ITMO UNIVERSITY

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Lecture 1: Introduction to Evolutionary Computing

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What is Evolutionary Computing?

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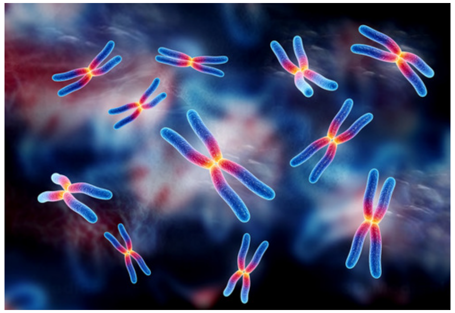
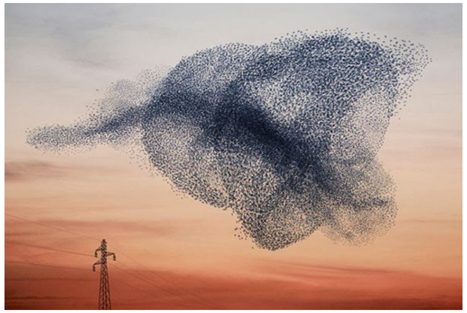
- Evolutionary Computing (EC) is a field of **stochastic optimization** techniques used to search for an optimal solution through a multidimensional solution spaces.
- Evolutionary Computing is a part of Soft Computing
- Almost all Evolutionary Algorithms (EAs) are nature inspired





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What is the optimization?

- Optimization has the goal of constructing and analyzing approximate solutions to problems which cannot be solved exactly
- Optimization algorithms use smart ways of choosing input values of a system and evaluate output values
- The search takes place within given constraints and optimization criteria

Optimization definition

$\vec{X} = [x_1, x_2, \ldots, x_D]^T$ parameter vector, input

$f(\vec{X})$ system values, output

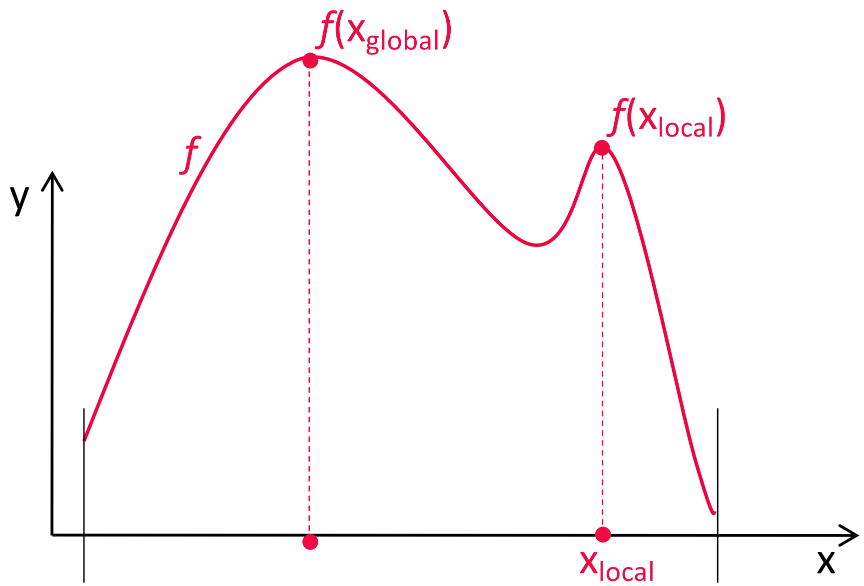
f objective function: $\mathbb{R}^D \xrightarrow{f} \mathbb{R}$

We are looking for $\vec{X}^* \in \mathbb{R}^D$ that minimizes the objective function *f.*

or $f(\vec{X}^*) < f(\vec{X})$ for all $\vec{X} \neq \vec{X}^*$.

