Cognitive Algorithms
Lecture 1 - Introduction

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Stephanie Brandl

Berlin Institute of Technology
Dept. Machine Learning

Integrated lecture "Cognitive Algorithms"

Introductory course into Machine Learning
$\rightarrow$ 'Machine Learning Light'
About how computer programs learn "cognitive skills" from data

We will

- learn how a learning task is formalized
- study methods of Machine Learning that solve the learning task
  - focus on methods that are simple to implement
  - implement them
  - apply them on real pre-processed data
  - understand them mathematically
- learn how to evaluate our methods
- do some applied maths

Integrated lecture "Cognitive Algorithms"

Introductory course into Machine Learning
→ 'Machine Learning Light'
About how computer programs learn "cognitive skills" from data

For a more mathematical advanced, in-depth treatment go to:
→ M.Sc. module "Machine Learning 1" (9 ECTS)

For an advanced practical treatment go to:
→ M.Sc. module "Project Machine Learning" (9 ECTS)

Integrated lecture "Cognitive Algorithms"

Overall responsibility
Prof. Dr. Klaus-Robert Müller

Lecture + technical questions
Dr. Wojciech Samek (wojciech.samek@hhi.fraunhofer.de)

Practice sessions + assignments + administrative questions
Stephanie Brandl (stephanie.brandl@tu-berlin.de)

Correction of assignments
Hannah Marienwald
(hannah.marienwald@campus.tu-berlin.de)

- We will meet **every week** and alternate between lecture and practice session
- Tentative schedule:

20.	October	VL 1 **Introduction**
27.	October	Practice Session
03.	November	VL 2 **Neurons and Neural Networks**
10.	November	Practice Session
17.	November	VL 3 **Linear Classification**
24.	November	Practice Session
01.	December	VL 4 **Linear Regression**
08.	December	Practice Session
15.	December	VL 5 **Kernel Trick (Nonlinear methods)**
05.	January	Practice Session
12.	January	VL 6 **Neural Networks**
19.	January	Practice Session
26.	January	VL 7 **Unsupervised methods**
02.	February	Practice Session
09.	February	VL 8 **(Repetition)**
16.	February	???
23.	February	**Exam**

Programming Assignments Overview

After each lecture you will receive programming assignments:

- Implement algorithms from the lecture in Python
- Apply algorithms to some real world data

Tentative tasks:

- Automatic handwritten character recognition
- 'Mind-reading' from brain signals
- Prediction of hand-positions from muscle activity
- Topic detection in news texts

Submit programming assignments via ISIS (in groups of 2-4)

Prerequisites

- Knowledge in Linear Algebra: vector norm, scalar product, matrix operations, eigenvectors
- Knowledge in Calculus: derivatives (of functions that depend on more than one variable), partial derivatives
- Basic programming knowledge, programming in Python

Credits

B.Sc. module "Kognitive Algorithmen" (6 ECTS) consists of

- This lecture (3 ECTS), and
- An elective (3 ECTS):
  - Math course, *or*
  - Python course, *or*
  - Seminar "Applications of Cognitive Algorithms"
    1^{st} meeting: Thursday, 17.11.2016, 2pm, MAR 0.016

Written exam at the end of the semester
To take the exam, you'll need to have

- passed the elective
- 50 % points in the homework (from 6-7 assignments with 30 points)

Teaching overview

Winter term

- Lecture: "Machine Learning I"
- **Lecture: "Cognitive Algorithms"**
- Lab Course: "Machine Learning and Data Analysis"
- Seminar: "Classical Topics in Machine Learning"
- Seminar: "Neural Networks"
- **Seminar: "Applications of Cognitive Algorithms"**
- Seminar: "Machine Learning and Data Management"
- **Course: "Mathematische Grundlagen"**
- **Course: "Python Programming"**
- Project: "Project Machine Learning"

Literature

Two standard text books of Machine Learning, that you can find online, are:

Hastie T. et al. - The Elements of Statistical Learning

`http://statweb.stanford.edu/~tibs/ElemStatLearn/`

Bishop C. - Pattern Recognition and Machine Learning

`http://home.ustc.edu.cn/~hshl05/addition/Pattern_Recongnition_and_Machine_Learning-1.pdf`

`http://home.ustc.edu.cn/~hshl05/addition/Pattern_Recongnition_and_Machine_Learning-2.pdf`

A less mathematical treatment with practical examples in Python:

Marsland S. - Machine Learning, An algorithmic Perspective

`http://biblioteca.cio.mx/ebooks/e0209.pdf`

A book for practitioners from Hastie et al.:

James G. et al. - An Introduction to Statistical Learning

`http://www-bcf.usc.edu/~gareth/ISL/`

For each lecture, optional reading material can be found in ISIS.

What is Cognition?

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

  e.g. attention, memory, learning, problem solving, decision making, language ...
- Cognitive processes can be

  natural or artificial, conscious or unconscious
- Cognition is studied by

  linguistics, neuroscience, philosophy, psychology
  AND computer science (artificial intelligence, machine learning)

Here we focus on the **machine learning** view on cognition

Artificial Intelligence and Machine Learning

Artificial Intelligence (AI)

= *"the science and engineering of making intelligent machines"* [McCarthy et al., 1955]

Machine Learning (ML)

= a branch of AI that uses statistical techniques to learn from data

- *Prediction*

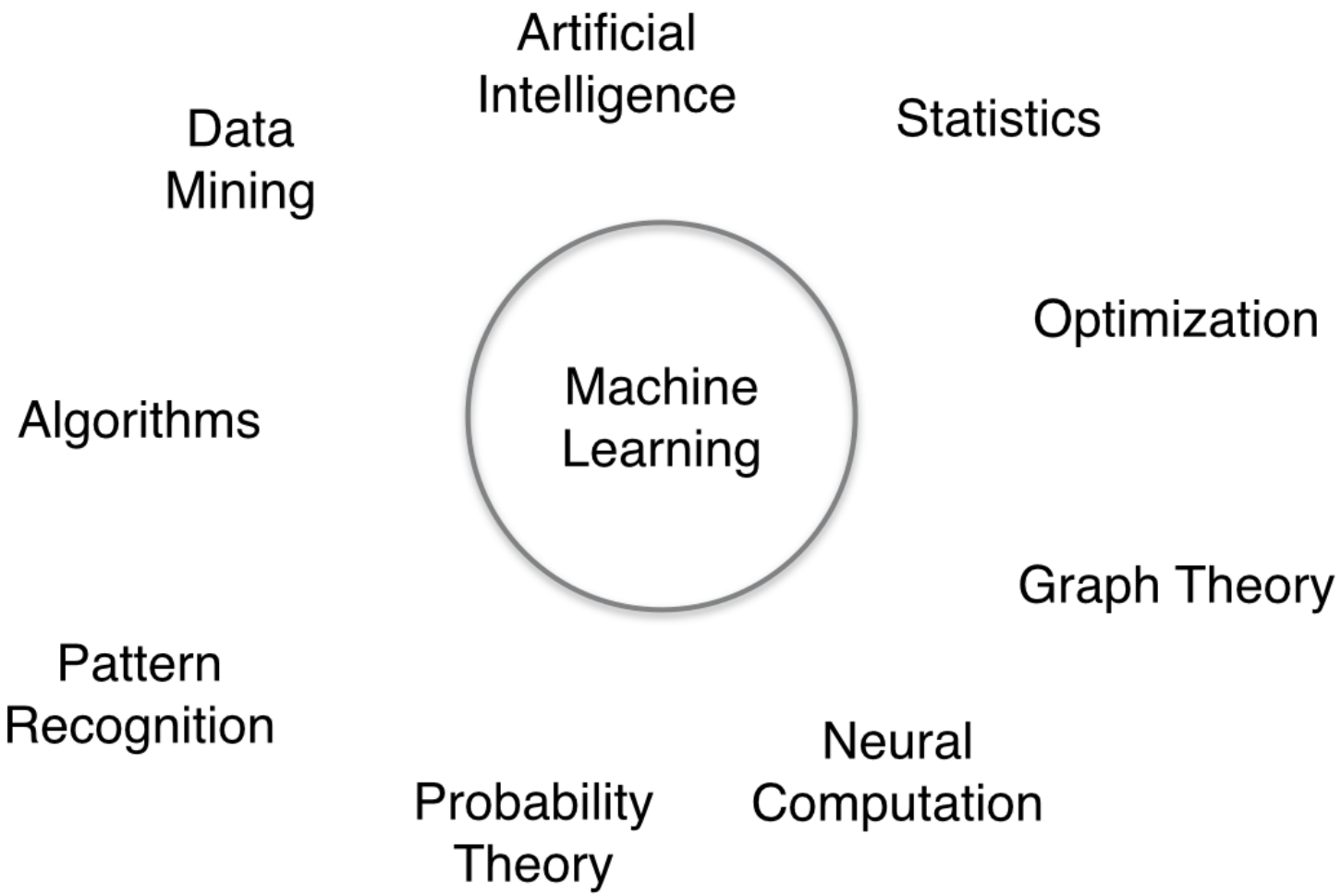
  Examples: Spam detection, document classification, "mind reading"
- *Visualization/Interpretation*

