) level (inside)

  Genotype $\xrightarrow{\text{決定}}$ Phenotype

- Genotype encodes its phenotype (NOT one-to-one!!)
- i.e., One gene might affect more phenotypic traits; one phenotypic trait can be determined by more than one gene. (complex mapping! Eg. Lab mice, eye/skin colors)
- Phenotypic variations are caused by genotypic variations, which are the consequences of mutations 突變 of genes or recombination 交配/交換 of genes.

Natural Genetics

- The information required to build a living organism is coded in the DNA of that organism
- Genotype determines phenotype
- Genes → phenotypic traits is a complex mapping
- Small changes in the genotype lead to small changes in the organism (e.g., height, hair colour)???
  - UK Woman Gives Birth To Black And White Twins
  - 0000→1000

THE stunned black dad of a newborn, WHITE, baby girl declared yesterday — "I'm sure she's my kid ... I just don't know why she's BLONDE."

➔ unknown mutation was the most likely explanation

➔ The rules of genetics are complex and we still don't understand what happens in many cases


© Ross Parry Agency

Genes and the Genome

- Genes are encoded in strands of DNA called chromosomes (染色體由DNA與蛋白質構成，基因是一段DNA的片段)
- The complete genetic material in an individual's genotype is called the Genome (整組基因), is arranged in several chromosomes (Ex. 46).
- Within a species, most of the genetic material is the same (細胞都具有相同數目和相同內容的染色體遺傳資料)
  - Humans and mice look nothing alike. However, human and mouse chromosomes share many of the same genes. In fact, 99% of the 20,000 to 25,000 genes in humans have a similar mouse counterpart. ~ Nature
  - **人和老鼠共享99%的類似基因**

Example: Homo Sapiens（智人、人類）

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

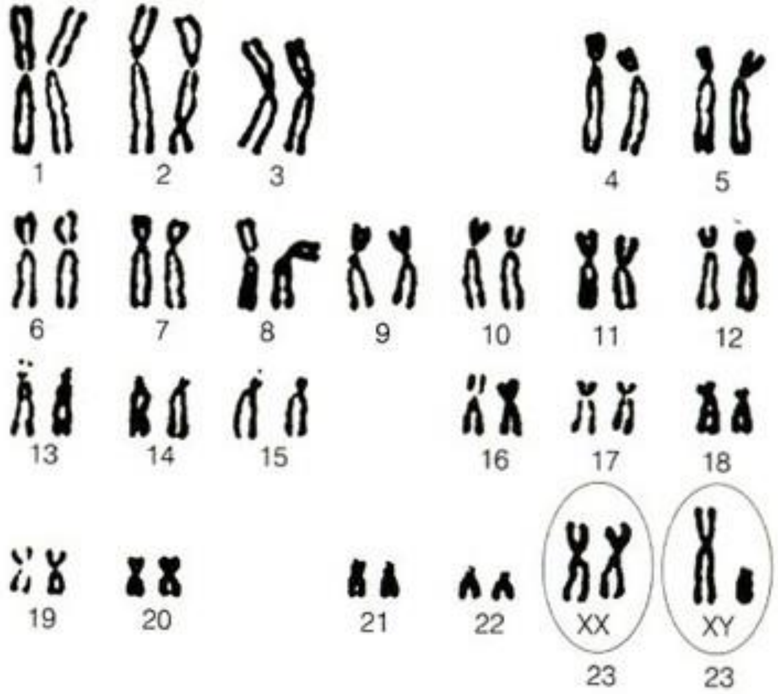
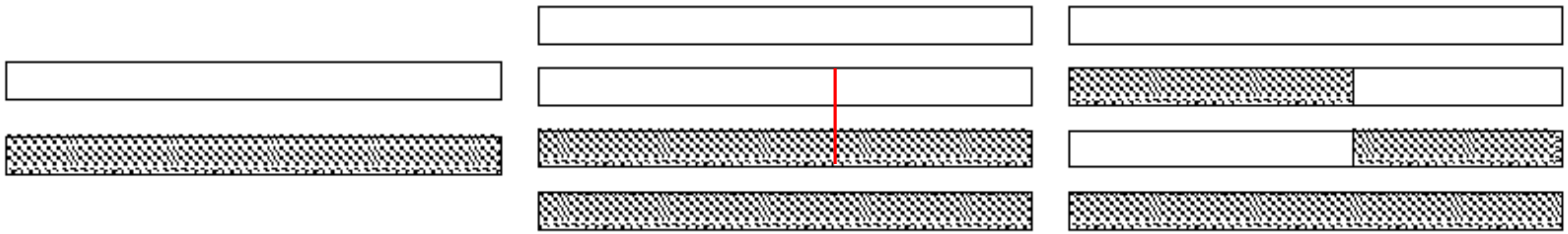


圖8-4 人類的染色體
染色體按長短排列，最末一對爲性染色體
XX爲女性；XY爲男性

Crossing-over during meiosis 細胞核分裂

- 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
- Different from their parents → genotypic variation

- Unlike what is traditionally perceived in EC!

i.e., features acquired during an individual's lifetime could be passed on to its offspring via inheritance.

A central claim in molecular genetics: only one way flow

Genotype $\longrightarrow$ Phenotype

Genotype $\not\longleftarrow$ Phenotype

- Phenotypic features cannot influence genotypic information.
- Changes in the genetic material of a population can only arise from random variations and natural selection, and definitely not from learning.
- Variations (crossover and mutation) happen at the genotypic level; selection is based on actual performance in a given environment, that is, at the phenotypic level.

Mutation

- Occasionally some of the genetic material changes very slightly during this process (replication error)突變導致細胞體內的遺傳信息發生改變
- This means that the child might have genetic material information not inherited from either parent

due to：

  - Environmental factors 外力干擾(人為突變)
  - Spontaneous 自然偶發的錯誤(自然突變)

- Low probability 十萬分之一
- Advantageous: strong new feature occurs

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"
- the evolution mechanism that created the human brain (after Darwin's Origin of Species)

Answer 1 → neurocomputing (neural networks)

Answer 2 → **evolutionary computing**

Motivations for EC: 2

- Developing, analyzing, applying problem solving methods / algorithms is a central theme in mathematics and computer science
  中心主題

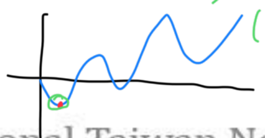
- Time available for thorough problem analysis decreases (since tailored algorithms (specifically designed or customized) are time-consuming to design)
  ↳ 量身定製の

- Complexity of problems to be solved increases

Consequence➔:
緊急の Urgent need of robust problem solving technology needed with satisfactory performance for a wide range of problems.

