INF3490 - Biologically inspired computing

Lecture 1

UNIVERSITY OF OSLO

INF 3490: Biologically inspired computing - Autumn 11

- **Lecturer:** Jim Tørresen (jimtoer@ifi.uio.no)

  Kazi Shah Nawaz Ripon (ksripon@ifi.uio.no)
- **Lecture time:** Tuesday 10.15-12.00
- **Lecture room:** OJD 1416 Auditorium Smalltalk
- **Group Lecture:** Monday 10.15-12.00 (OJD 3468 Datastue Fortress)
- **Course web page:** www.ifi.uio.no/inf3490

INF3490

Syllabus:

- Selected parts of the following books (details on course page):
  - A.E. Eiben and J.E. Smith: Introduction to Evolutionary Computing, 2nd printing, 2007. Springer. ISBN: 978-3-540-40184-1.
  - S. Marsland: Machine learning: An Algorithmic Perspective. ISBN:978-1-4200-6718-7
- On-line papers (on course web page).
- The lecture notes.

Obligatory Exercises:

- Two exercises on evolutionary algorithm and machine learning.
- Students registered for INF4490 will be given additional excercises within area of the course.

Lecture Plan Autumn-2011

Date	Lecturer	Place	Topic	Syllabus
30.08.2011	Jim Tørresen	OJD 1416 Auditorium Smalltalk	Course Overview, Introduction to EC and ML	Marsland (chapter 1), Eiben & Smith (chapter 1)
06.09.2011	Kazi Shah Nawaz Ripon	OJD 1416 Auditorium Smalltalk	Search & optimization algorithms, Introduction to evolutionary algorithm	Marsland (chapter 11), Eiben & Smith (chapter 2)
13.09.2011	Kazi Shah Nawaz Ripon	OJD 1416 Auditorium Smalltalk	Genetic algorithms	Eiben & Smith (chapter 3)
20.09.2011	Kazi Shah Nawaz Ripon	OJD 1416 Auditorium Smalltalk	Evolutionary strategies, Evolutionary programming, Genetic programming, Multi-objective evolutionary algorithm	Eiben & Smith (chapter 4, 5, 6, 9.5)
27.09.2011	Kazi Shah Nawaz Ripon	OJD 1416 Auditorium Smalltalk	Swarm intelligence, Artificial immune system, Interactive evolutionary computation	On-line papers
04.10.2011	Kazi Shah Nawaz Ripon	OJD 1416 Auditorium Smalltalk	Working with evolutionary algorithms, Hybridization (Memetic algorithms), Coevultion	Eiben & Smith (chapter 10, 13, 14)
11.10.2011	Kazi Shah Nawaz Ripon	OJD 1416 Auditorium Smalltalk	Introduction to learning/classification, Neuron, Perception, Multi-Layer perception (FF ANN)	Marsland (chapter 1, 2, 3)
18.10.2011	Kazi Shah Nawaz Ripon	OJD 1416 Auditorium Smalltalk	Multi-Layer perception (FF ANN), Backpropagation, Practical issues (generalization, validation.....)	Marsland (chapter 3), On-line resources
25.10.2011	Kazi Shah Nawaz Ripon	OJD 1416 Auditorium Smalltalk	SVM, Dimensionality reduction (PCA)	Marsland (chapter 5, 10)
01.11.2011	Kazi Shah Nawaz Ripon	OJD 1416 Auditorium Smalltalk	Naive bayes classifier, Bias-variance trade-off, k-NN	Marsland (chapter 8)
15.11.2011	Kazi Shah Nawaz Ripon	OJD 1416 Auditorium Smalltalk	Unsupervised learning, k-means, SOM, Reinforcement learning	Marsland (chapter 9, 13)
22.11.2011	Kazi Shah Nawaz Ripon	OJD 1416 Auditorium Smalltalk	Discussion	

What the Course is About

- **Evolutionary Computing (EC):** Search algorithms based on the mechanisms of natural selection and natural genetics (survival of the fittest).

- **Machine Learning (ML):** About making computers *modify* or *adapt* their actions so that these actions get more accurate, where accuracy is measured by how well the chosen actions reflect the correct ones.