  Unsupervised learning finds simple structures in complex data

  Exampels: De-noising [Mika et al., 1999], topic detection
- *Compression*

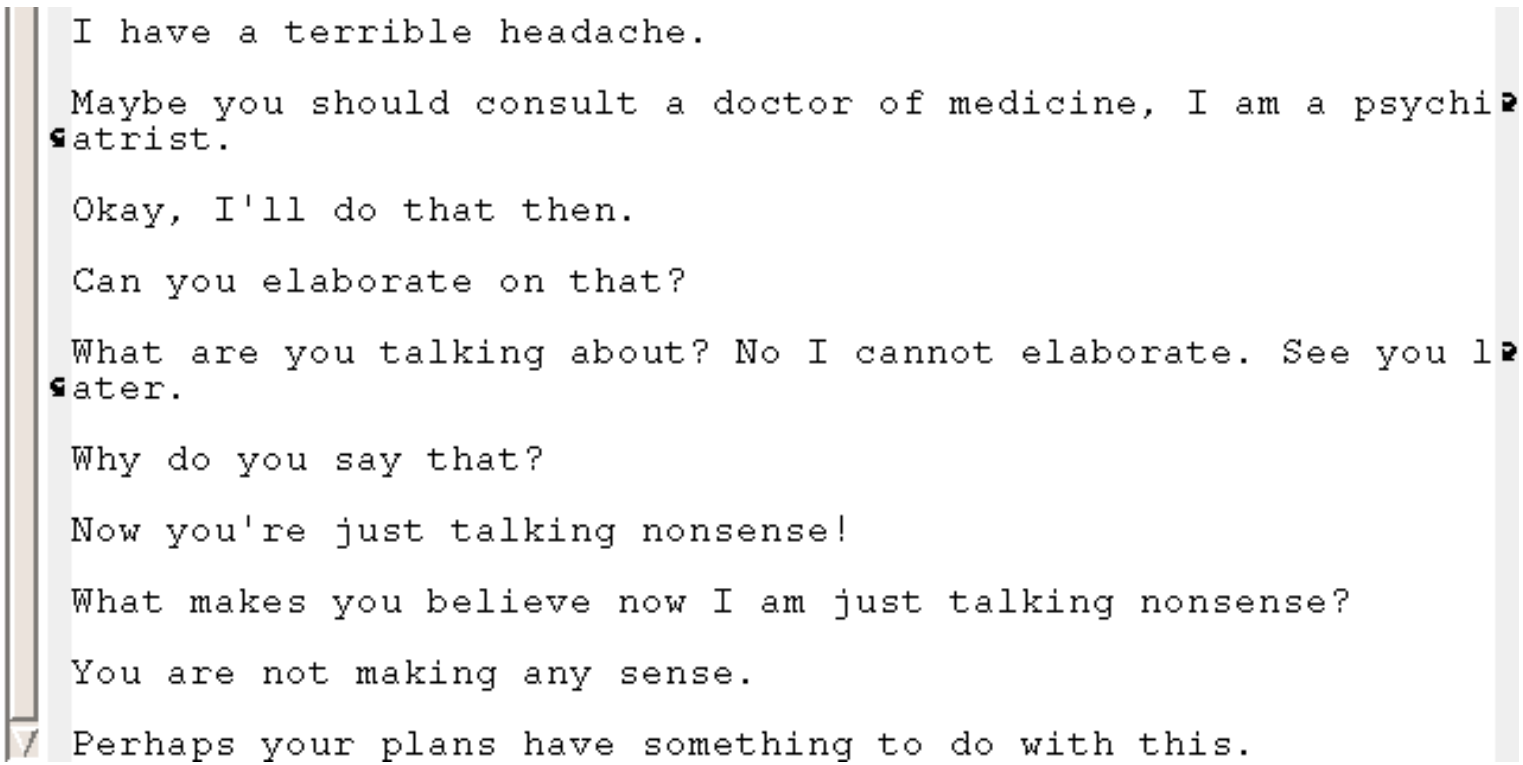
  If we know the *relevant* structure in a data set, we can keep that part (and discard the noise) [Cover and Thomas, 2006; Hansen and Yu, 2001]
- ...

Machine learning

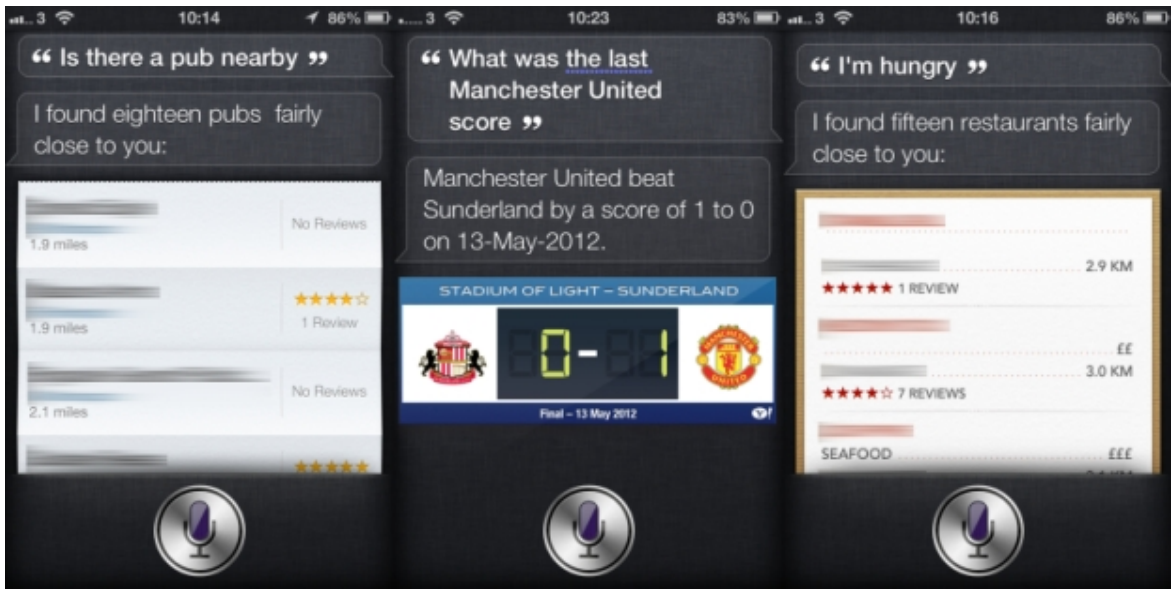


From machines to machine learning

Cybernetics – the art of controlling [Wiener, 1948]
Turing Test [Turing, 1950]: *Can machines think?*
Perceptron [Rosenblatt, 1958]: *Artificial 'brains'*
Eliza [Weizenbaum, 1966]: *Better than psychotherapy!*



ELIZA's legacy



From machines to machine learning

1960s **Widespread optimism**
"machines will be capable, within twenty years, of doing any work a man can do" [Simon, 1965]

1973 **AI winter**
"In no part of the field have discoveries made so far produced the major impact that was then promised" [Lighthill, 1973]

→ Classical AI was mainly built on hand made rules
Problem: No scalability, no unified theory of cognition

→ **New AI**:
Focus more on specific subproblems
1997 - Deep Blue beats chess world champion Garry Kasparov
Let machines learn rules from data [Russell and Norvig, 2010]

Artificial Intelligence today

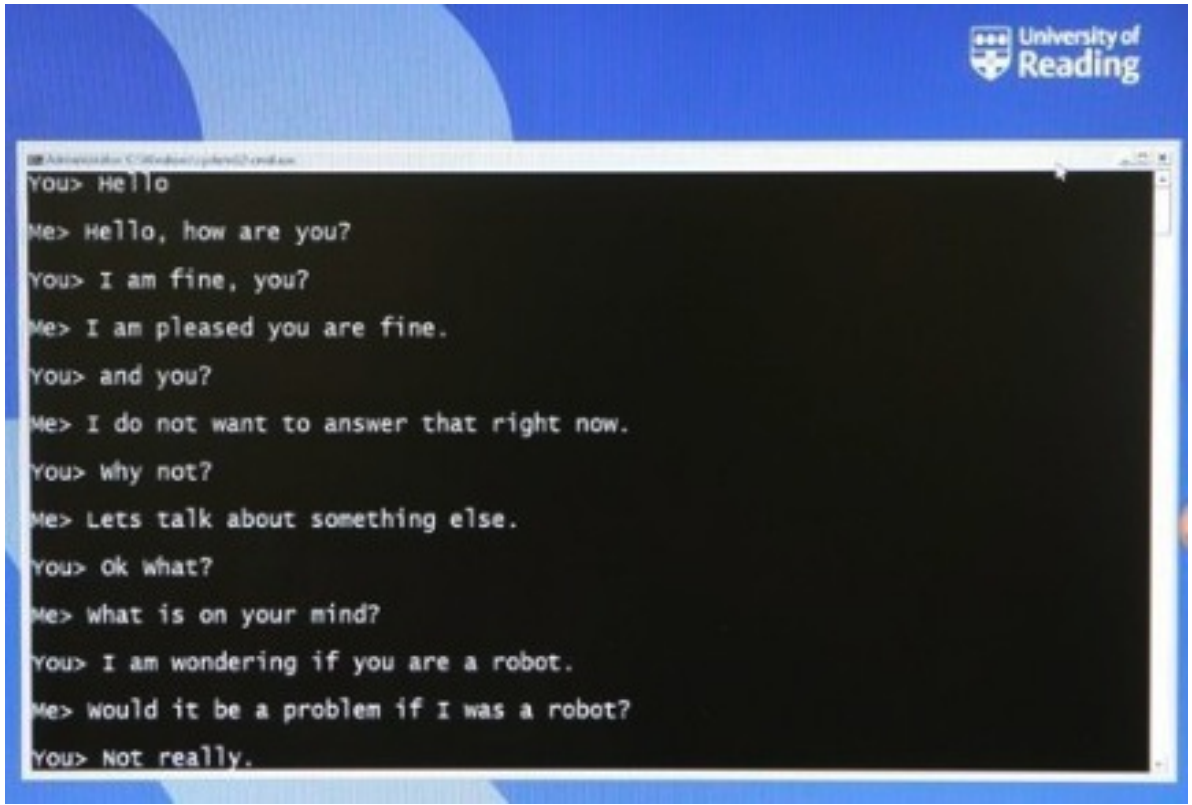
Artificial Intelligence today

Artificial Intelligence today

Turing-test:

Scientists dispute whether computer 'Eugene Goostman' passed Turing test

The program fooled 10 out of 30 judges at the Royal Society in London that it was human, but not all are convinced



Artificial Intelligence today

MIT Technology Review

A View from **Emerging Technology from the arXiv**

Best of 2015: Deep Learning Machine Beats Humans in IQ Test

Artificial Intelligence today

Forbes / Tech

The Little Black Book of Billionaire Secrets

FEB 19, 2015 @ 01:06 PM 10,049 VIEWS

Microsoft's Deep Learning Project Outperforms Humans In Image Recognition

IMAGENET

14.2 Million images, 22.000 classes

Artificial Intelligence today

Artificial Intelligence today

What is easier chess or soccer ?

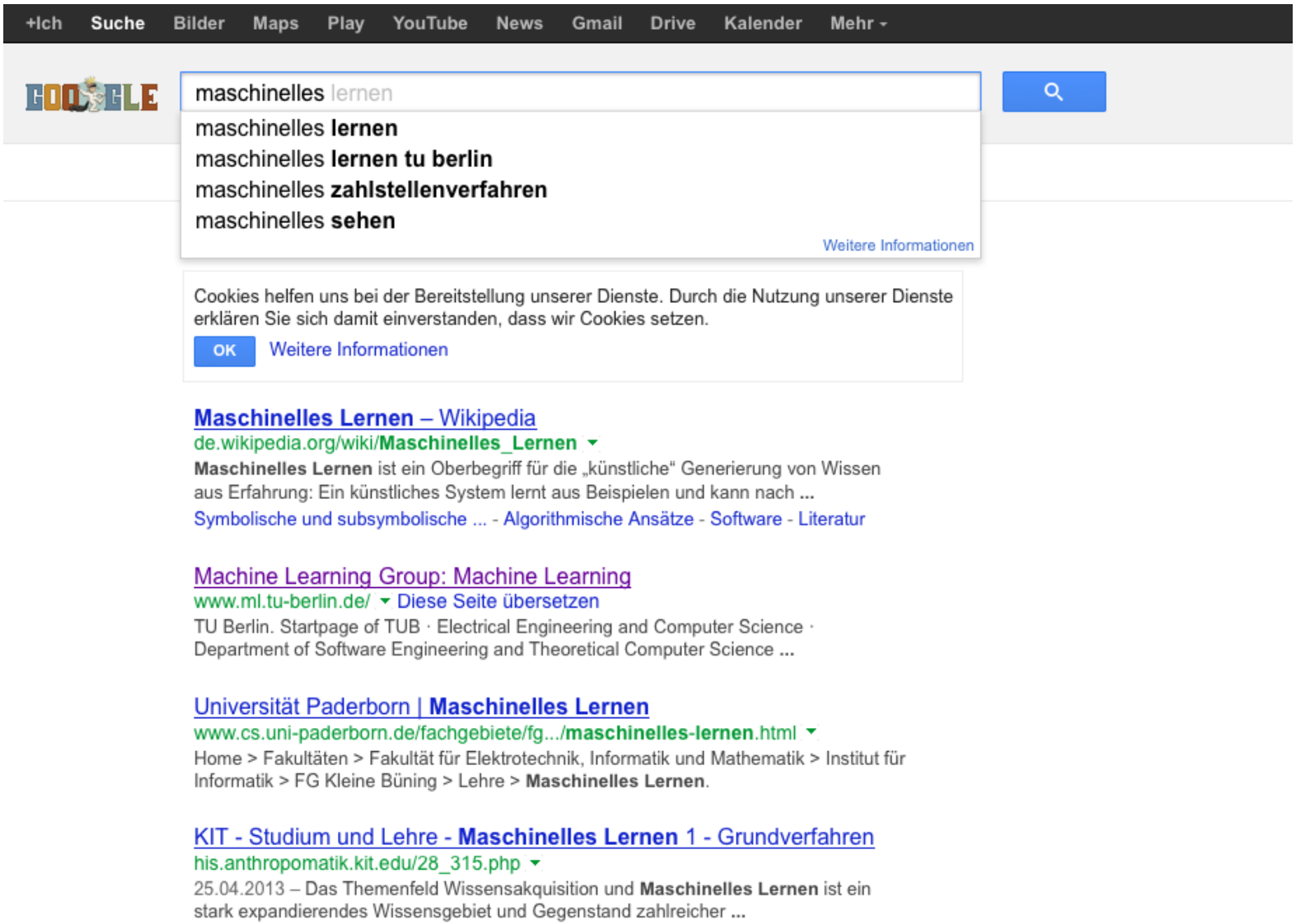
Fundamental differences exist between chess and soccer

- Environment
- State change
- Information accessibility
- Sensor readings
- Control

– > many problems appear easy for humans but are extremely difficult for a machine.

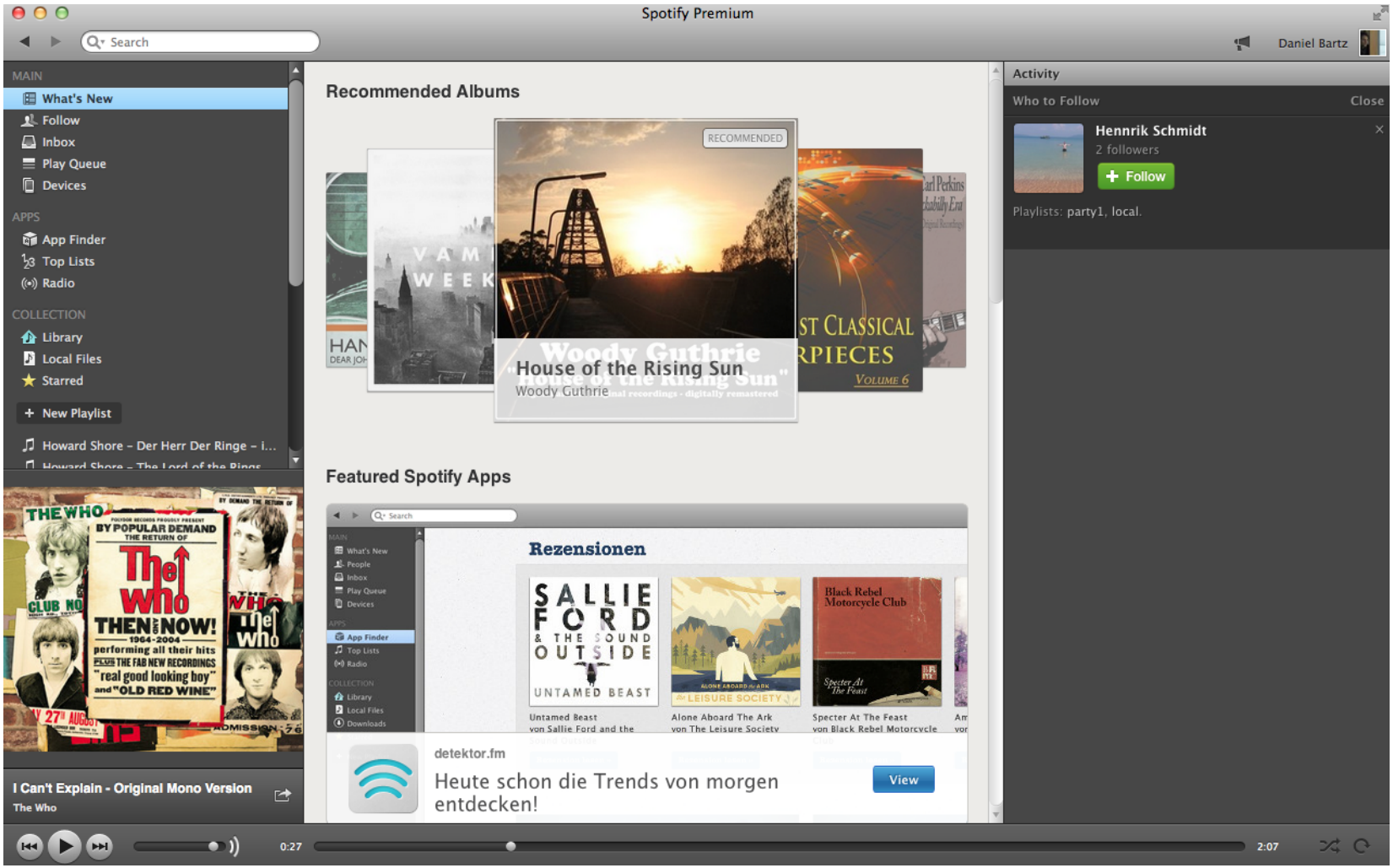
Machine learning today

Google:



Machine learning today

Spotify:



Machine learning today

Android:

Machine learning today

Amazon:

Mein Amazon.de › **Unsere Empfehlungen für Sie**
(Wenn Sie nicht Daniel Bartz sind, klicken Sie bitte hier.)