Finding a maximum is the same, because $max\{f(\vec{X})\} = -min\{-f(\vec{X})\}$

Global vs local optimization



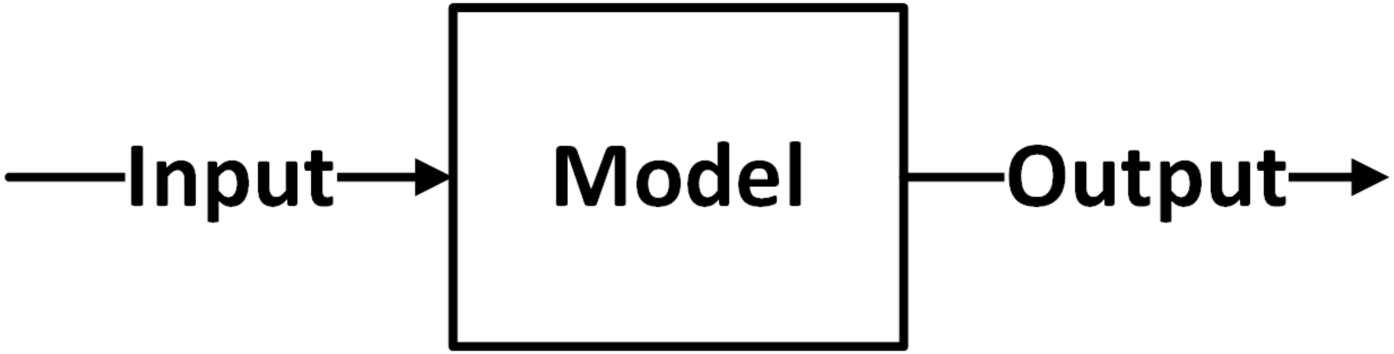
- Global optimization is more difficult than local optimization.
- Optimization algorithm should has a possibility to avoid local optima.
- But not always.

Examples of applications

Problems can be classified in different ways:

- Black box model
- Search problems
- Optimization vs constraint satisfaction
- NP problems

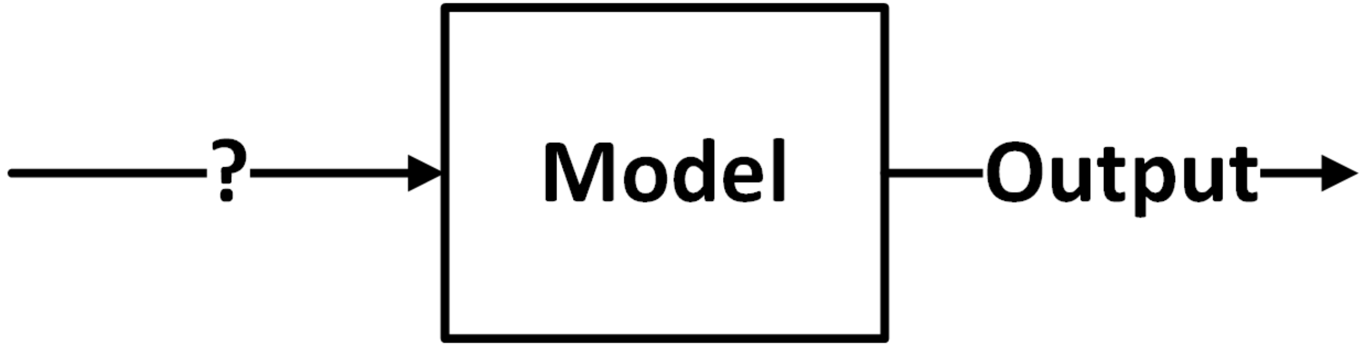
“Black box” optimization



- “Black box” model consists of 3 components
- When one component is unknown: new problem type

“Black box” model: optimization

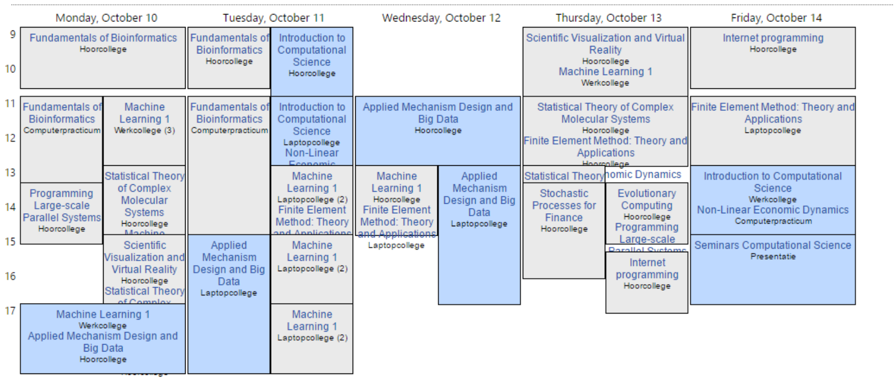
- Model and desired output is known, task is to find inputs



