Machine Learning

Lecture 1
Introduction and Overview

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Hello

- BSc in Cognitive Science
  - Computational Linguistics
  - Neuroscience
- MSc in Neuroscience
  - Brain-Computer-Interfaces
  - Functional Magnetic Resonance Imaging data
- PhD in Machine Learning
  - Biomedical Applications
  - Multimodal neuroimaging data
  - Text analysis on web data
- Amazon Research
  - Computer Vision
  - Recommender Systems
  - Machine Learning Infrastructure
  - ML for Data Quality

Course Structure

- Lectures:
  - Important concepts of Applied Machine Learning
  - Some derivations
  - Focus on practical aspects
- Exercises:
  - Guided programming exercises
  - Python
  - Passing is requirement for final exam
- Final Exam: First week of July

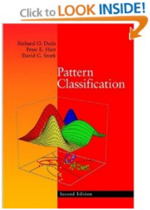
Programming Exercises

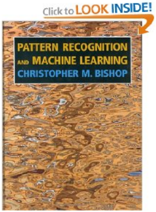
We will use Python to implement ML Applications for

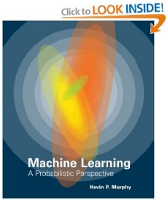
- Automatic handwritten character recognition
- Topic detection on web/text data
- Recommender Systems using Collaborative Filtering
- Spam detection on emails
- Face recognition
- 'Mind-reading' from brain signals
- ...

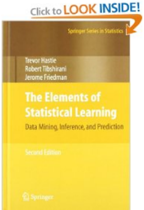
Some Textbooks

Some of the books I used for this course:









Why not just calling it Artificial Intelligence?

- Intelligence is very difficult to define [Tomasello, 2003]
- Artificial and human intelligence is difficult to compare [Turing, 1950]
- Scientists use a simpler term: Machine Learning (ML):

  $\Rightarrow$ **ML are Algorithms that learn from data.**

Machine Learning – The Big Picture

Given data $x \in \mathcal{X}$ (neural signals, internet user data, ...)

$\rightarrow$ predict variable $y \in \mathcal{Y}$ (thoughts, user intentions, ...)

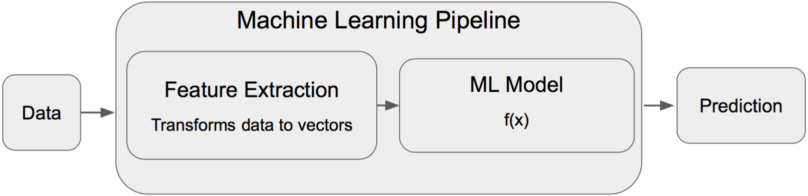
ML algorithms learn a function $f(.)$ from examples (x,y)

$$f(x) = y \tag{1}$$

Most of ML is about:

- Find the right function class for $f(.)$
- Fitting $f(.)$ correctly

Machine Learning Pipelines



Machine Learning In Practice

ML algorithms

- are defined using vector / matrix operations
- are usually some mathematical function

$\rightarrow$ That's why we will need some math basics.

Some Historical Remarks

- We will take a quick tour through the history of ML
- This will help us to understand
    - Where does ML come from?
    - For how long have scientists been working on this?
    - What can we learn from past mistakes?
    - Should we believe the AI hype these days?

AI, ML and Cognition

- Machine Learning can be defined from the algorithm point of view:

  $\Rightarrow$ **ML are Algorithms that learn from data.**

- Another useful view

  $\Rightarrow$ **Algorithms that emulate biological cognition**

What is Cognition?

- Derived from cognoscere (latin): *to recognize*
- Refers to processing of information

  Learning, recognizing and categorizing concepts
  Inference based on these concepts (e.g. language)
- Cognitive processes can be

  natural or artificial, conscious or unconscious
- **Easier to define and measure than intelligence**
- Cognition is studied by

  linguistics, neuroscience, philosophy, psychology

  AND computer science (artificial intelligence, machine learning)

A short history of Machine Learning

Where does Machine Learning come from?

The aim of building artificial cognitive systems goes back to

- The concept of **automata**
- The insight that our cognitive processes emerge from biological tissue (brains)
- The combination of these two ideas led to the fields of **Cybernetics, Artificial Intelligence**, and **Machine Learning**

A short history of Machine Learning

Illustration of an Aeolipil

Modern version of an Aeolipil

Automata are self-operating systems.

The concept of automata is very important for deterministic systems of artificial cognition.