EVOLUTIONARY COMPUTING

Evolutionary Computing

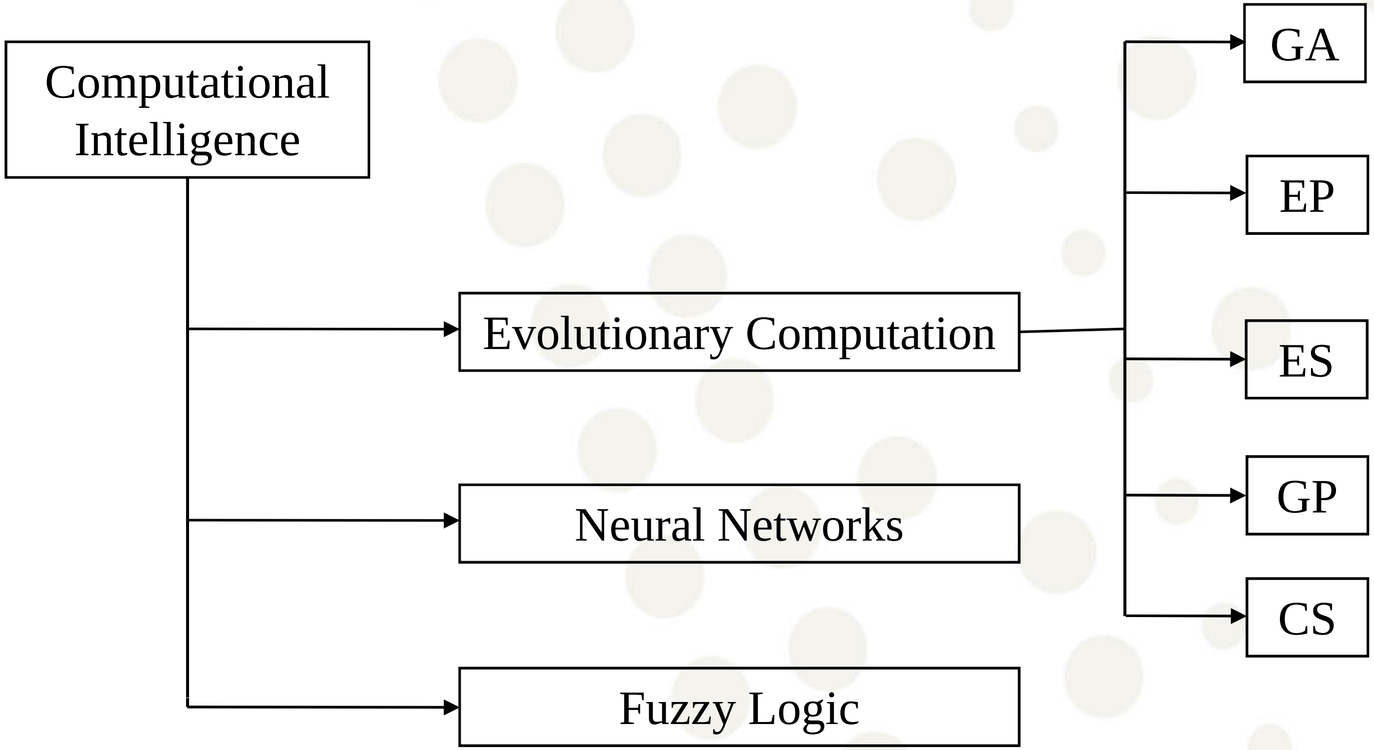


Fig: Families of evolutioanry algorithms [1]

[1] http://neo.lcc.uma.es/opticomm/introea.html

Evolutionary Computing

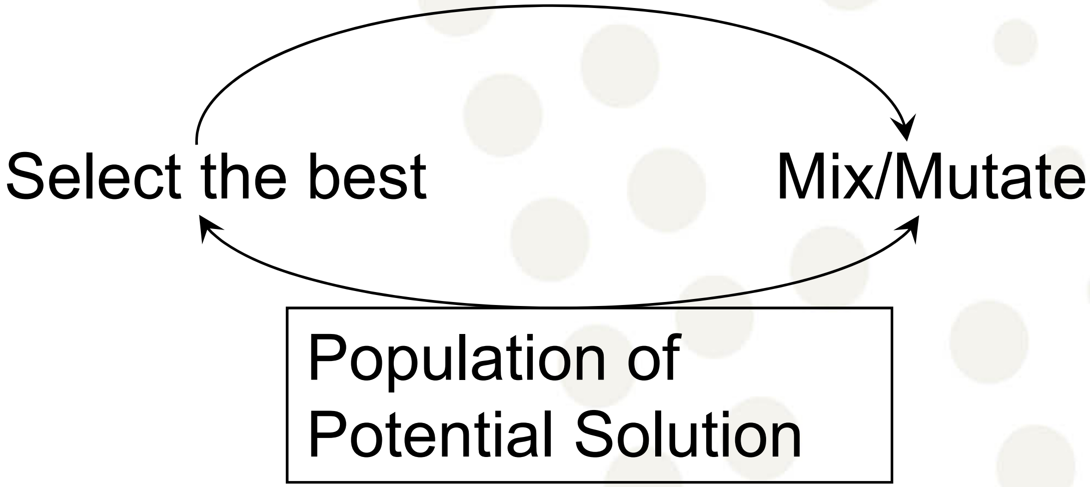
- Can we learn and use - the lessons that ***Nature*** is teaching us - for our own profit?
  - ***YES***
  - The optimization community has repeatedly shown in the last decades.

- `*Evolutionary algorithm'* (EA) are the key words here.
- EA is used to designate a collection of optimization techniques whose functioning is loosely based on metaphors of biological processes.

What is EC?

- Methods based on
  - Mendelian genetics
    - units of inheritance
  - Darwin's survival of the fittest
    - a population of animals/planets/etc that compete for resources
    - variations within population that affects individulas' chance for reproduction
    - inheritance of favorable characteristics.

What is EC?


Select the best
Mix/Mutate
Population of
Potential Solution

What is EC?

- Evolution is a process that does not operate on organisms directly, but on chromosomes.
  - Chromosomes (more precisely, the information they contain) pass from one generation to another through reproduction.
- The evolutionary process takes place precisely during reproduction.
  - Mutation and re-combination.
- Natural selection is the mechanism that relates chromosomes with the adequacy of the entities they represent
  - proliferation of effective environment-adapted organisms
  - extinction of lesser effective, non-adapted organisms.