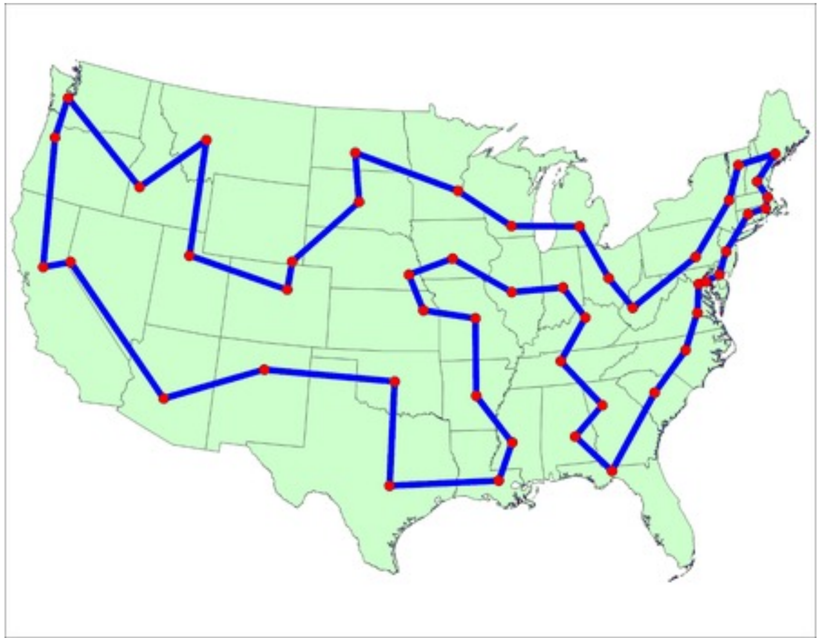
- Examples:
  - Time tables for university, schools, hospitals,…
  - Traveling salesman problem
  - Eight-queens problem

University timetable

- 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



Traveling salesman problem (TSP)



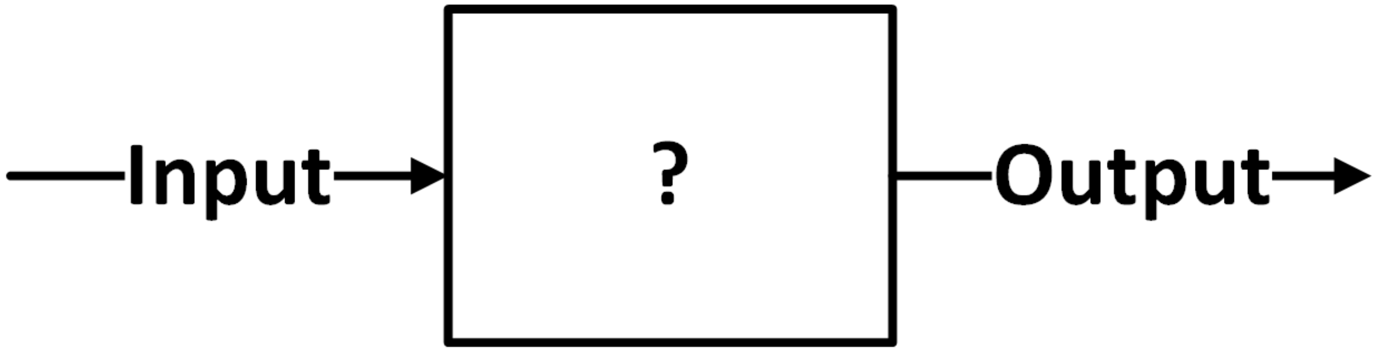
- Given N cities with distances between them
- Find the shortest path across all cities

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)