An ancient automaton

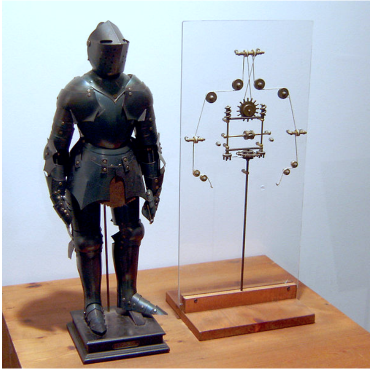
60 AD Hero of Alexandria invents **Aeolipil** (Ball of Aeolus)

First record of a jet engine, a steam engine and an automaton:

A ball filled with water turns if heated

A short history of Machine Learning

A robot knight



A humanoid robot

1495 AD Leonardo Da Vinci invents a **robot knight**

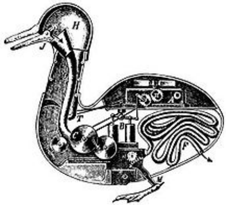
It can sit, stand, raise visor and maneuver its arms

But:

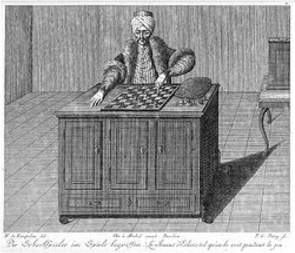
- No central control unit
- No sensory devices

A short history of Machine Learning

A digesting duck



A mechanical chess player



Biological machines?

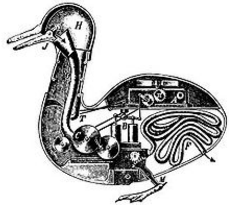
1739 J. Vaucanson invents **digesting duck**

Artificial cognition?

1770 AD Johann Ritter invents **The Turk**, a mechanical chess player
Operated for 84 years, won against Napoleon and Benjamin Franklin.

A short history of Machine Learning

A digesting duck



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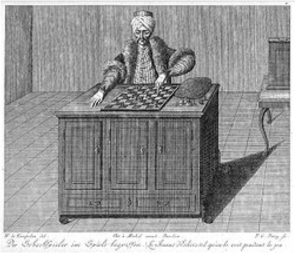

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Artificial cognition?

1770 AD Johann Ritter invents **The Turk**,
a mechanical chess player
Operated for 84 years, won against
Napoleon and Benjamin Franklin.

But: Both machines were fake!

- The duck contained **predigested food**
- Human player was sitting in the Turk

A short history of Machine Learning

1632 Bodies as biological machines [Descartes, 1632]

1940 From machines to intelligent machines
Cybernetics – mechanics of cognition [Wiener, 1948]
Turing Test [Turing, 1950]: *Can machines think?*
Perceptron [Rosenblatt, 1958]: *Artificial 'brains'*
Eliza [Weizenbaum, 1966]: *Better than psychotherapy!*
Chinese Room argument [Searle, 1980]: Against functionalism

1973 AI winter [Lighthill, 1973]

→ Classical AI was mainly built on hand made rules

Problem: No scalability, no unified theory of cognition

⇒ **New AI**:
Let machines learn rules from data [Russell and Norvig, 2010]

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Cybernetics: First Approaches to Cognitive Algorithms

- **Macy Conferences** (1946-53, New York):
  Interdisciplinary effort to set the foundations for a general science of the workings of the human mind.

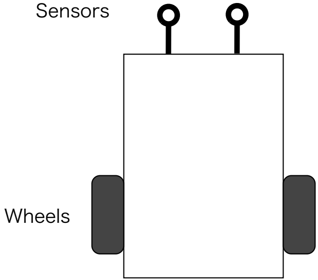
$\rightarrow$ Cybernetics – the art of controlling [Wiener, 1948]

- Some famous cyberneticists:
  Norbert Wiener (Wiener Filters), John von Neumann (Computers), Claude E. Shannon (Information Theory), Werner Reichhardt (Reichhardt Correlator), Valentino Braitenberg (Braitenberg Vehicles), ...

ELIZA [Weizenbaum, 1966]

Human	All men are alike
Eliza	*In what way?*
Human	They're always bugging us about something or other
Eliza	*Can you think of a specific example*
Human	Well, my boyfriend made me come here
Eliza	*Your boyfriend made you come here?*
Human	He says I'm depressed much of the time
Eliza	*I am sorry to hear you're depressed*
Human	It's true, I am unhappy
Eliza	*Do you think coming here will help you not to be unhappy?*
Human	I need some help, that much seems certain.
Eliza	*What would it mean to you if you got some help?*
Human	Perhaps I could learn to get along with my mother.
Eliza	*Tell me more about your family*
...	