Search Problem

- Travelling salesperson problem: find shortest path when visiting all cities only once
- Here: 43 589 145 600 possible combinations

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 "Laws" of the Nature

- **Law of Evolution:** Biological systems develop and change during generations.
- **Law of Development:** By cell division a multi-cellular organism is developed.
- **Law of Learning:** Individuals undergo learning through their lifetime.

Evolution

Biological evolution:

- Lifeforms adapt to a particular environment over successive generations.
- Combinations of traits that are better adapted tend to increase representation in population.
- Mechanisms: heredity, variation, natural selection

Evolutionary Computing (EC):

- Mimic the biological evolution to optimize solutions to a wide variety of complex problems.
- In every new generation, a new set of solutions is created using bits and pieces of the fittest of the old.

The Main EC Metaphor

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

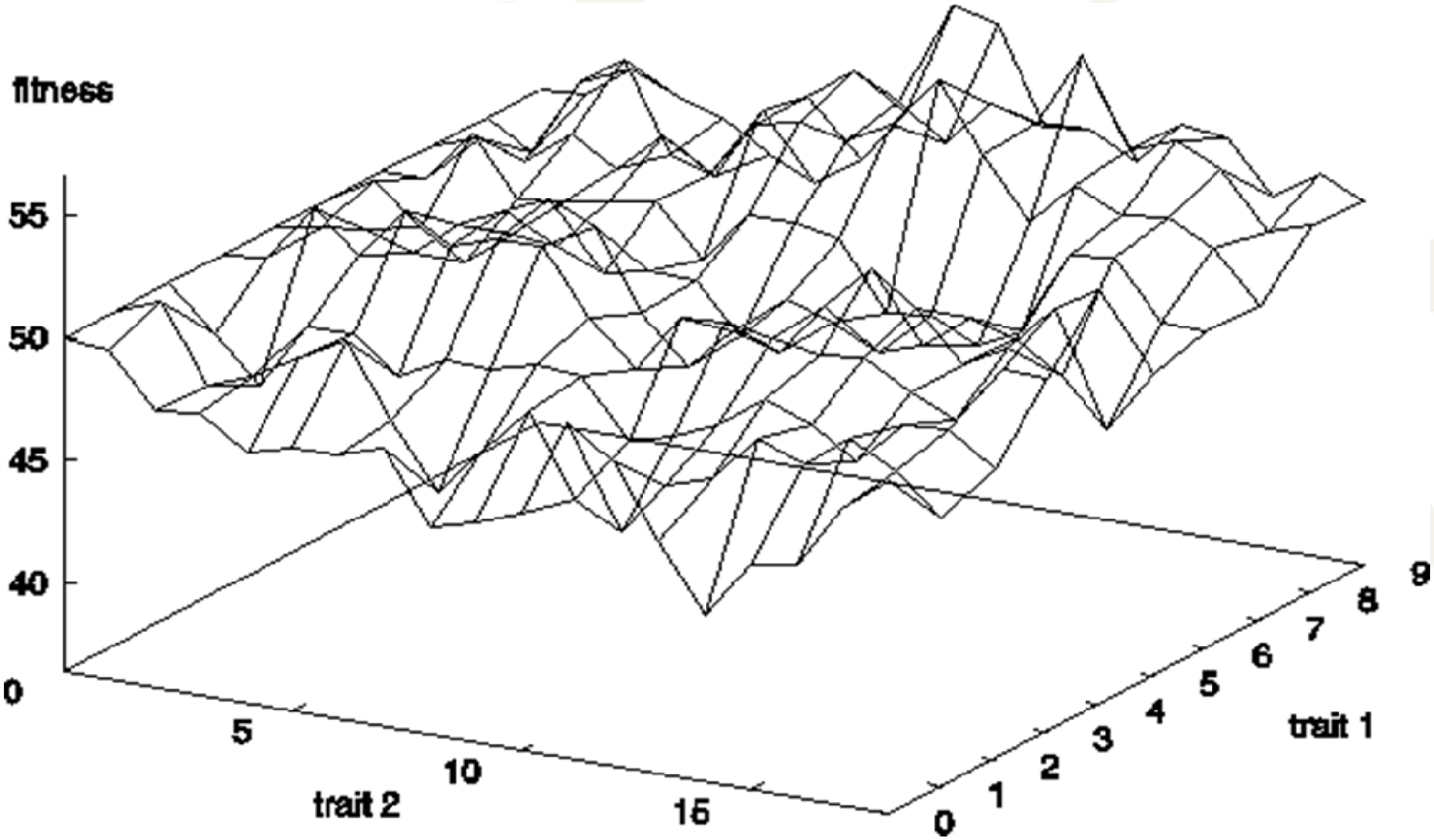
Fitness → chances for survival and reproduction

Quality → chance for seeding new solutions

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



Performance

- For a wide range of applications
  - acceptable performance
  - acceptable cost
- Implicit parallelism
  - robustness
  - fault tolerance
- Acceptable performance even under uncertainties and change

Major Areas in EC

- Optimisation
- Learning
- Design
- Theory

Summary of EC algorithms

- 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 and thereby facilitate novelty.
- Selection reduces diversity and acts as a force pushing quality.