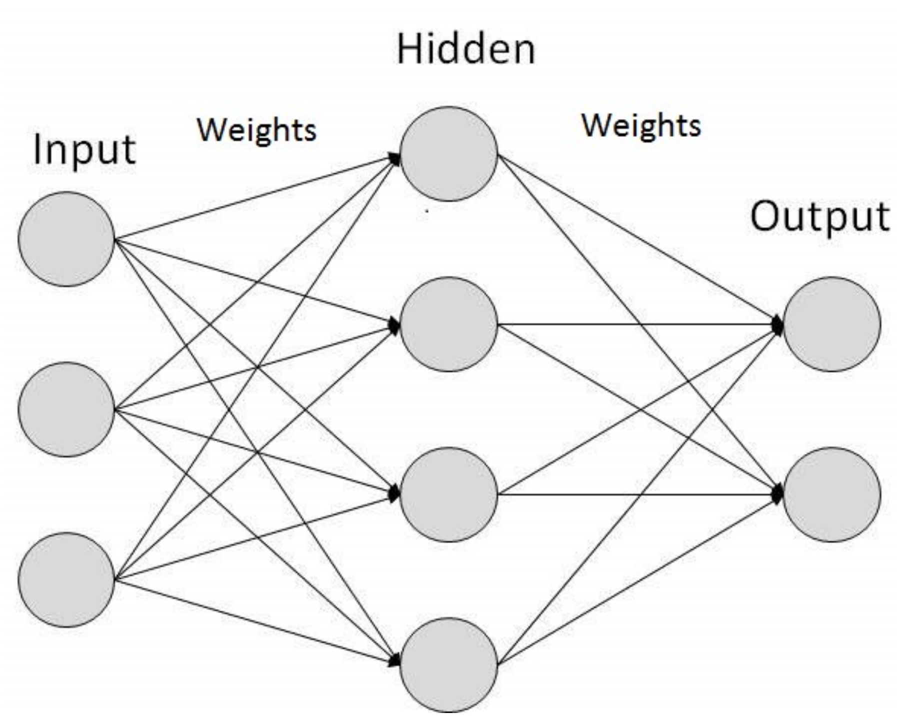
“Black box” model: modelling

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



- Note: modelling problems can be transformed into optimisation problems
    - Evolutionary machine learning

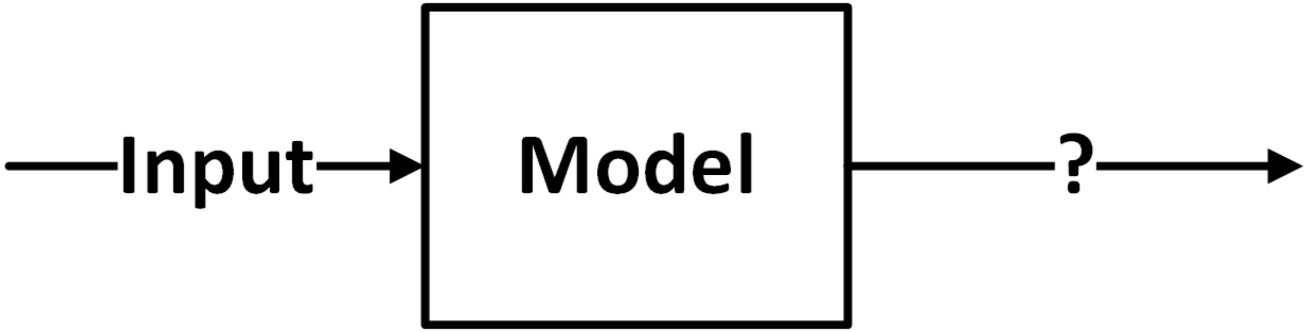
Neural networks training



- Learning of net's parameters
- Suitable for reinforcement learning

“Black box” model: 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
  - Evolutionary economics, Artificial Life
  - Weather forecast system
  - Impact analysis new tax systems

Search problems

- Simulation is different from optimization/modelling
- Optimization/modelling problems search through huge space of possibilities
- Search space: collection of all objects of interest including the desired solution

Benefit of classifying these problems: distinction between
- search problems, which define search spaces, and
- problem-solvers, which tell how to move through search spaces.

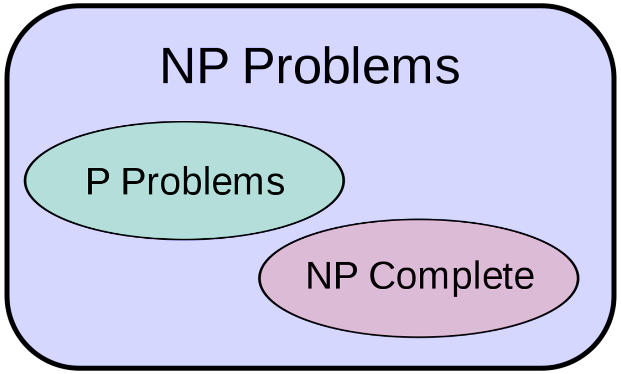
Optimization vs. constraint satisfaction

- Objective function: a way of assigning a value to a possible solution that reflects its quality on scale
  - Number of un-checked queens (maximize)
- Constraint: binary evaluation telling whether a given requirement holds or not
  - Find a configuration of eight queens on a chessboard such that no two queens check each other

	Objective function	
Constraints	Yes	No
Yes	Constrained optimization problem	Constrained satisfaction problem
No	Optimization problem	No problem

NP problems

- This classification scheme needs the properties of the problem solver
- Benefit of this scheme: possible to tell how difficult the problem is
- Explain the basics of this classifier for combinatorial optimization problems (booleans or integers search space)



NP problems: key notions

- Problem size: dimensionality of the problem at hand and number of different values for the problem variables
- Running-time: number of operations the algorithm takes to terminate
  - Worst-case as a function of problem size
  - Polynomial, super-polynomial, exponential
- Problem reduction: transforming current problem into another via mapping