Traveling Salesman Problem
(to find the shortest path)

↳ satisfactory solution



(near optimize solution)

Urgent needs and requirements:

- Applicable to a wide range of problems
- Do not need much tailoring for specific problems
  定製の
- Deliver good (not necessarily optimal) solutions within acceptable time

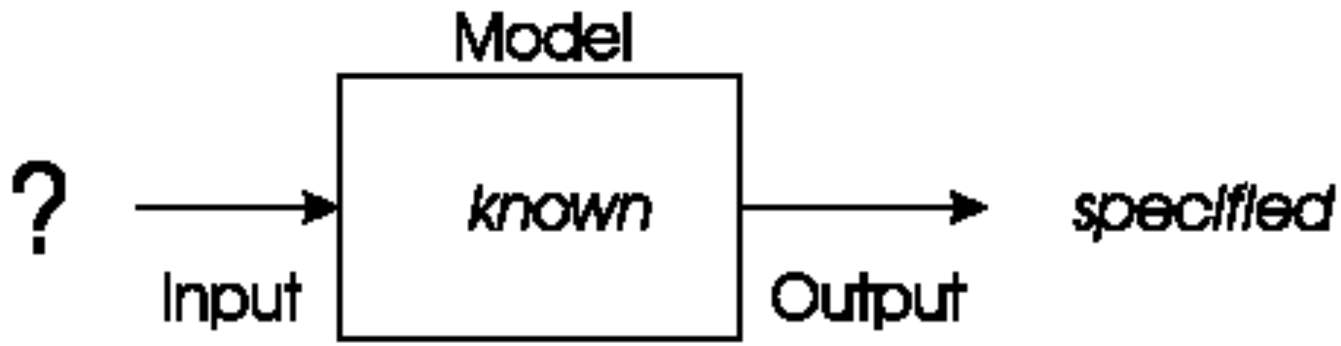
➔ **Evolutionary algorithms**

Motivations for EC: 3

- Human curiosity:
  - Understanding how evolution works
  - To experiment differently from traditional biology
    - ✓ Evolutionary process simulated by computers
    - ✓ Million generations in minutes / hours
  - Learning more about evolutionary algorithms in general can help in designing better algorithms later.

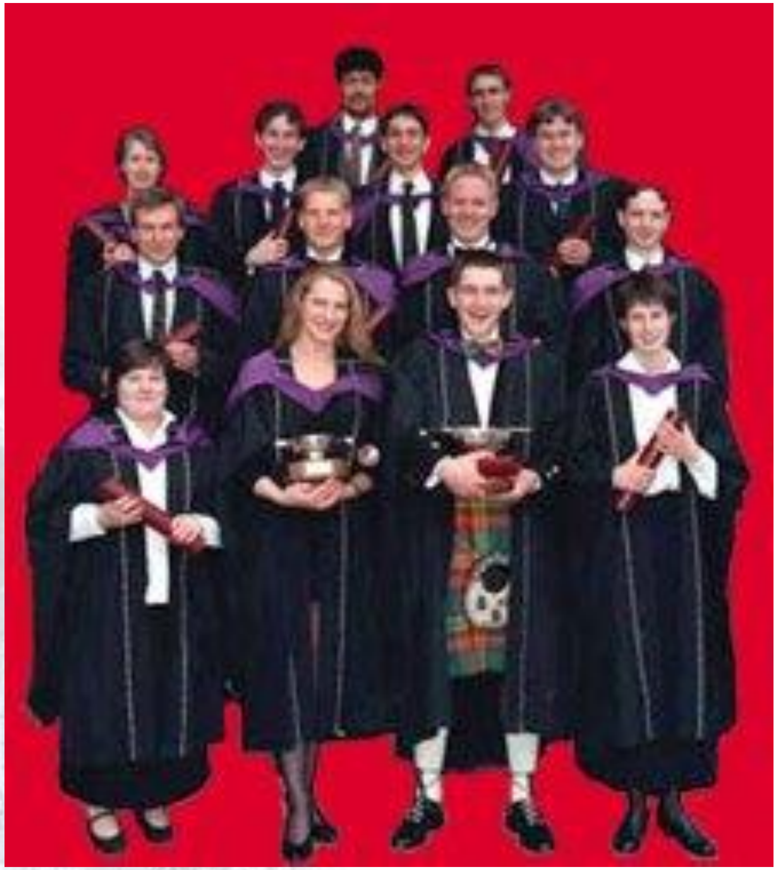
Problem type 1 : Optimisation

We have a model of our system and seek inputs that give us a specified goal (or, generate desired optima)



- e.g.
  - time tables for university, call center, or hospital
  - traveling salesman problem (TSP), which finds the shortest tour around a number of cities.