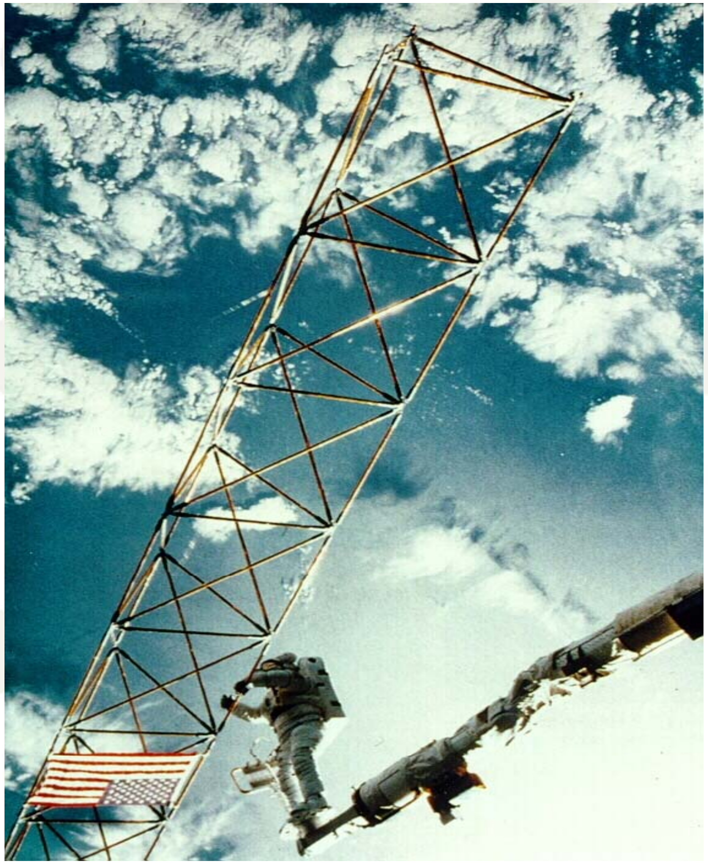
What Good is EC?

Areas in which EC has been successfully applied:

- Game playing (chess, go, tic tac toe, tic tac dough)
- Economics and politics (prisoner's dilemma, evolution of co-operation)
- Planning (robot control, air traffic control)
- Scheduling (job shop, precedence-constrained problems, workload distribution)
- Machine vision
- Manufacturing
- VLSI design
- Many, many more

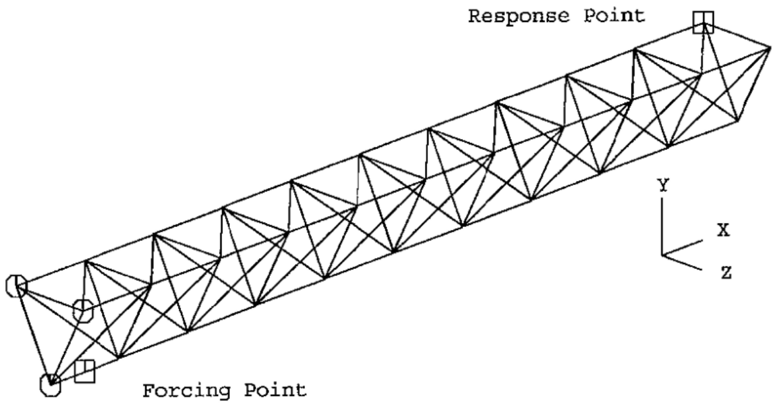
Example

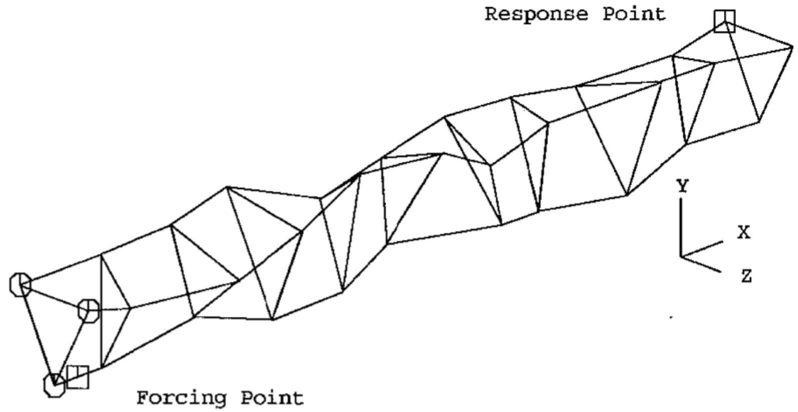
- optimisation problem: NASA satellite design
- Fitness: vibration resistance
- Evolutionary "creativity"



Example cont.