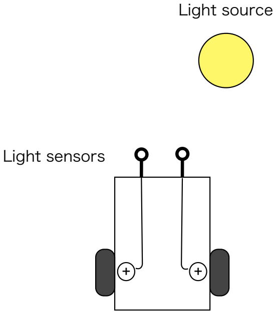
Braitenberg Vehicles
Artificial organisms with 'emotions'



Artificial organisms with very simple hardware can exhibit complex behavior.

Behaviour of Braitenberg Vehicles can be interpreted as different 'characters' [Braitenberg, 1984].

Braitenberg Vehicles



In which direction will
the Braitenberg Vehicle go?

Why is Cybernetics important?

- Many algorithms from Cyberneticists are still state of the art
- Understanding biological cognition improves artificial cognition
- Cybernetic principles are independent of sensory modality!
- This also a goal of Machine Learning:
  Modeling of cognitive mechanisms (independent of data type).

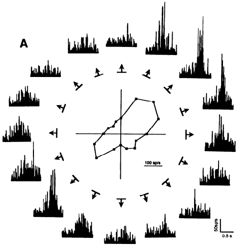
Also in biological systems cognitive mechanism can be decoupled from sensory modalities

→ Audiovisual re-routing in animals [Roe et al., 1992]

→ Sensory substitution [Bach-y Rita et al., 1969]

Audiovisual Re-routing

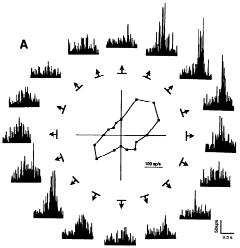
Neural response in Visual Brain Area



In an experiment on ferrets [Roe et al., 1992] the nerve fibers from the eye were re-routed to the brain areas that process information from the ear (auditory brain areas).

Audiovisual Re-routing

Neural response in Visual Brain Area



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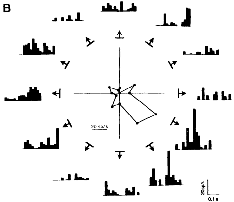
Neural response in Auditory Brain Area



⇒ Neural responses in auditory brain area became selective like neurons in visual areas

Sensory Substitution

Sensory Substition

Program new cognitive functions into existing sensory modality

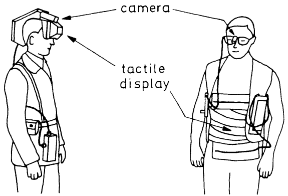
Examples:

Haptic Vision [Bach-y Rita et al., 1969]
$\rightarrow$ Luminance on photosensors translated to vibrations on skin

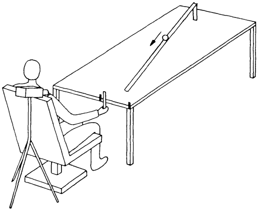
Feelspace [Nagel et al., 2005]
$\rightarrow$ Allocentric orientation through haptic feedback

Sensory Substitution: Tactile Vision

Tactile vision device



Experimental setup



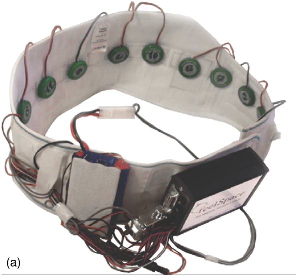
Pioneered by [Bach-y Rita et al., 1969], tested in [Jansson, 1983]

- Tactile matrix (20×20 vibrators) on the subject's back
- Tactile information about catching device and ball

⇒ **Blind subjects can catch the ball!**

Sensory Substitution: Feelspace

Feelspace belt



http://feelspace.cogsci.uni-osnabrueck.de/

Creating an allocentric sense of orientation [Nagel et al., 2005]

- Direction of north pole is translated to vibration in belt
- After wearing the belt for some weeks subjects acquire an allocentric sense of orientation

  "I was intuitively aware of the direction of my home or of my office."

Summary

- Cognitive processes:
  Perception, recognition of / inference on semantic concepts
- Cybernetics
  - simple (hardwired) models of cognition
  - inspired by biological organisms
  - different from classical engineering approaches
  - modeled motion detection, navigation, ...
  - $\rightarrow$ but what about higher cognitive functions?
- Artificial intelligence
  - took over ideas from Cybernetics
  - focused on (biologically inspired) models of higher cognition
  - Old AI: rule based systems (like ELIZA)
  - AI Winter: Most research stopped, AI hype broke down
  - New AI (machine learning): learns rules from data

Lecture Overview

Some topics we will cover:

- Quick Introduction to Python
- Math Recap
- Feature Extraction
- Classification:
  Perceptrons, K-Nearest Neighbor, Logistic Regression, Support Vector Machines, Random Forests
- Regression:
  Linear Regression, Gaussian Processes
- Artificial Neural Networks
- Unsupervised Learning:
  Clustering, Principal Component Analysis, Topic Models
- Generalization and Model Selection

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