Optimisation example 1: University timetabling



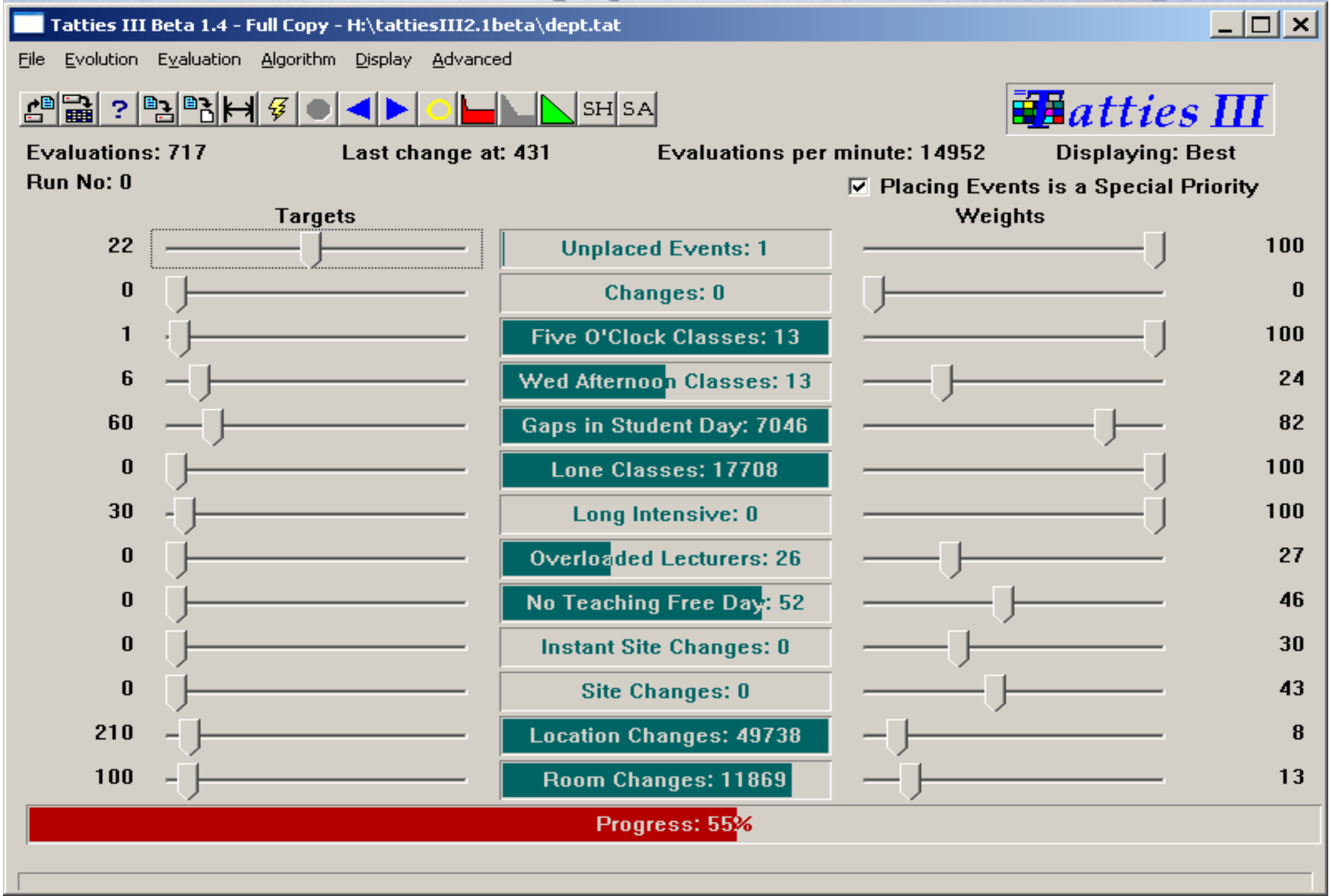
Enormously big search space

Timetables must be *good*

"Good" is defined by a number of competing criteria

Timetables must be feasible (no clashes!)

Vast majority of search space is infeasible
不可行の解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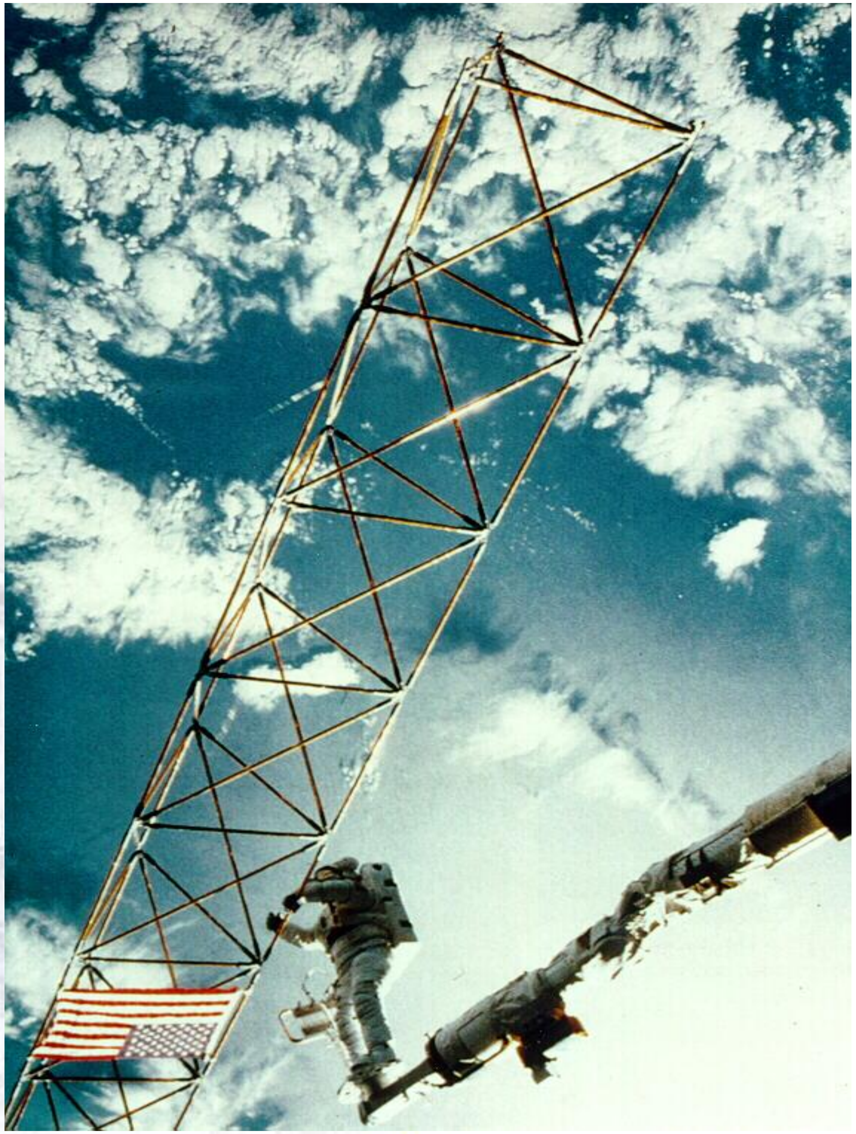
File Evolution Evaluation Algorithm Display Advanced
SH SA
Tatties III
Evaluations: 717
Last change at: 431
Evaluations per minute: 14952
Displaying: Best
Run No: 0
Placing Events is a Special Priority
Targets
Weights
22 Unplaced Events: 1 100
0 Changes: 0 0
1 Five O'Clock Classes: 13 100
6 Wed Afternoon 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