Nur für heute
In Empfehlungen stöbern

Empfehlungen
Apps für Android
Auto
Bücher
Baby
Baumarkt
Bekleidung
Beleuchtung
Computer & Zubehör
Drogerie & Körperpflege
Elektro-Großgeräte
Elektronik & Foto
Filme & TV
Games
Garten
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Musik
Musikinstrumente
Parfümerie & Kosmetik
Schmuck
Schuhe & Handtaschen
Software
Spielzeug
Sport & Freizeit
Uhren
VHS
Zeitschriften

Diese Empfehlungen basieren auf den von Ihnen gekauften Artikeln und weiteren Informationen.

Anzeigen: Alle | **Neuerscheinungen** | In Kürze

1. 
Praktische Anwendung von Nervendruck- und Schlagtechniken
von Mario Masberg (16. Mai 2013)
Erhältlich bei **diesen Anbietern**.
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2. 

Faszientraining: Physiologische Grundlagen, Trainingsprinzipien, Anwendung im Team- und Ausdauersport sowie Einsatz in Prävention und Rehabilitation
von Frank Thömmes (14. Mai 2013)
Durchschnittliche Kundenbewertung: ★★★★★ (5)
Auf Lager.
Preis: EUR 16,90
59 Angebote ab EUR 15,99
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3. 

Software Engineering: Grundlagen, Menschen, Prozesse, Techniken
von Jochen Ludewig (30. April 2013)
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Preis: EUR 42,90
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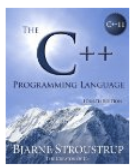
4. 

The C++ Programming Language
von Bjarne Stroustrup (28. Mai 2013)
Auf Lager.
Preis: EUR 48,95
16 Angebote ab EUR 36,10
In den Einkaufswagen | Auf meinen Wunschzettel

Machine learning today

HERAUSGEGEBEN VON WERNER D'INKA, BERTHOLD KOHLER, GÜNTHER NONNENMACHER, FRANK SCHIRRMACHER, HOLGER STELTZNER

Frankfurter Allgemeine
Wirtschaft

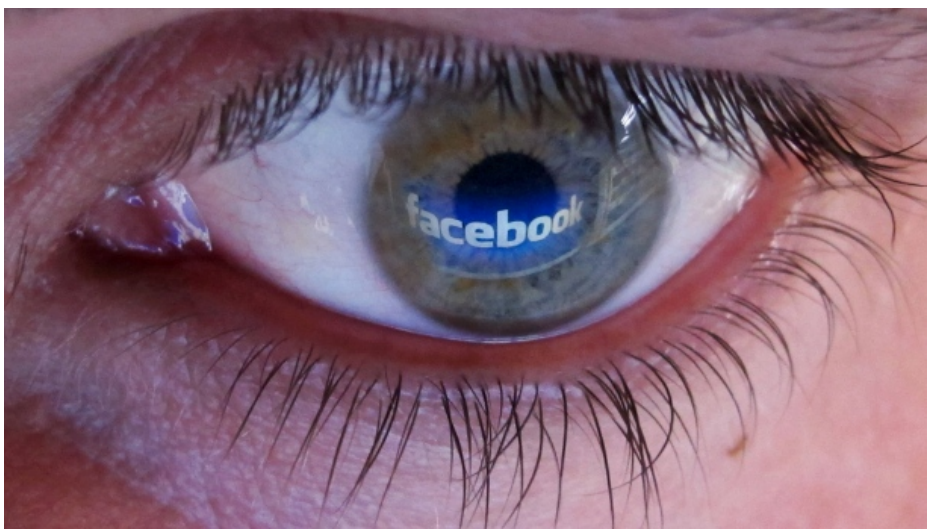
Umstrittene Funktion

Facebook stoppt Gesichtserkennung

21.09.2012 · Das soziale Netzwerk schaltet in der Europäischen Union die „Markierungsvorschläge für Fotos“ ab. Auch deshalb attestiert der zuständige irische Datenschutzbeauftragte Facebook Fortschritte.

Von MARTIN GROPP

Artikel



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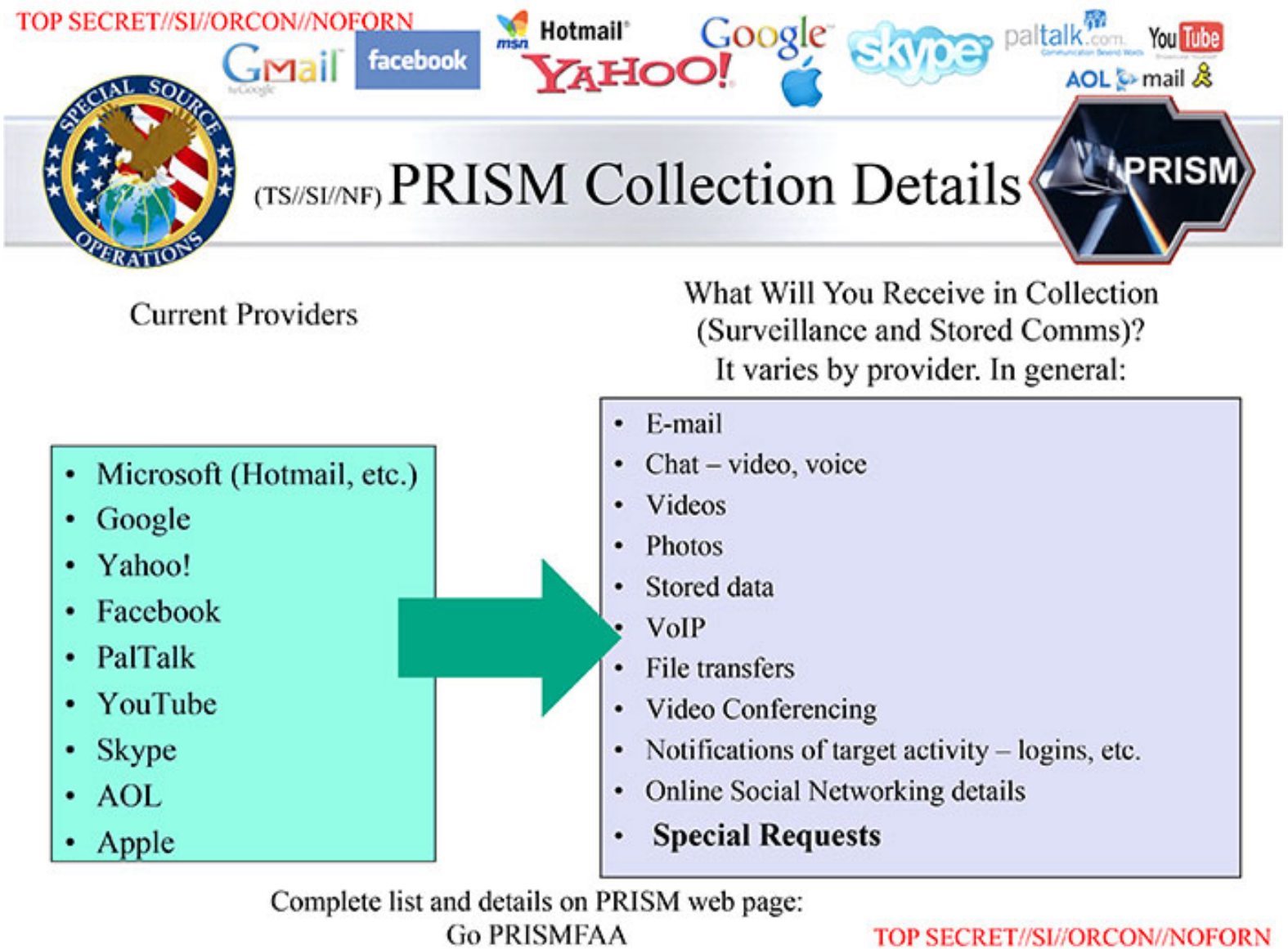
ie sollte Facebook-Nutzern das Leben erleichtern, doch erschwerte sie lange

Machine learning today

PRISM:



Machine learning today

Harvard Business Review

Data Scientist: The Sexiest Job of the 21st Century

by Thomas H. Davenport and D.J. Patil

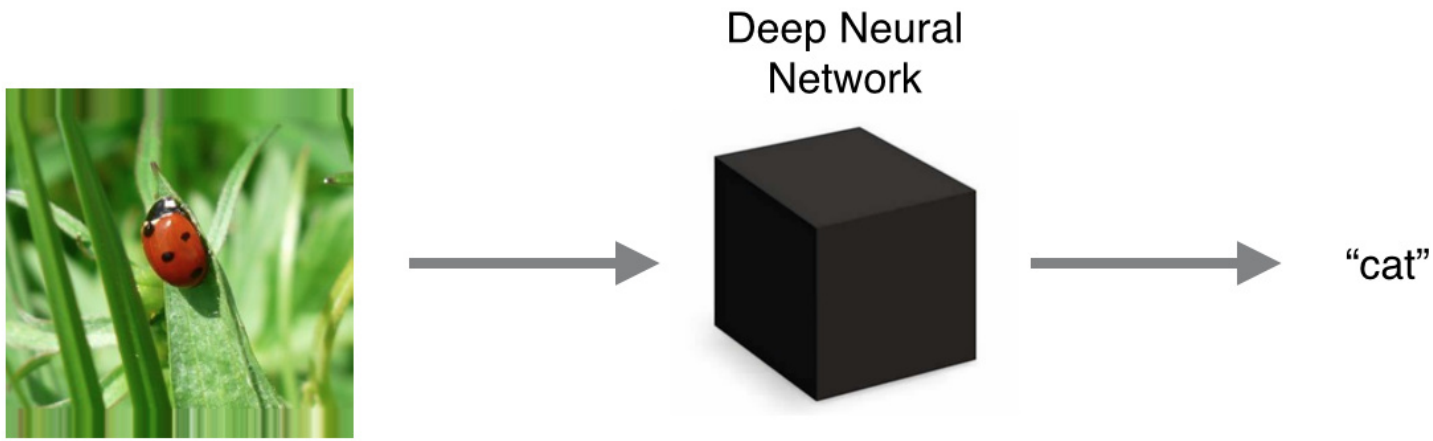
FROM THE OCTOBER 2012 ISSUE

Reasons for Progress

Reasons for Progress

Reasons for Progress

So are we done ?



Can we trust the DNN ?

What's wrong ?

So are we done ?

In the 1980s, the Pentagon trained a NN to identify tanks in the forest.

100 photos of tanks hiding behind trees
100 photos of trees with no tanks.

The NN performed very well, but did it really do the *right* thing (i.e., detect tanks) ?

They tested it on another data set.
-> The results were completely random

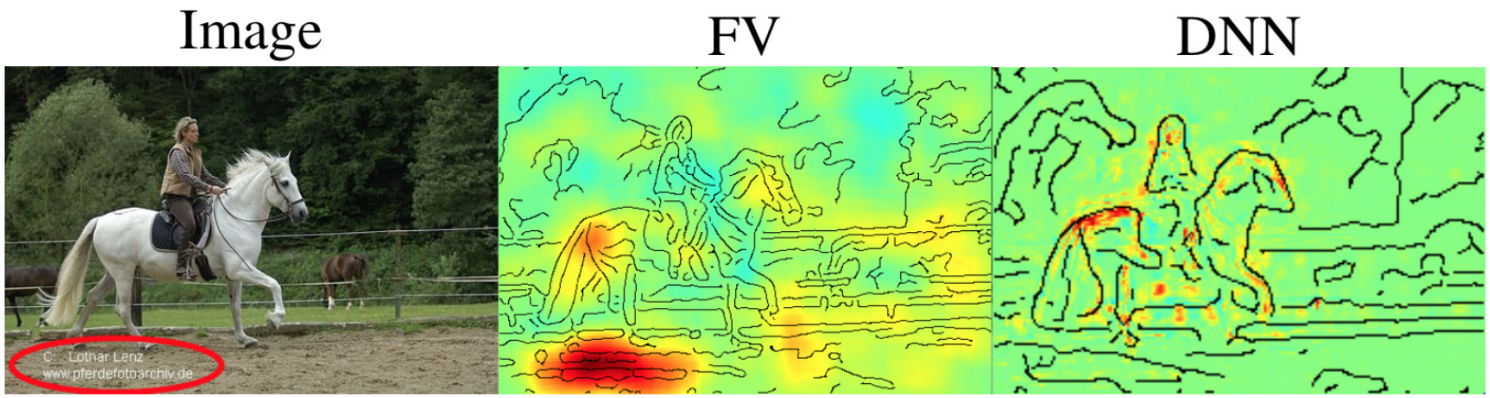
What was the problem ?

(Source: https://neil.fraser.name/writing/tank/)

So are we done ?

Test error for various classes:

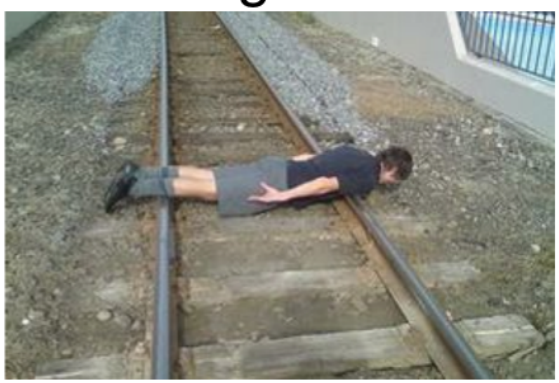
	aeroplane	bicycle	bird	boat	bottle	bus	car
Fisher	79.08%	66.44%	45.90%	70.88%	27.64%	69.67%	80.96%
DeepNet	88.08%	79.69%	80.77%	77.20%	35.48%	72.71%	86.30%
	cat	**chair**	**cow**	**diningtable**	**dog**	**horse**	**motorbike**
Fisher	59.92%	51.92%	47.60%	58.06%	42.28%	80.45%	69.34%
DeepNet	81.10%	51.04%	61.10%	64.62%	76.17%	81.60%	79.33%
	person	**pottedplant**	**sheep**	**sofa**	**train**	**tvmonitor**	**mAP**
Fisher	85.10%	28.62%	49.58%	49.31%	82.71%	54.33%	59.99%
DeepNet	92.43%	49.99%	74.04%	49.48%	87.07%	67.08%	72.12%



So are we done ?

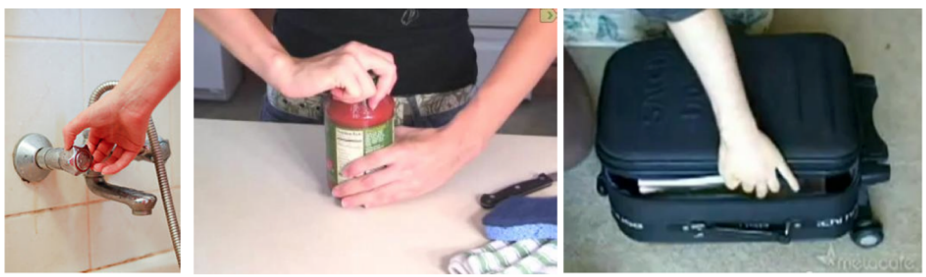
How to recognize this as unusual?


How to recognize this as dangerous?

So are we done ?

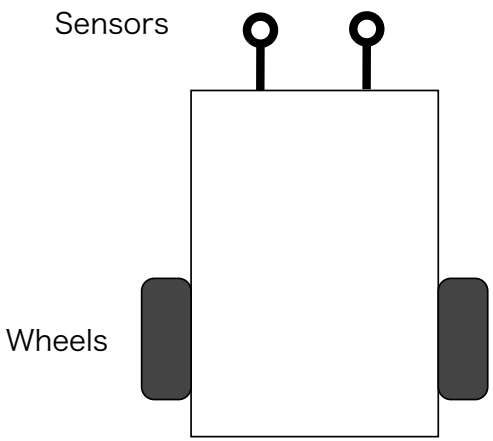
Examples of an action “Open”



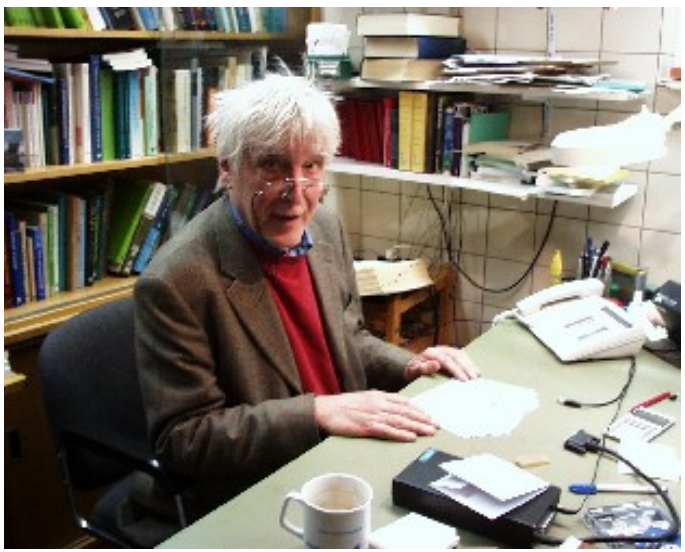
Cybernetics: First Approaches to Cognitive Algorithms

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

→ Cybernetics – *"scientific study of control and communication in the animal and the machine."* [Wiener, 1948]

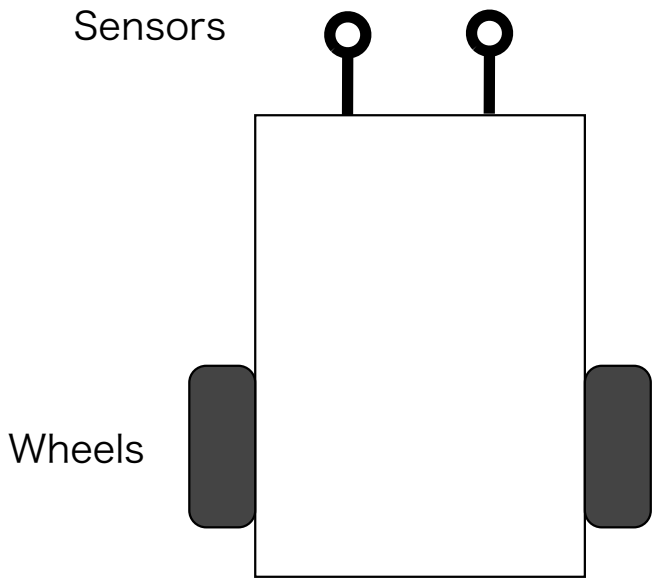


Braitenberg Vehicles



Valentino Braitenberg (1926-2011)