NP problems: class

- The difficultness of a problem can now be classified:
  - Class P: algorithm can solve the problem in polynomial time (worst-case running-time for problem size n is less than F(n) for some polynomial formula F)
  - Class NP: problem can be solved and any solution can be verified within polynomial time by some other algorithm (P subset of NP)
  - Class NP-complete: problem belongs to class NP can be reduced to this problem by algorithm running in polynomial time
  - Class NP-hard: problem is at least as hard as any other problem in NP-complete but solution cannot necessarily be verified within polynomial time

Motivation for EC

- Developing, analyzing, applying problem solving methods is central theme in mathematics and computer
- Complexity of problems to be solved increases
- Global optimization problems
- Multi-objective optimization problems
- Combinatorial or fuzzy representation of problem
- It's funny

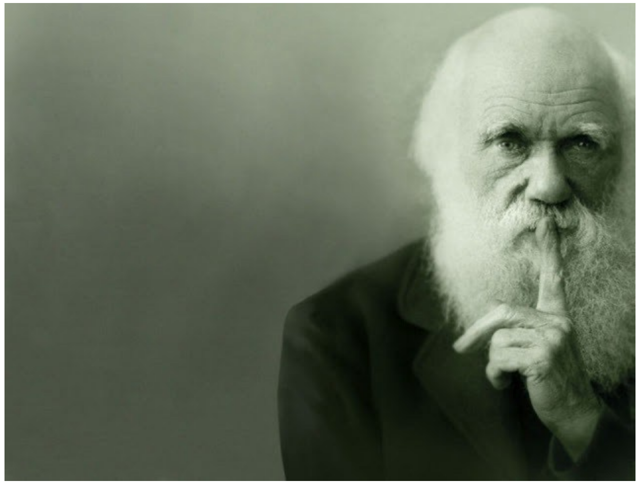
- The best problem solver known in nature:
  - Human brain -> Machine Learning
  - Evolution mechanism -> Evolutionary Computing

Brief History of EC

- 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

GENETIC ALGORITHM

- Pre-notes:
  - 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



Darwinian Evolution: “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

Mutation

- Darwin: “small, random variations in phenotypic traits occur during reproduction from generation to generation.
- 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

Darwinian Evolution

- 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, selection lead to evolution

Population is the “unit of evolution”

- There is no “guiding force”

The main EC Metaphor

- Evolution
  - Environment → Problem
  - Individual → Candidate solution
  - Fitness → Quality
- Problem Solving

Evolution		Problem Solving
Environment	→	Problem
Individual	→	Candidate solution
Fitness	→	Quality

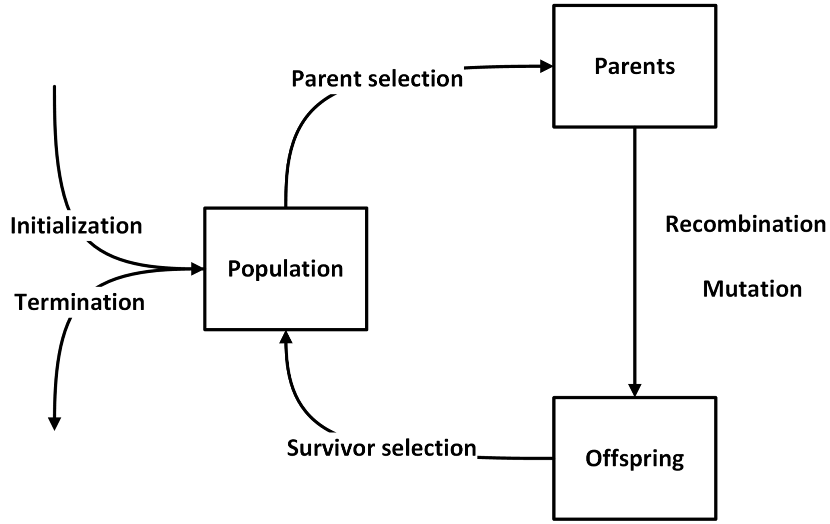
Fitness – chances for survival and reproduction

Quality – chance for seeding new solutions

What is an Evolutionary Algorithm?