Design of a Satellite dish holder

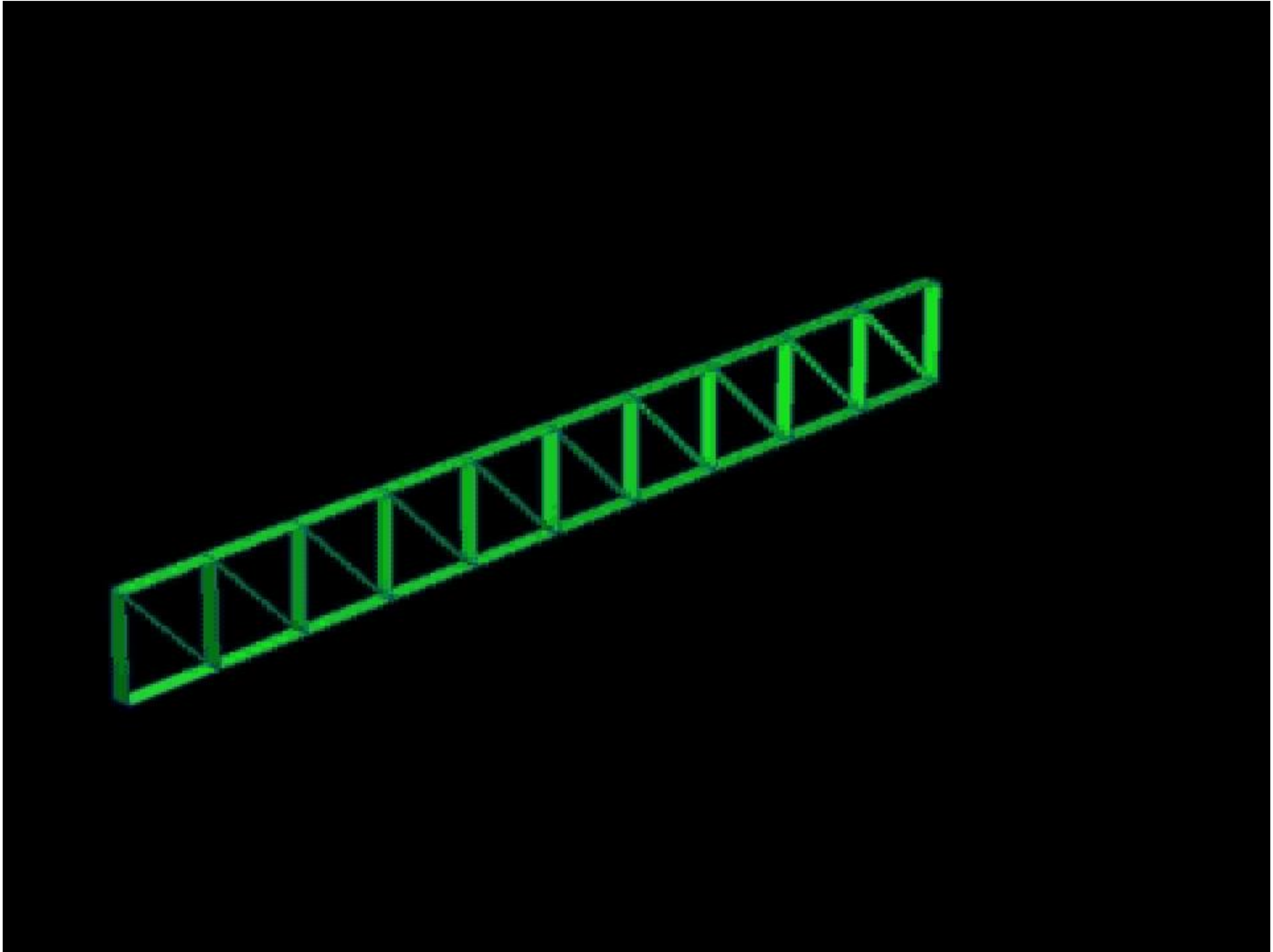
•Evolving: design structures

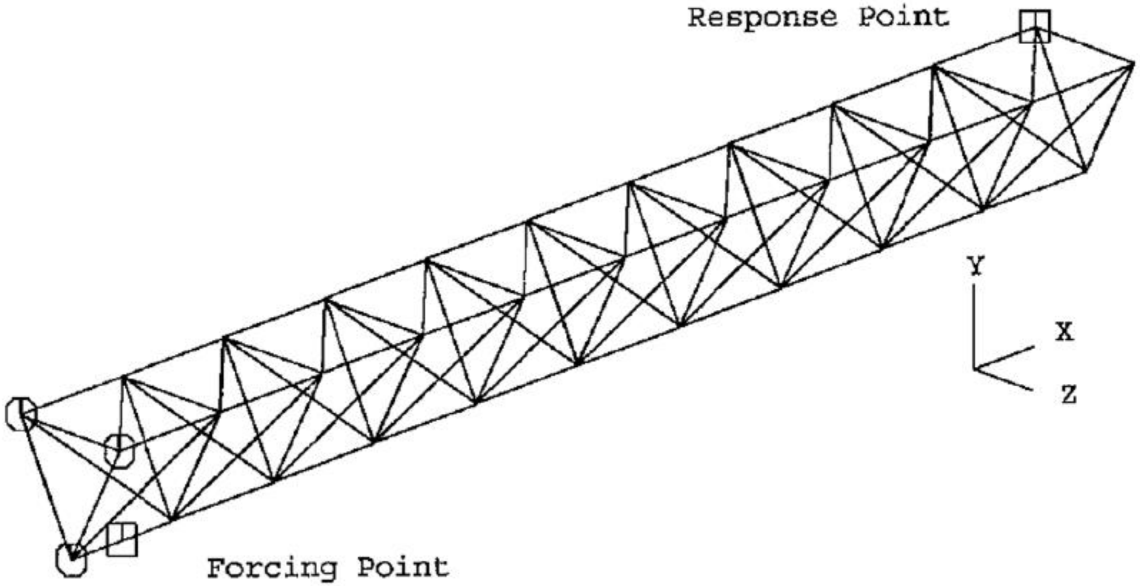
•Objective: vibration resistant (no air in space!!) 振动 抵抗

•Optimised satellite designs for NASA to maximize vibration isolation

•The results: 20000% better than traditional shape, but looks strange!