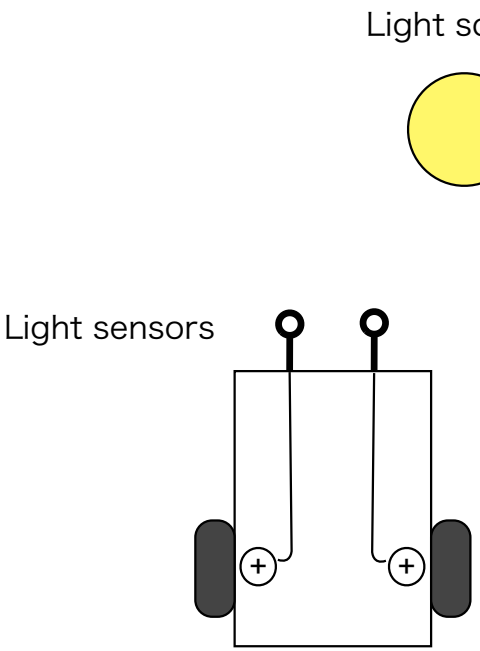
Braitenberg Vehicles
Artificial organisms with 'emotions'



Artificial organisms with very simple hardware can exhibit complex behavior.

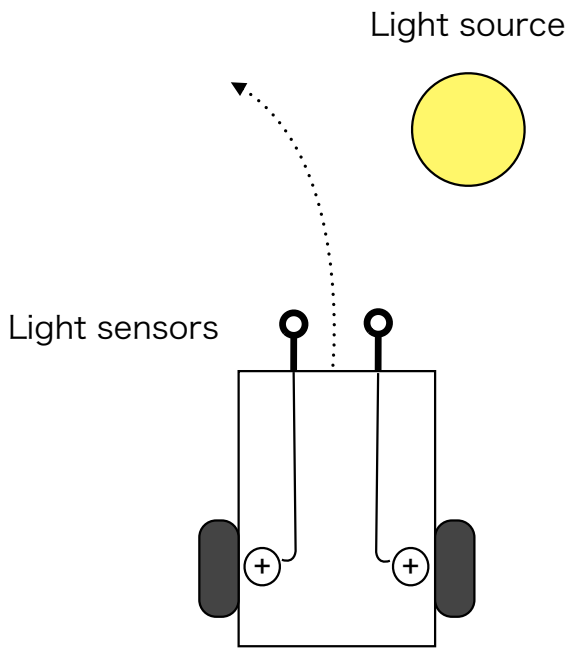
Behaviour of Braitenberg Vehicles can be interpreted as different 'characters' [Braitenberg, 1984].

Braitenberg Vehicles



In which direction will
the Braitenberg Vehicle go?

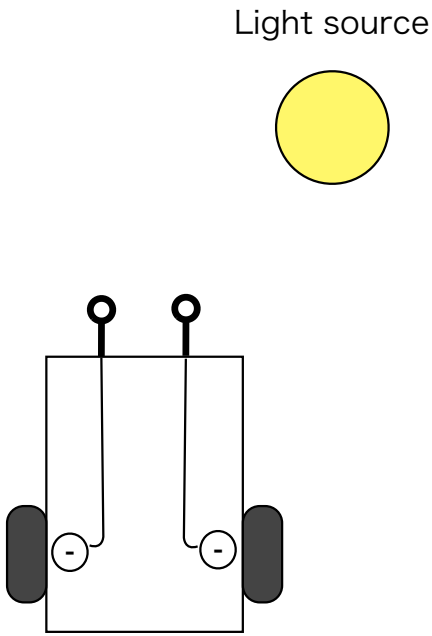
Braitenberg Vehicles: Fear



The vehicle drives away from light.

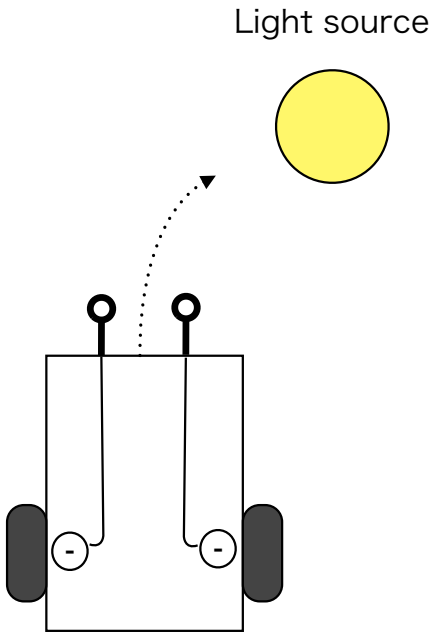
It is 'afraid' of light.

Braitenberg Vehicles



In which direction will
the Braitenberg Vehicle go?

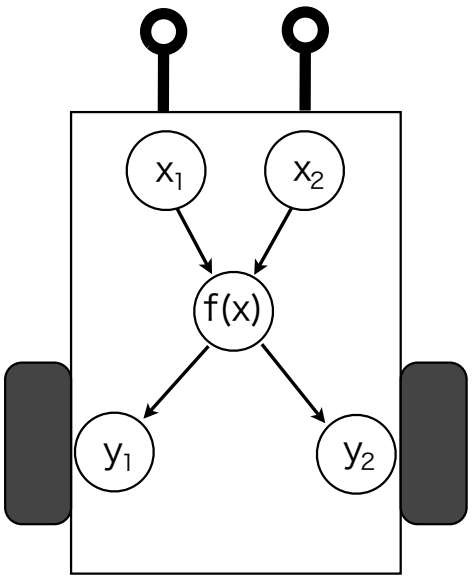
Braitenberg Vehicles: Love



The vehicle drives
towards light sources
and stops in front of them.

It 'loves' the light.

Braitenberg Vehicles
A Machine Learning View



The 'character' of a Braitenberg Vehicle is a function $f(.)$ that maps the inputs $x \in \mathbb{R}^2$ to some motor output $y \in \mathbb{R}^2$

A simple example for $f(.)$ is a linear mapping A:

$$y = Ax.$$

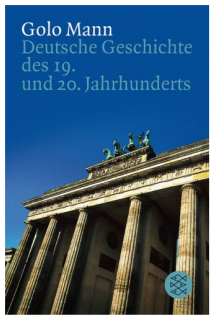
$$A_{Fear} = \begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix}$$

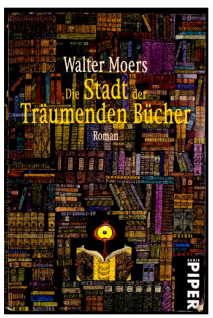
Strong AI vs. Machine Learning

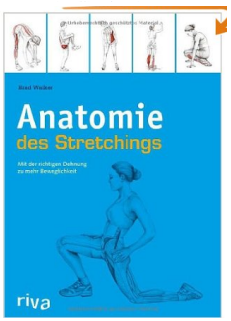
- Strong AI = "Machine intelligence with the full range of human intelligence" [Kurzweil 2005]
  Video - "The rise of Artificial Intelligence"
- ML - focus on specific problems
  e.g. image classification, hand written digit classification, sales prediction, spam detection, fraud detection, ...
- In this course: focus on key ideas/methods that are applied in different subproblems