- Initial design evolved design (20,000% better)

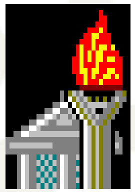




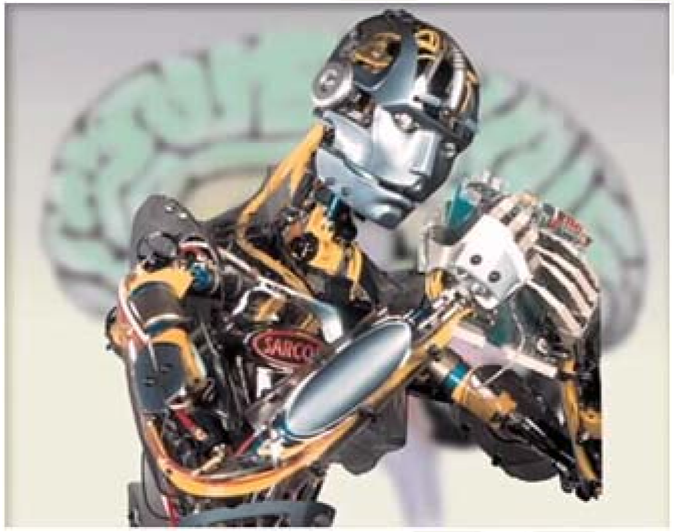
Example: ”Genetic art”

Example: 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



MACHINE LEARNING

Idea Behind

- Humans can:
  - think, ***learn,*** see, understand language, reason, etc.

- Artificial Intelligence aims to reproduce these capabilities.
- Machine Learning is ***one*** part of Artificial Intelligence.

Learning

- Humans and other animals can display behaviours that we label as *intelligent* by *learning from experience*.

- A machine learns with respect to a particular task ***T***, performance metric ***P***, and type of experience ***E***, if the system reliably improves its performance ***P*** at task ***T***, following experience ***E***.

Learning

- Important parts of learning:
  - **Remembering**: Recognising that last time we were in this situation, we tried out some particular action, and it worked.
  - **Adapting**: So, we will try it again, or it didn't work, so we will try something different.
  - **Generalising**: Recognising similarity between different situations, so that things that applied in one place can be used in another.

For example – Which of these things is NOT like the others? Why?

And…which of these things is not like the other? And why?

Machine Learning

- Ever since computers were invented, we have wondered whether they might be made to learn.
- ML studies the programs that improve with experience.
- According to Mitchell [1], "machine learning is concerned with the question of how to construct computer programs that automatically improve with experience."
- One measure of progress in machine learning is its significant real-world applications, such as speech recognition, computer vision, bio-surveillance, robot control, web search, computational biology, finance, e-commerce, space exploration, information extraction, etc.

[1] T. M. Mitchell. Machine Learning, McGraw-Hill, 1997.

Why "Learn" ?

- Machine learning is programming computers to optimize a performance criterion using example data or past experience.
- There is no need to "learn" to calculate payroll.
- **Learning is used when:**
  - Human expertise does not exist (navigating on Mars).
  - Humans are unable to explain their expertise (speech recognition).
  - Solution changes in time (routing on a computer network).
  - Solution needs to be adapted to particular cases (user biometrics)
  - Interfacing computers with the real world (noisy data)
  - Dealing with large amounts of (complex) data

Why Machine Learning?

- Extract knowledge/information from past experience/data
- Use this knowledge/information to analyze new experiences/data
- Designing rules to deal with new data by hand can be difficult
  - How to write a program to detect a cat in an image?
- Collecting data can be easier
  - Find images with cats, and ones without them
- Use machine learning to automatically find such rules.
- Goal of this course: introduction to machine learning techniques used in current object recognition systems

Steps in ML

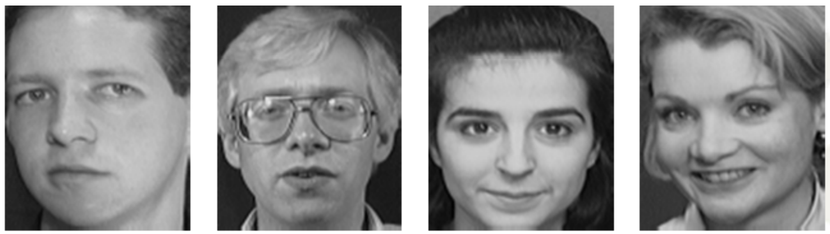
- Data collection
  - "training data", optionally with "labels" provided by a "teacher".
- Representation
  - how the data are encoded into "features" when presented to learning algorithm.
- Modeling
  - choose the class of models that the learning algorithm will choose from.
- Estimation
  - find the model that best explains the data: simple and fits well.
- Validation
  - evaluate the learned model and compare to solution found using other model classes.
- Apply learned model to new "test" data

Machine Learning (Example)

Face Recognition

Training examples of a person

Test images



AT&T Laboratories, Cambridge UK. http://www.uk.research.att.com/facedatabase.html

Machine Learning (Example)

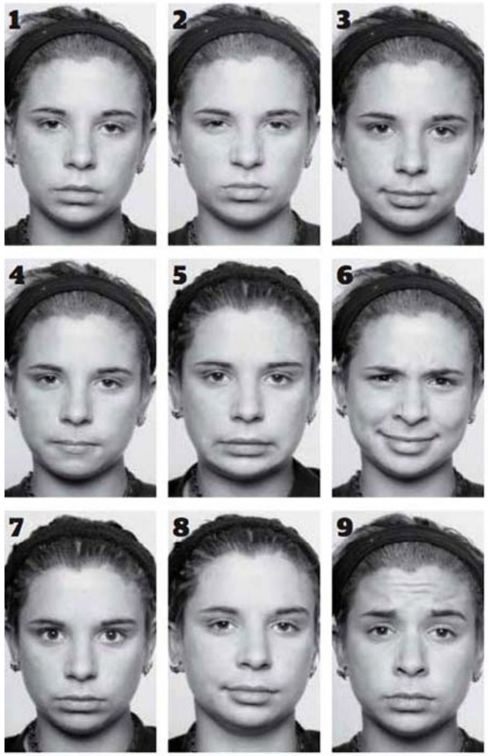
Using machine learning to recommend books.