➔Evolutionary "creativity"

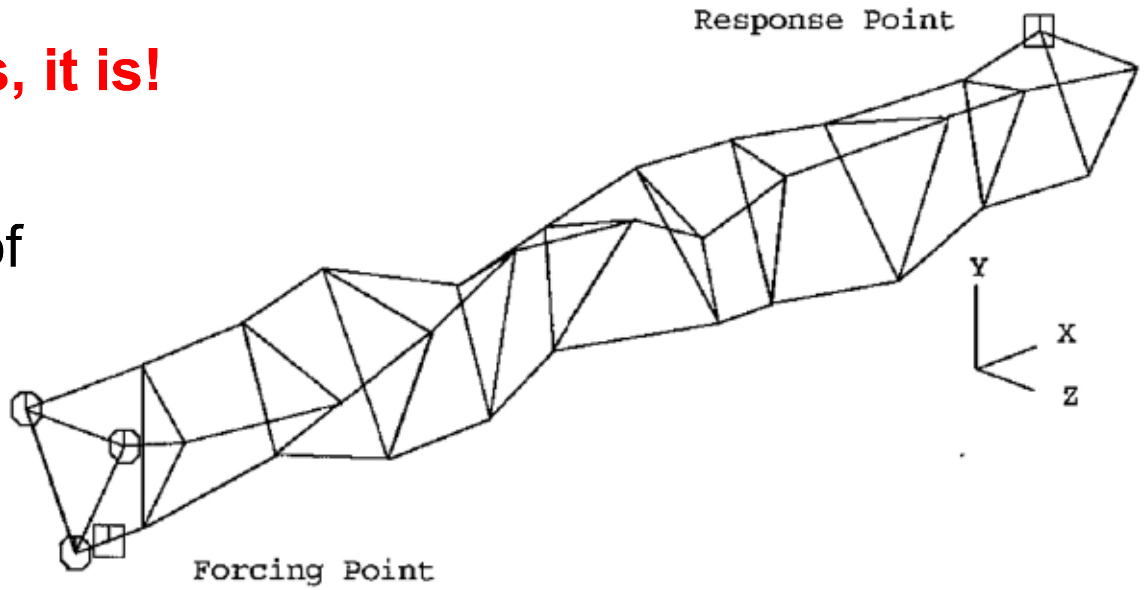




← Regular design

Design via a GA

- No symmetry!
- Like a random drawing! **Yes, it is!**
- Purely driven by quality, therefore outside the scope of human thinking!