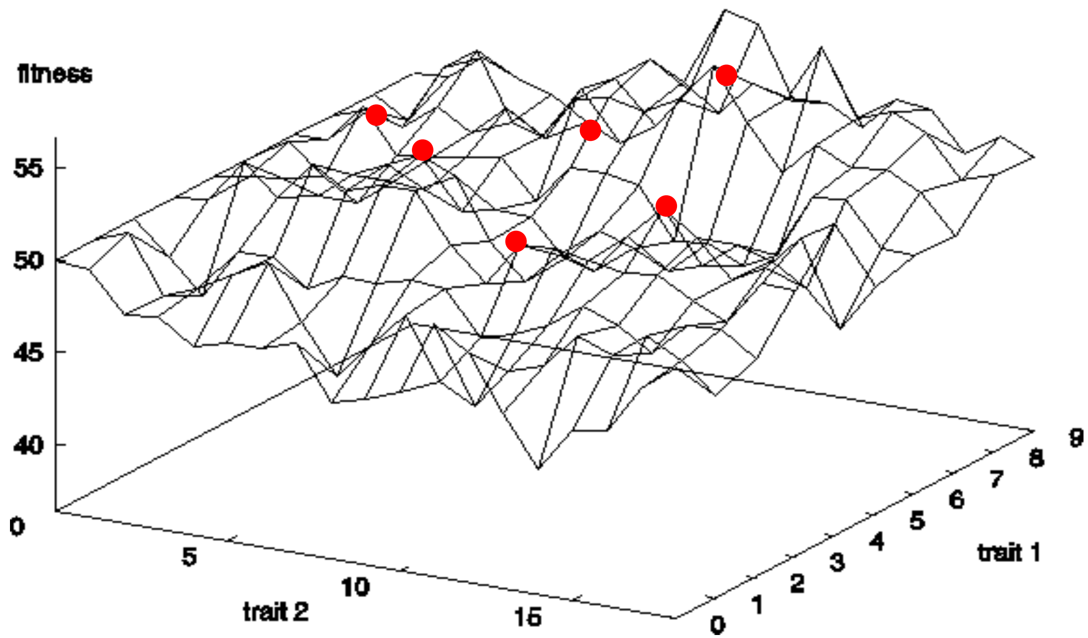
General Description

- EAs fall into the category of “generate and test” algorithms
- They are stochastic, population-based algorithms
- Variation operators (recombination and mutation) create the necessary diversity



Fitness landscape

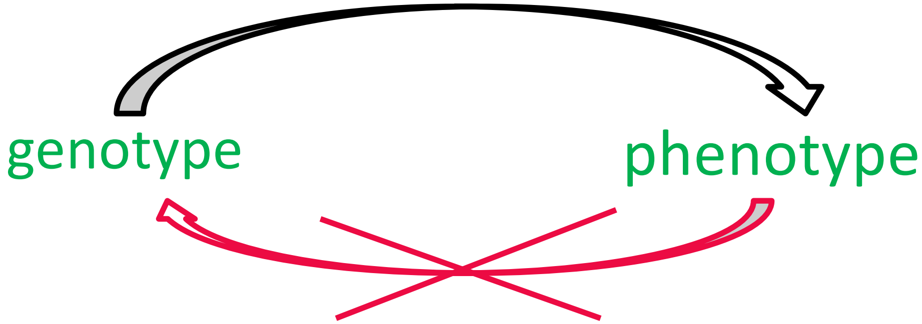
- fitness landscape, or adaptive landscape
- population is seen as a cloud of points in this landscape
- individual = candidate solution is one point



Genetics

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

In nature



in EC:

decoding

genotype **phenotype**

encoding

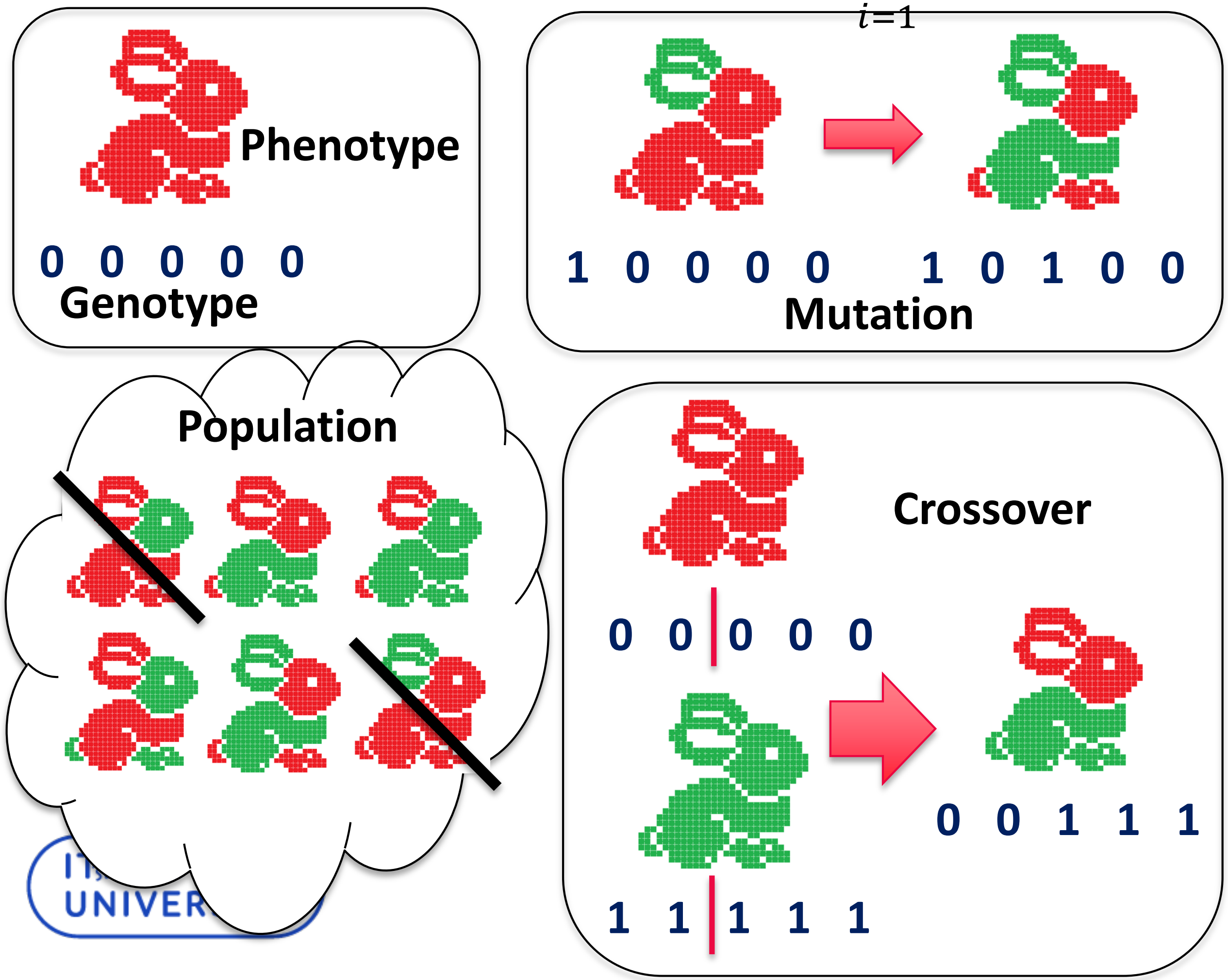
code
inside
evolutionary variations
(mutation, recombination)
chromosome
point in genotype space

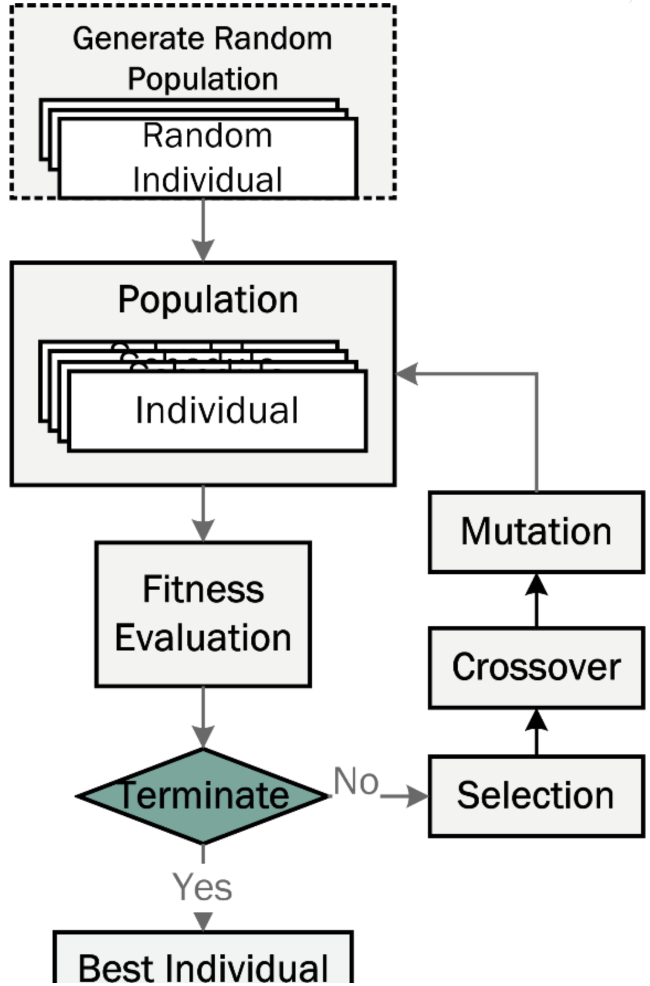
features & behaviour
outside
environment
selection
survival
candidate solution
point in phenotype space

fitness problem

GA example

$$Fitness = \sum_{i=1}^{n} Genotype_i$$





Contents

- Genetic algorithm
- Representations of chromo (integer, combinatorial)
- Selection strategies
- Fitness function
- Algorithm tuning, genetic drift