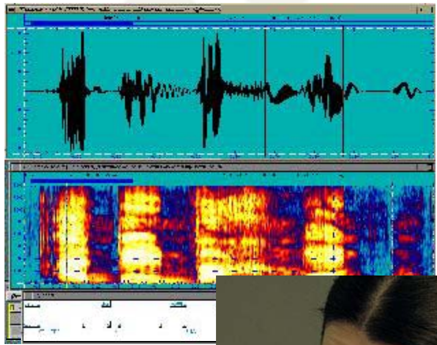
ALGORITHMS

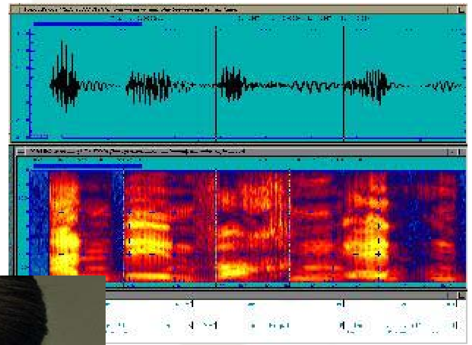
- Collaborative Filtering
- Nearest Neighbour
- Clustering

Machine Learning (Example)

Using machine learning to identify vocal patterns







ALGORITHMS

- Feature Extraction
- Probabilistic Classifiers
- Support Vector Machines
- + many more….

Types of Machine Learning

- ML can be loosely defined as getting better at some task through practice.
- This leads to a couple of vital questions:
  - How does the computer know whether it is getting better or not?
  - How does it know how to improve?

There are several different possible answers to these questions, and they produce different types of ML.

Types of ML (1)

1. **Supervised learning:** Training data includes desired outputs. One typically tries to uncover hidden regularities or to detect anomalies in the data.

2. **Unsupervised learning:** Training data does not include desired outputs, instead the algorithm tries to identify similarities between the inputs that have something in common are categorised together.

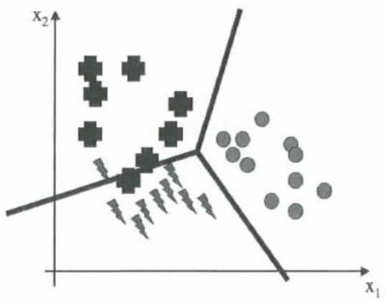
Types of ML (2)

3. **Reinforcement learning:** Rewards from policy (correct actions to reach the goal). The ML program should be able to assess the goodness of policies and learn from past good action sequences to be able to generate a policy.

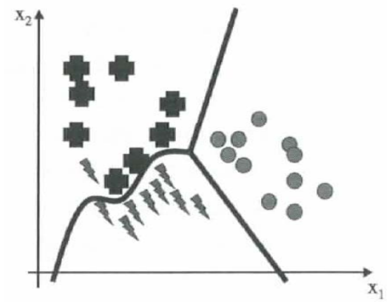
4. **Evolutionary learning:** Biological organisms adapt to improve their survival rates and chance of having offspring in their environment, using an idea of *fitness (how good the current solution is)*.

Classification

The classification problem consists of taking input vector and deciding which of N classes they belong to, based on training from exemplars of each class.



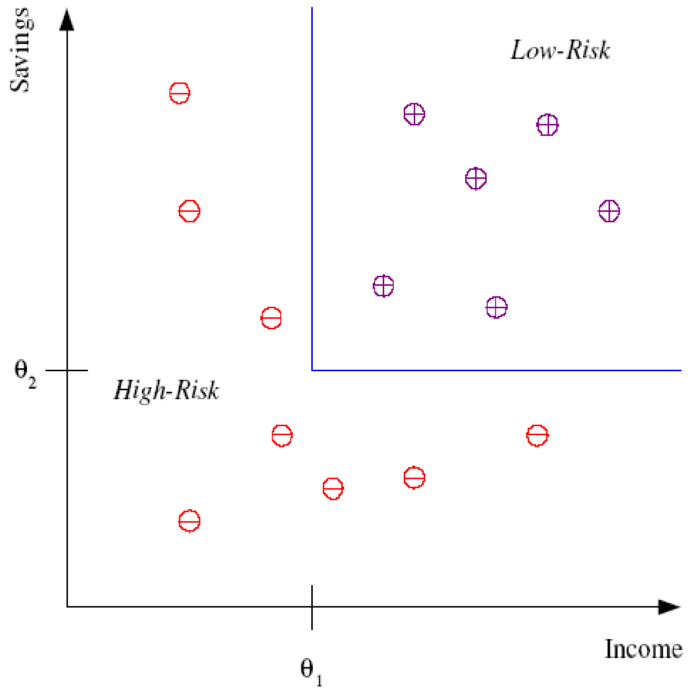
A set of straight line decision boundaries for a classification problem.