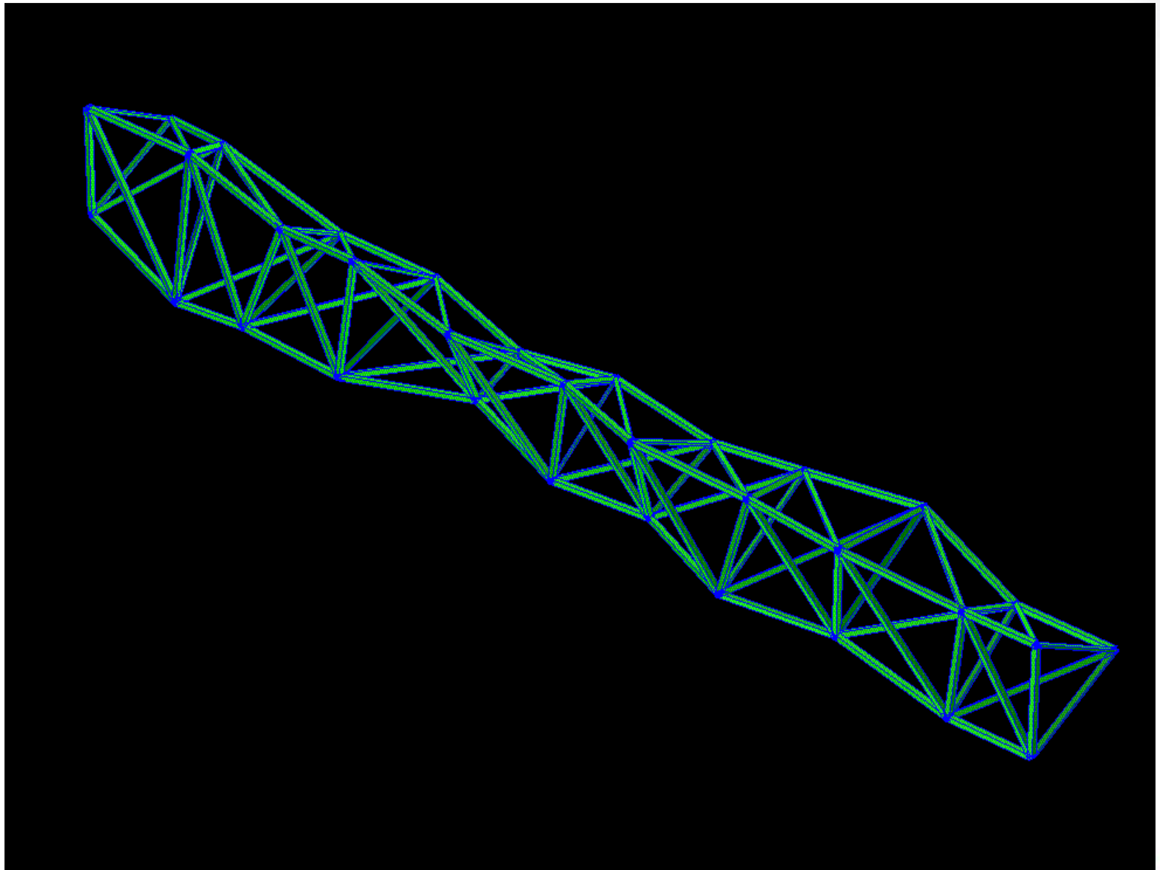


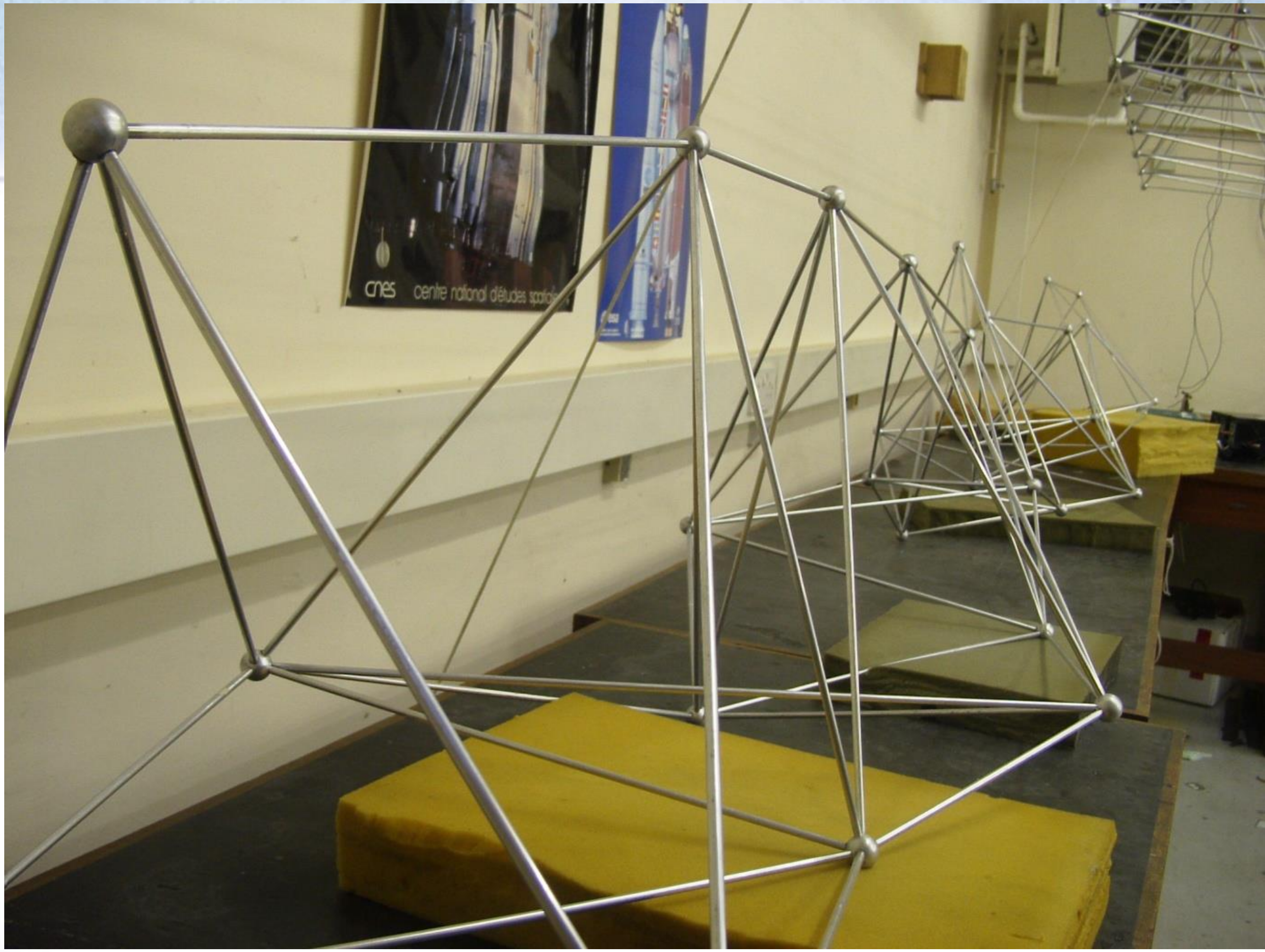
• Application of the Genetic Algorithm (GA) method within the OPTIONS package

• Using 4500 design evaluations spread over 18 generations

•Produced an optimized design with a predicted vibrational energy transmission reduced by 60dB over a 100Hz bandwidth.

• The GA was run in parallel on a 不同物質組成の heterogeneous collection of single and multi-processor workstations over a two week period.

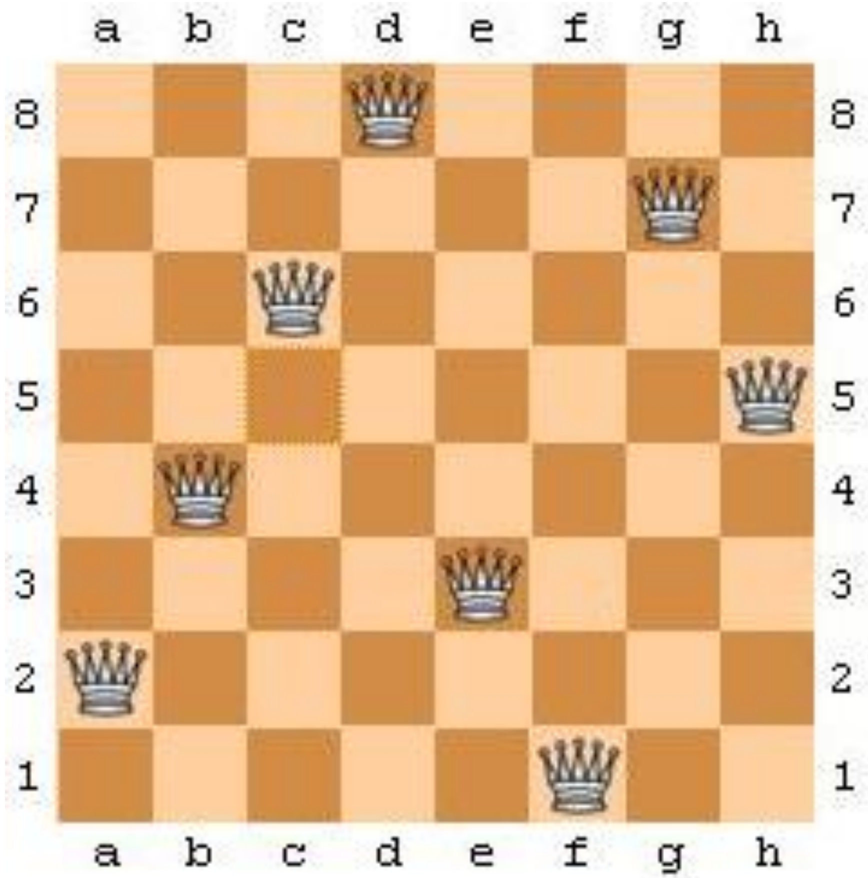




By A.J. Keane, School of Engineering Sciences, Southampton University, Highfield, Southampton, SO17 1BJ, U.K.