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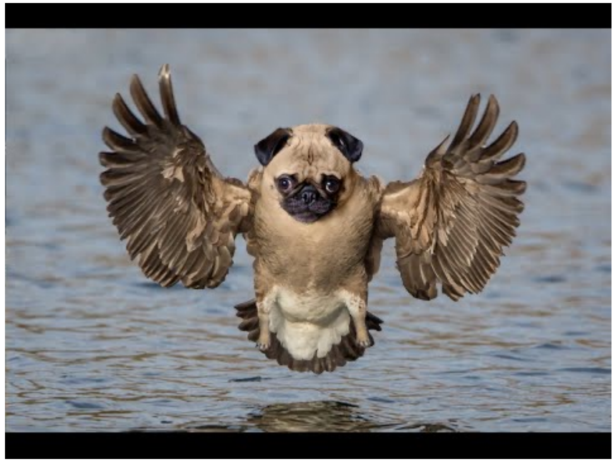
Contents

- Population management
- Another evolutionary algorithms
- Hybrid algorithms
- Multi-criteria algorithms, pareto-front
- Multipopulational algorithms, parallelization
- Coevolution algorithms



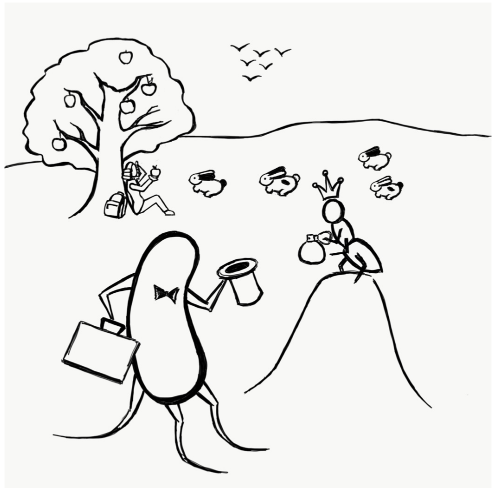
Practical tasks

- 1. Demonstrations
- 2. Real-valued optimization
- 3. Travelling salesman problem
- 4. Queens puzzle
- 5. Parallel models

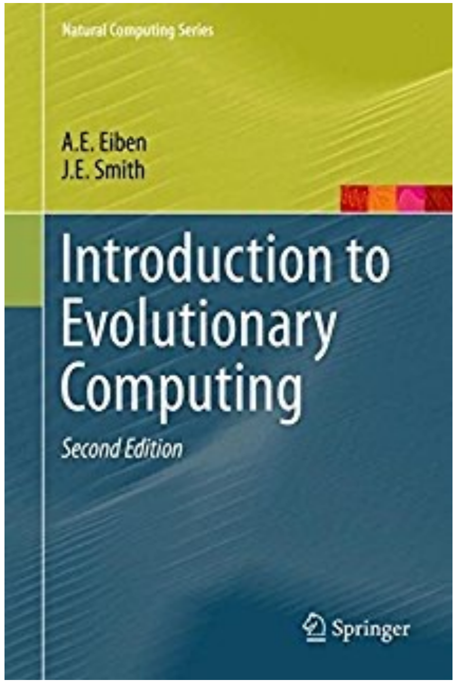
- Seminar classes:
  - Presentations on various population-based algorithms with discussion

Examples and literature

- http://www.southampton.ac.uk/~ajk/truss/welcome.html
- http://rednuht.org/genetic_walkers/
- http://rednuht.org/genetic_cars_2/
- https://youtu.be/qv6UVOQ0F44



https://books.ifmo.ru/file/pdf/2389.pdf



Introduction to Evolutionary Computing
Authors: **Eiben**, A.E., **Smith**, James E

Watchmaker demo

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Copy Watchmaker
Open IntelijIdea -> import from Maven

- BitsExample.java
  - Play around dimension of problem
- *MonaLisaApplet.java*
- TravellingSalesmanApplet.java
  - Select all and play with parameters:
    - Population size – number of solutions in population
    - Elitism – number of best solutions to save

Thank you for your attention!

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