An alternative set of decision boundaries that separate the plusses from lightening strikes better, but it requires a line that isn't straight.

Classification

- Example: Credit scoring
- Differentiating between low-risk and high-risk customers from their *income* and *savings*



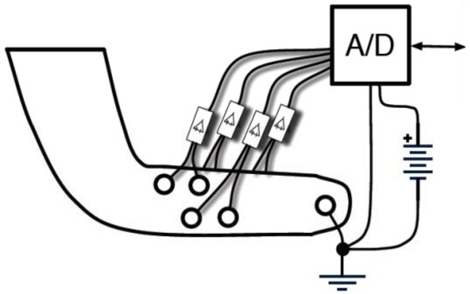
Discriminant: IF *income* > θ_1 AND *savings* > θ_2
THEN low-risk ELSE high-risk

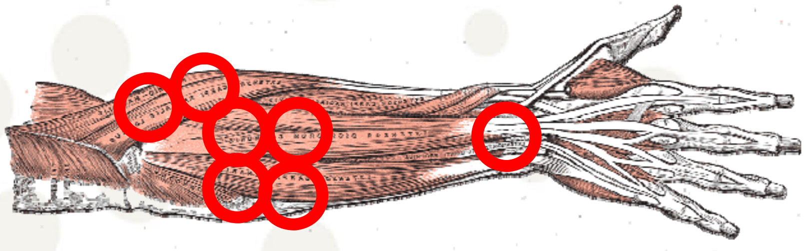
Classification: Applications

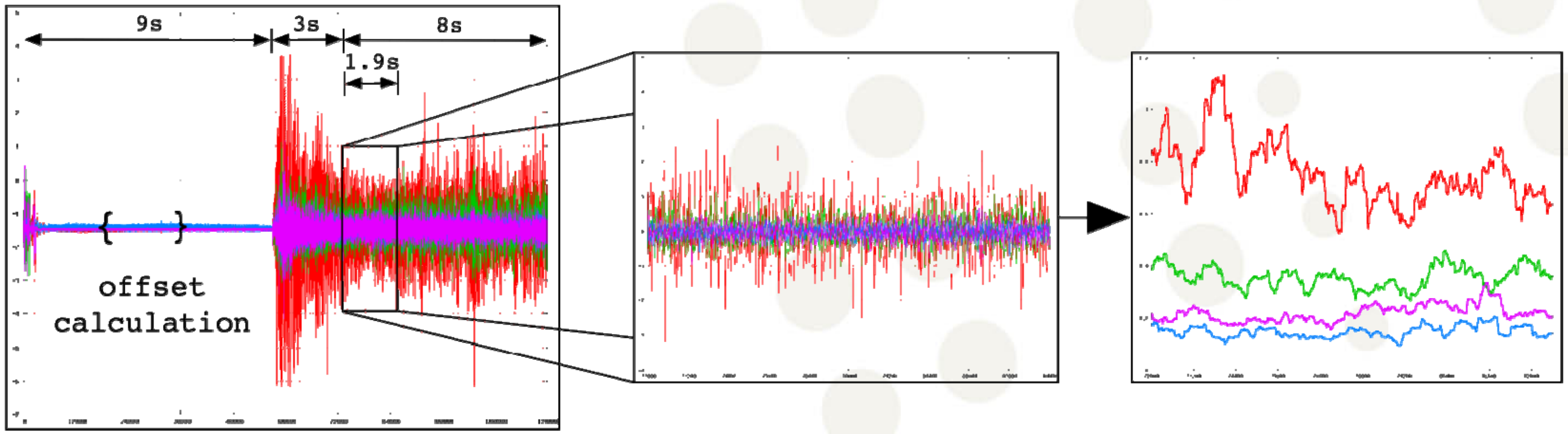
- Aka Pattern recognition
- Face recognition: Pose, lighting, occlusion (glasses, beard), make-up, hair style
- Character recognition: Different handwriting styles.
- Speech recognition: Temporal dependency.
  - Use of a dictionary or the syntax of the language.
  - Sensor fusion: Combine multiple modalities; eg, visual (lip image) and acoustic for speech
- Medical diagnosis: From symptoms to illnesses
- ...