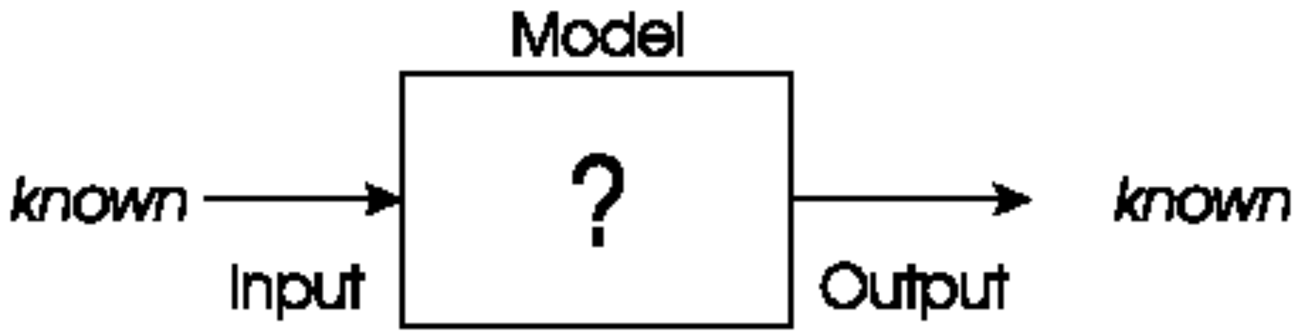
Optimisation example 3: 8 queens problem

- Given an 8-by-8 chessboard and 8 queens
- Place the 8 queens on the chessboard without any conflict
- Two queens conflict if they share same row, column or diagonal
- Can be extended to an n queens problem (n>8)



Problem types 2: Modelling

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



Uncountable applications

- System identification
- Model for Stock exchange (I/P: economic indices, O/P: Dow-Jones Index)
- AHL

Modelling example: loan applicant creditibility

•British bank evolved creditability model to predict loan paying behavior of new applicants

貸款

•Evolving: prediction models

•Fitness: model accuracy on historical data

A learning classifier system:

- To evolve sets of rules modeling the behavior of stock market traders, via GA.
- Inputs / outputs: ten years of trading history.
- evolve Conditions→ Action rules
- Good performance in comparison to well-known strategies.

cf: neural networks

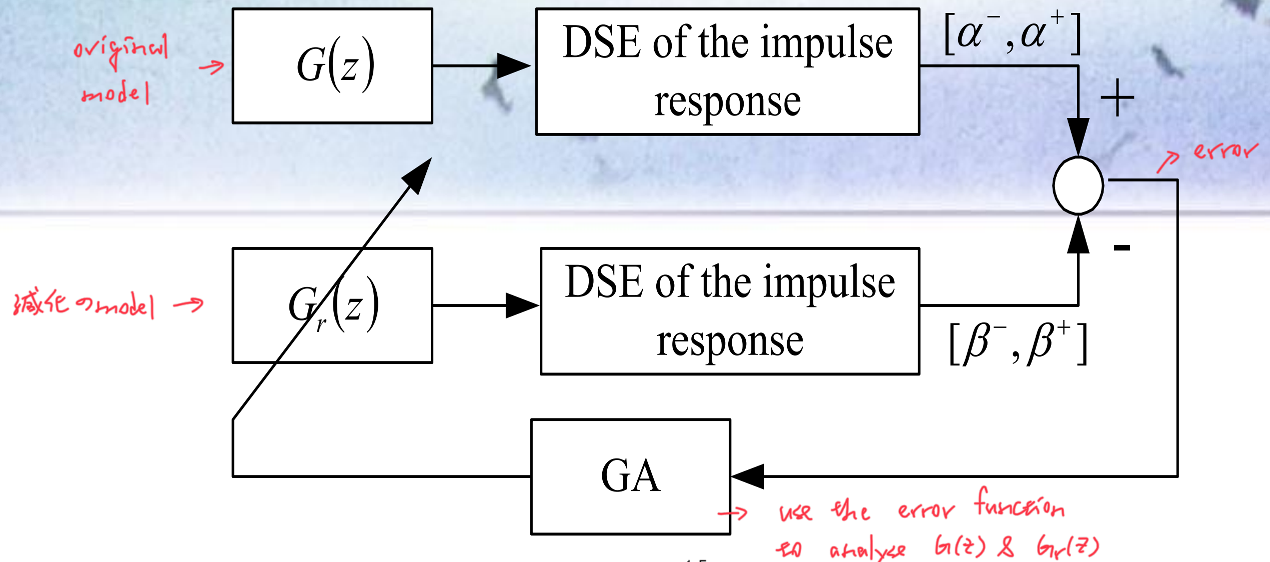
↳ compares

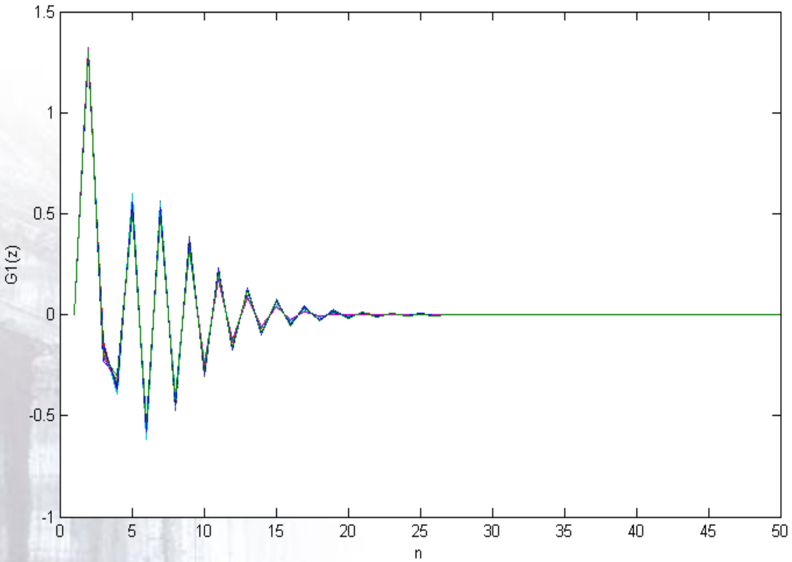
- Rule-base of the evolved traders are easily examinable.
- The evolved models are transparent to users.

