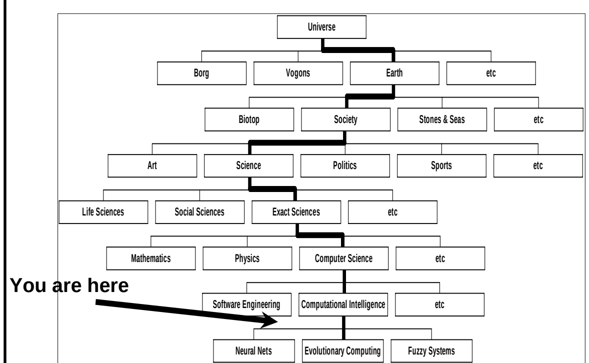
Evolutionary Computation: Introduction

Based on A.E. Eiben and J.E. Smith,
Introduction to Evolutionary Computing,
Springer, 2003.

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



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 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: The Ancestors

- 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 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

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

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/life cycles 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:
  - Behavior/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

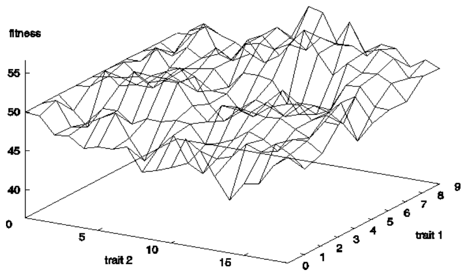
  Individuals are "units of selection"
- Variations occur through random changes yielding constant source of diversity, coupled with selection means that:

  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

Example With Two Traits



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

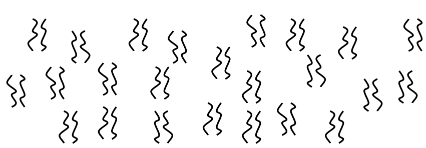
- The information required to build a living organism is coded in the DNA of that organism
- Genotype (DNA inside) determines phenotype
- Genes → phenotypic traits is a complex mapping
  - One gene may affect many traits (pleiotropy)
  - Many genes may affect one trait (polygeny)
- Small changes in the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

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

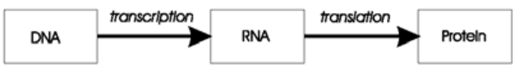
- Human DNA is organized into chromosomes
- Human body cells contains 23 pairs of chromosomes which together define the physical attributes of the individual:



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 in 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

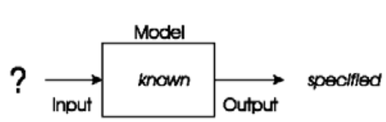
Motivations in EC: 2

- 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: Optimization

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



- Example:
  - time tables for university, call center, or hospital
  - design specifications, etc.

Optimization Example 1: University Timetabling

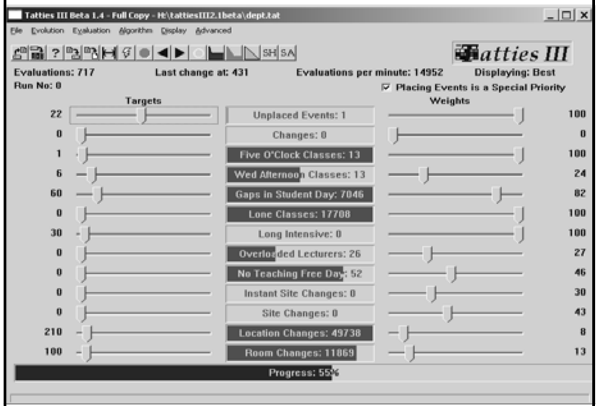
Enormously large search space

Timetables must be *good*

"Good" is defined by a number of competing criteria

Timetables must be feasible

Vast majority of search space is infeasible



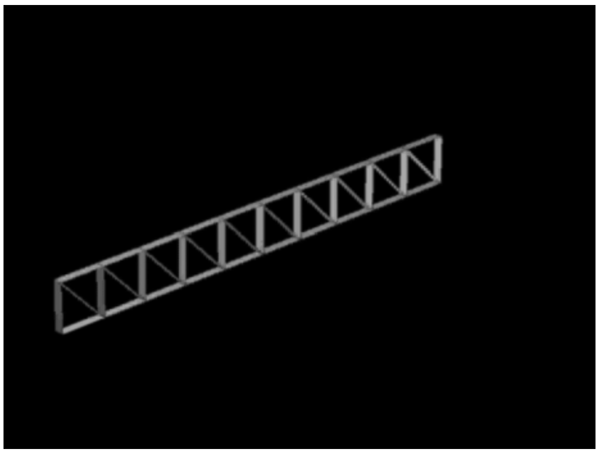
Optimization Example 2: Satellite Structure

Optimized satellite designs for NASA to maximize vibration isolation

Evolving: design structures

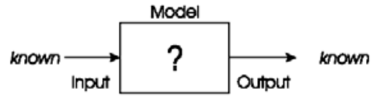
Fitness: vibration resistance

Evolutionary “creativity”



Problem Type 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: Loan Applicant Credibility

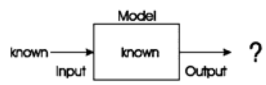
CC bank evolved creditability model to predict loan paying behavior of new applicants

Evolving: Prediction models

Fitness: Model accuracy on historical data

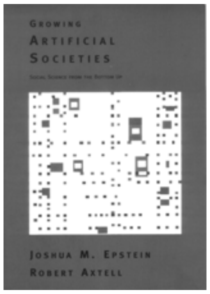
Problem Type 3: Simulation

- 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 optimize strategies and policies

Evolutionary economy

Survival of the fittest is universal (big/small fish)