Classification example

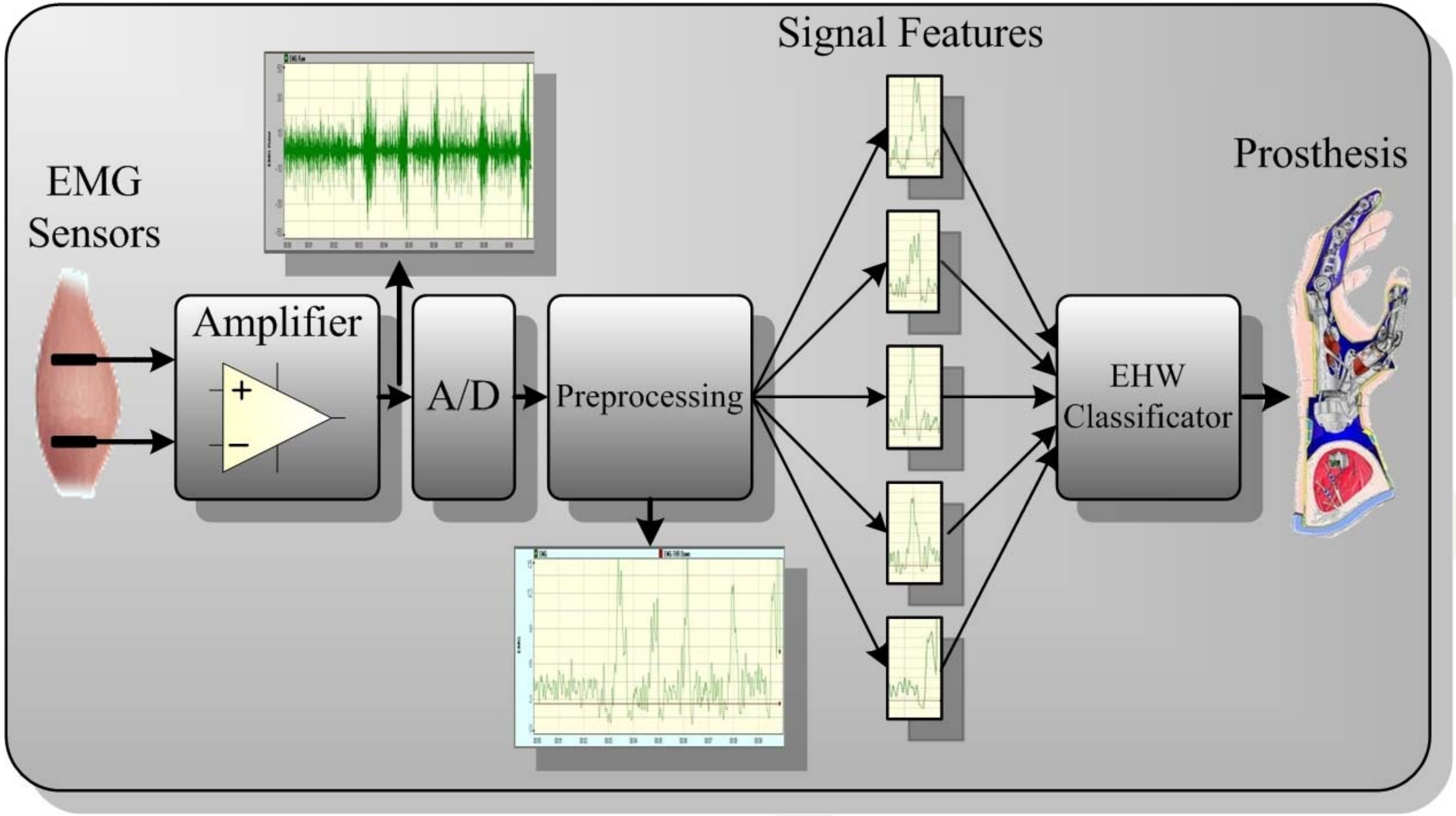
- Electromyography (EMG)
- Electrical potentials generated by muscle cells



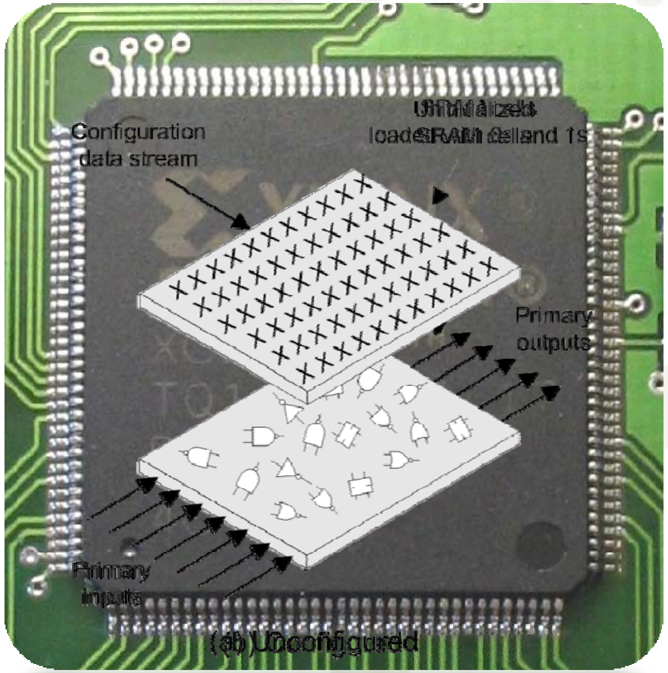




Classification example cont.

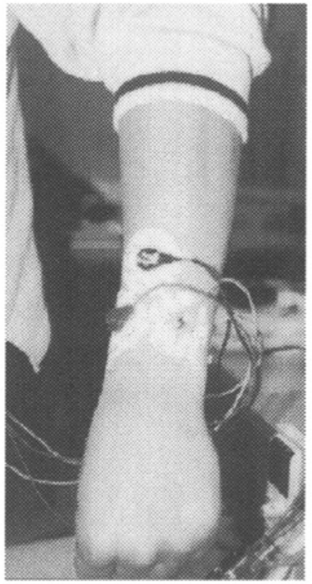


Classificator: evolvable hardware



Classification example cont.

- Adaptive hand prosthesis
  (e.g. AIST, Tsukuba)



- Exoskeleton
  (Sankai, U. Tsukuba)