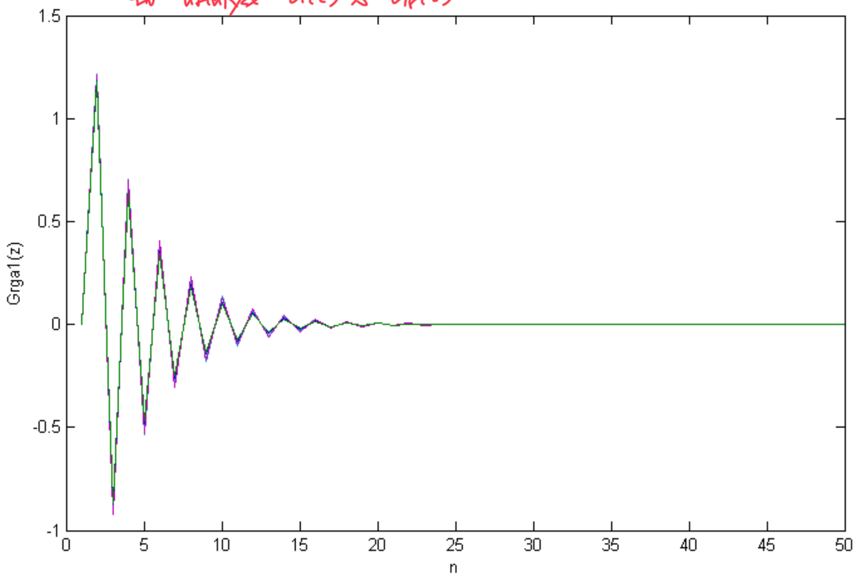
Control engineering:

- Model reduction
  - ➢ Model Reduction of Discrete Interval Systems

    離散 間隔 系統
- Design of controllers
  - ➢ Tolerance Design of Robust Controllers for Uncertain Interval Systems
  - ➢ Multi-objective Evolutionary Approach to the Design of Optimal Controllers for Interval Plants
  - ➢ Robust control of interval plants





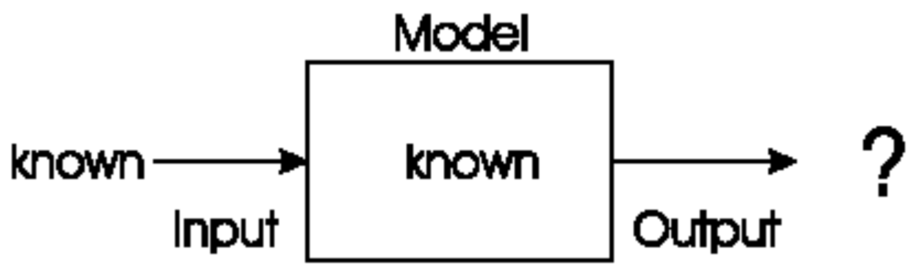


$$G_1(z) = \frac{[10.15,\ 10.35] + [8.5,\ 8.6]z}{[2.9,\ 3] + [8.7,\ 8.8]z + [6.5,\ 6.6]z^2}$$

$$G_{rga1}(z) = \frac{[4.6474\ ,\ 4.6657]}{[2.8851\ ,\ 2.9096] + [3.8313\ ,\ 3.9350]z}$$

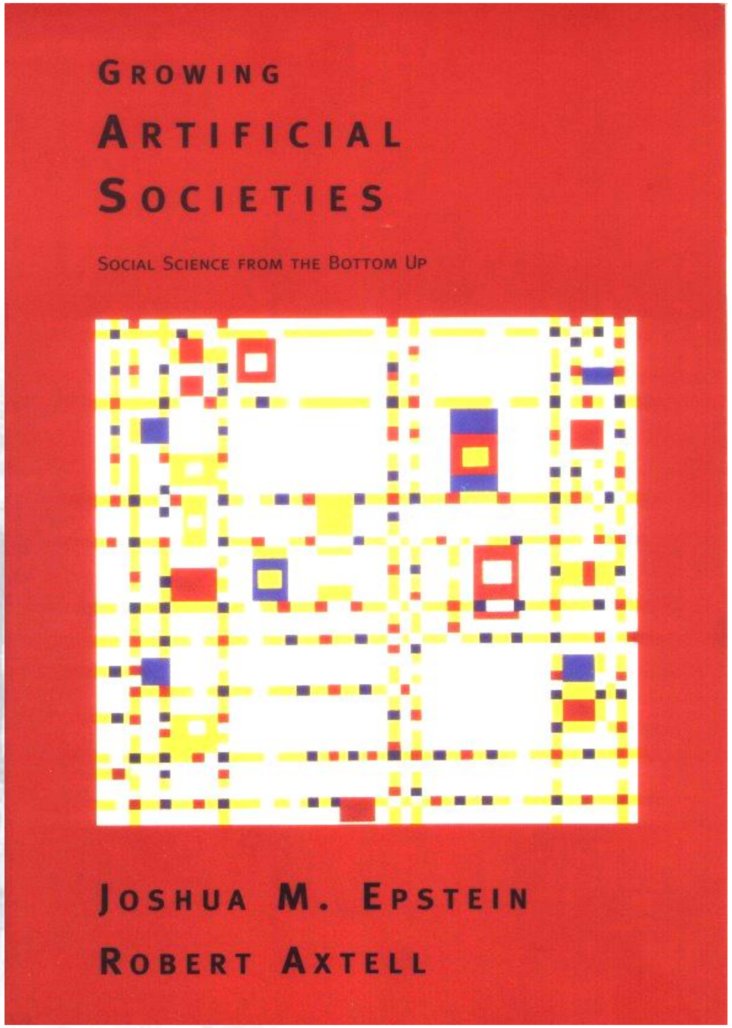
Problem type 3: Simulation

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, Weather forecast system, electronic circuit, etc.

Simulation example: evolving artificial societies



Simulating trade, economic competition, etc. among agents in a society to calibrate models

Use models to optimise strategies and policies

Evolutionary economy

Survival of the fittest is universal

Summary

- Try existing biological features

➔Nature will also work for algorithmic problem solving

- Try non-existing biological features

➔ Multi-parent reproduction, for example

➔ EC is a branch of computer science dedicated to the study of a class of algorithms that are broadly based on the Darwinian principles of natural selection, and draw inspiration from molecular genetics.

Demonstration: magic square

A square array nxn

- distinct positive integers 1,2,…,
- the sum of the n numbers in any column, row or both
- diagonals is equal to the magic constant $M = \frac{1}{2}n(n^2 + 1)$

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)

Application