Learning from experience

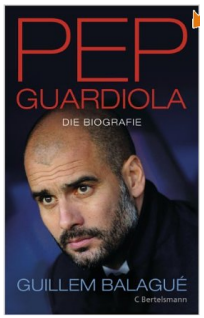
Daniel likes



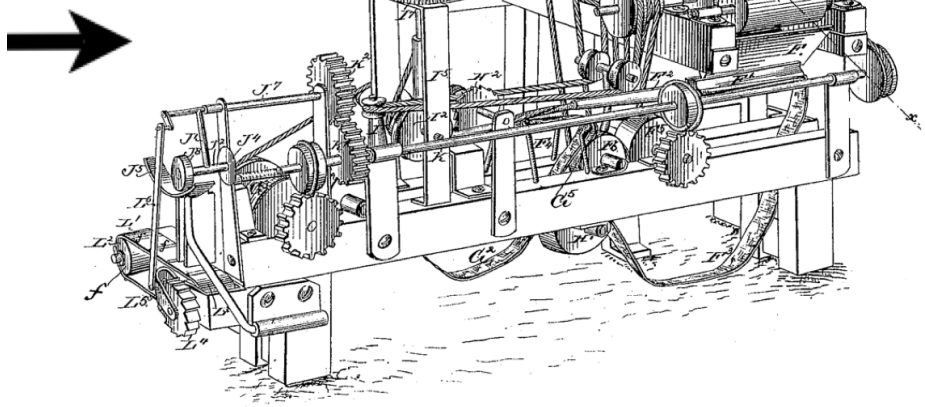




Daniel dislikes

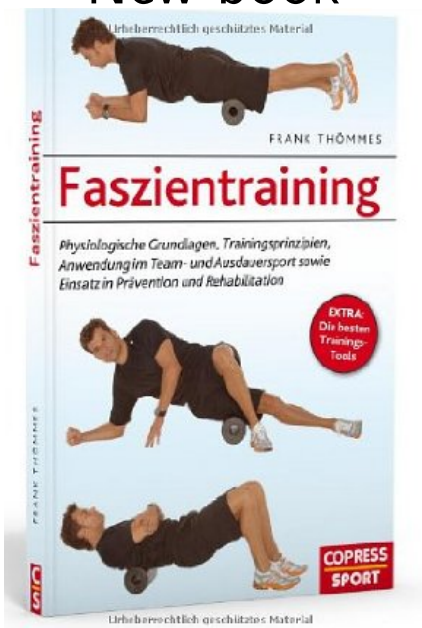


The learning machine

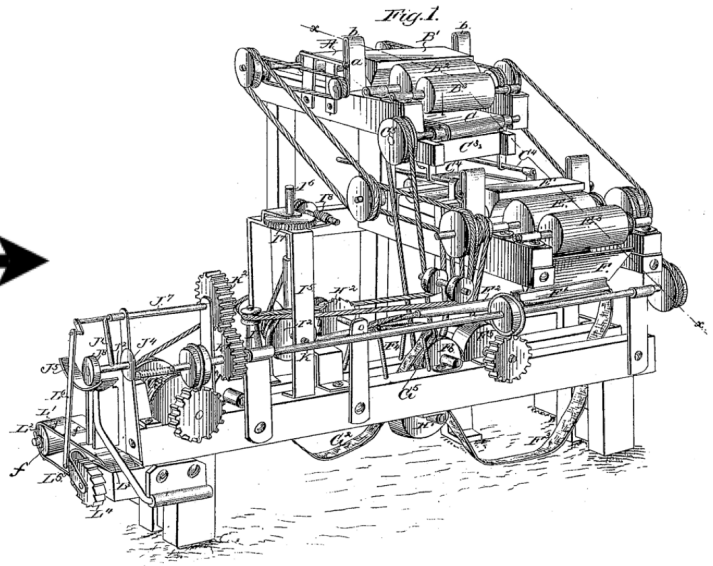


Prediction for a new object

New book



Does Daniel like it?



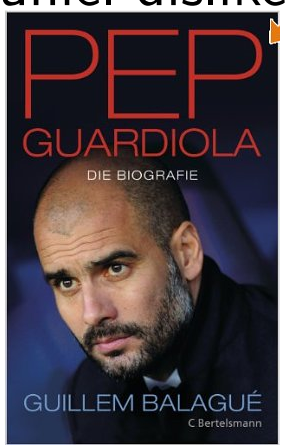
Prediction

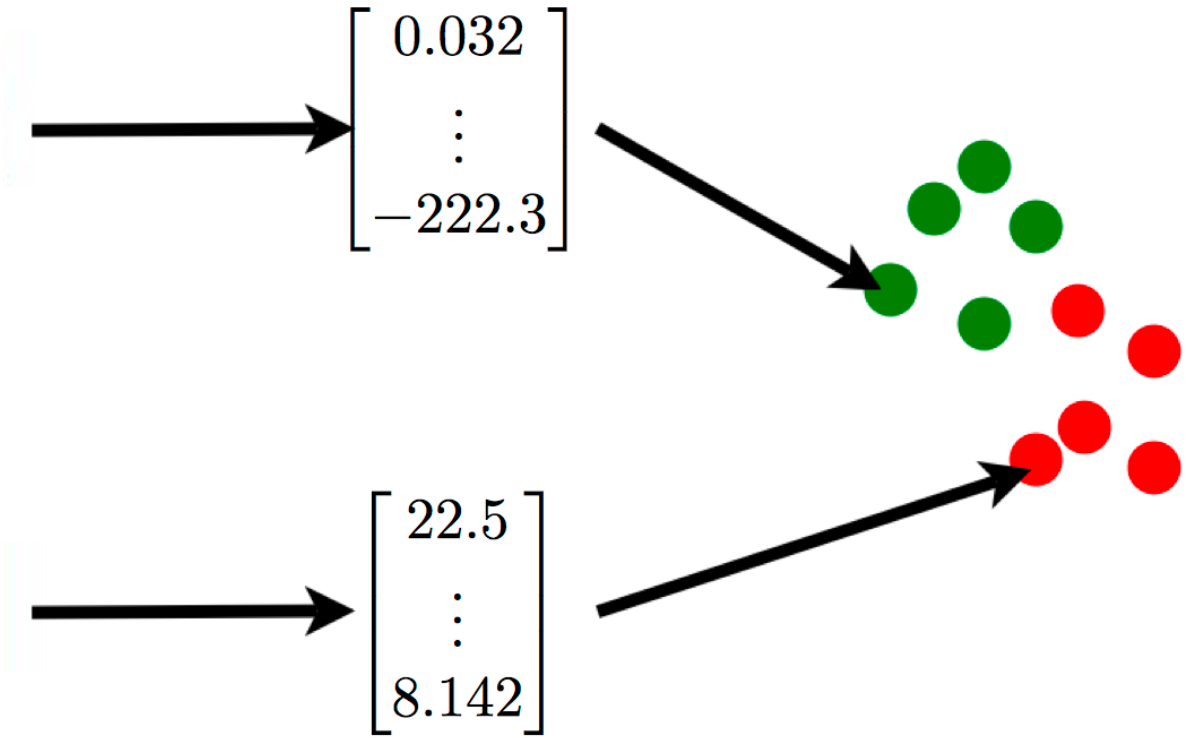
73%

Feature extraction

Daniel likes:

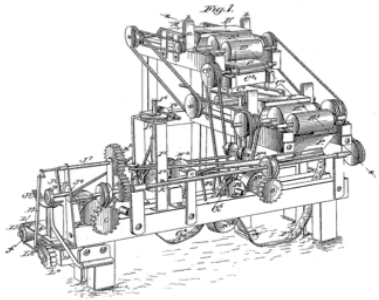
Daniel dislikes:





Every book is a vector in feature space

Discriminant function



$f_\theta(x) > 0$

$f_\theta(x) < 0$

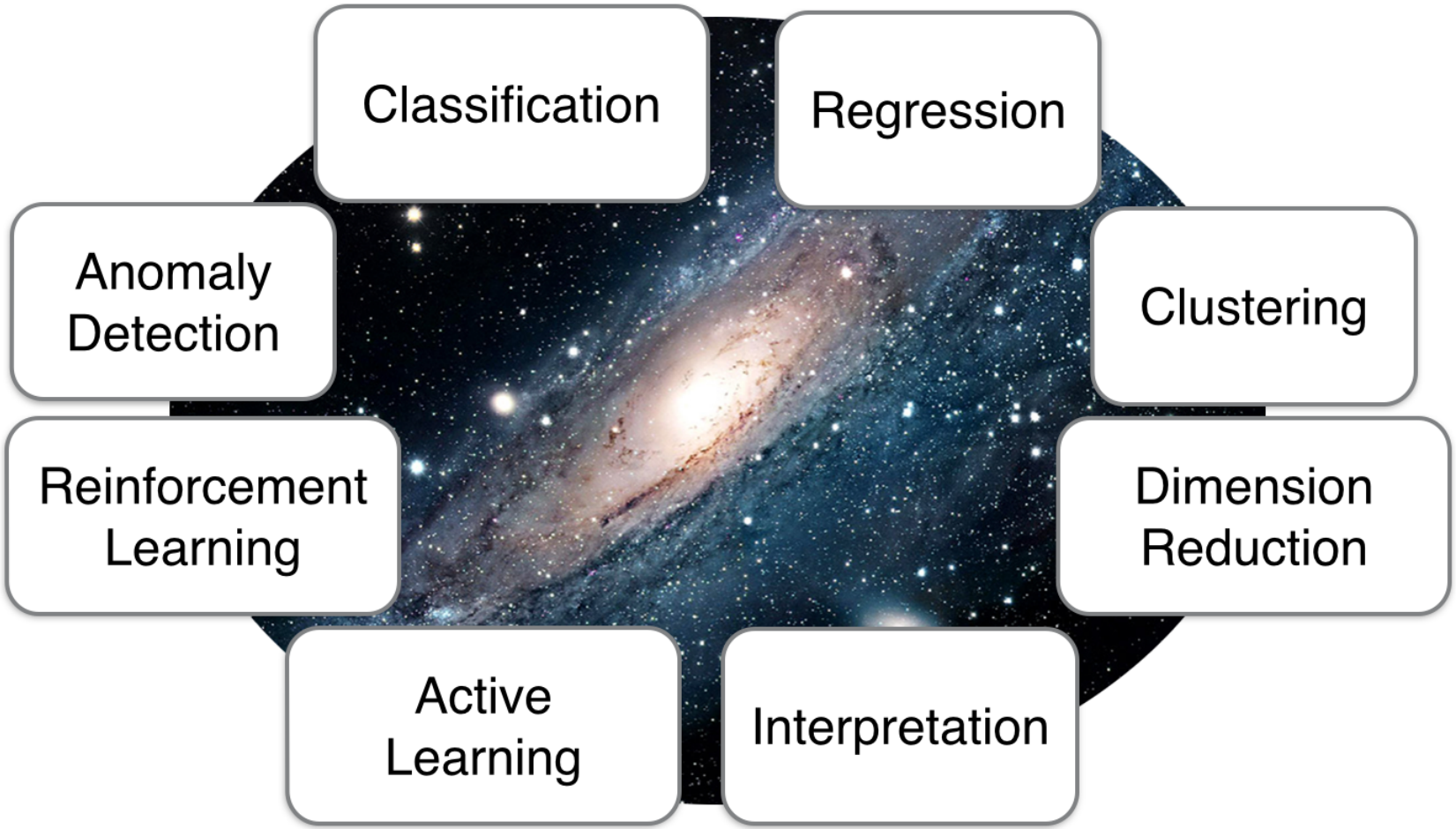
$f_\theta(x) = 0$

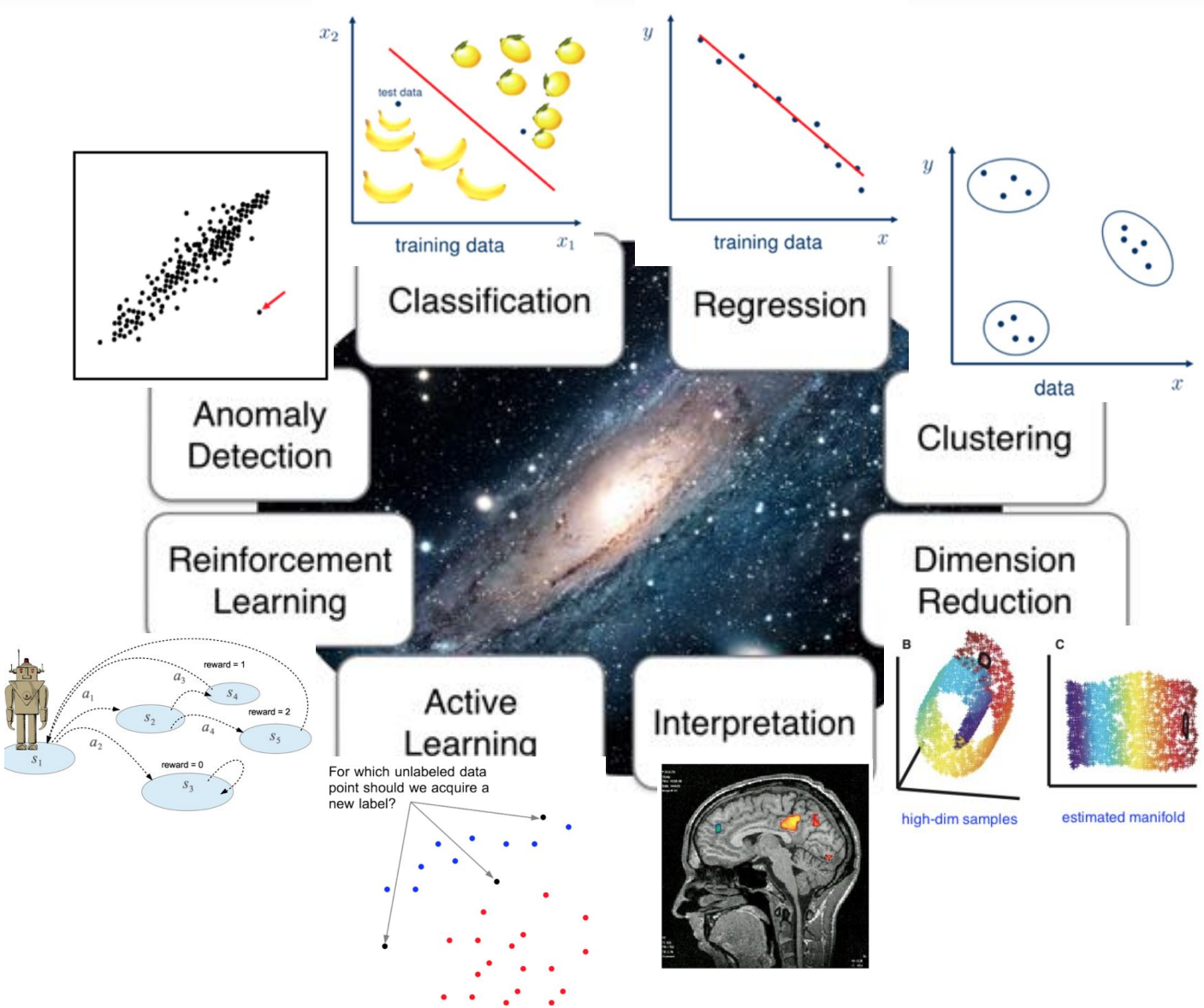
The learning machine learns the best possible discriminant function between the classes.

Types of Machine Learning problems

- **Supervised learning**: Given labeled training examples, learn a mapping from inputs (features) to output (label)
- **Unsupervised learning**: Find structure in data
  e.g. group similar objects together
- **Reinforcement Learning**: learn actions in an environment which maximize some notion of reward
  e.g. robots learning behaviour

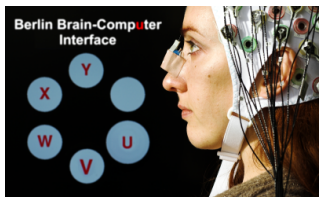
The Machine Learning Universe



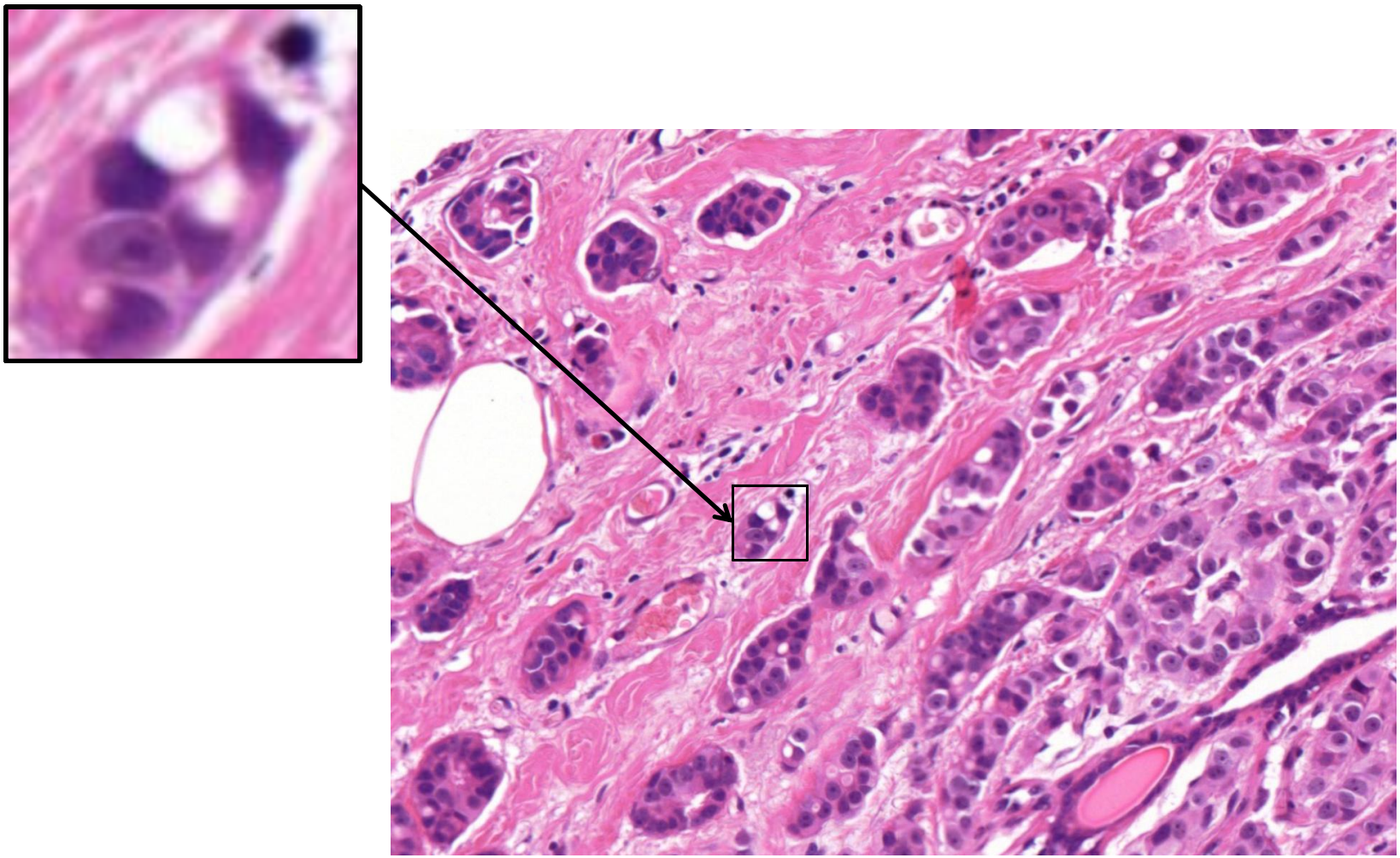

test data
training data
training data
data
Classification
Regression
Clustering
Anomaly Detection
Reinforcement Learning
Dimension Reduction
Active Learning
Interpretation
reward = 1
reward = 2
reward = 0
For which unlabeled data point should we acquire a new label?
high-dim samples
estimated manifold

Projects

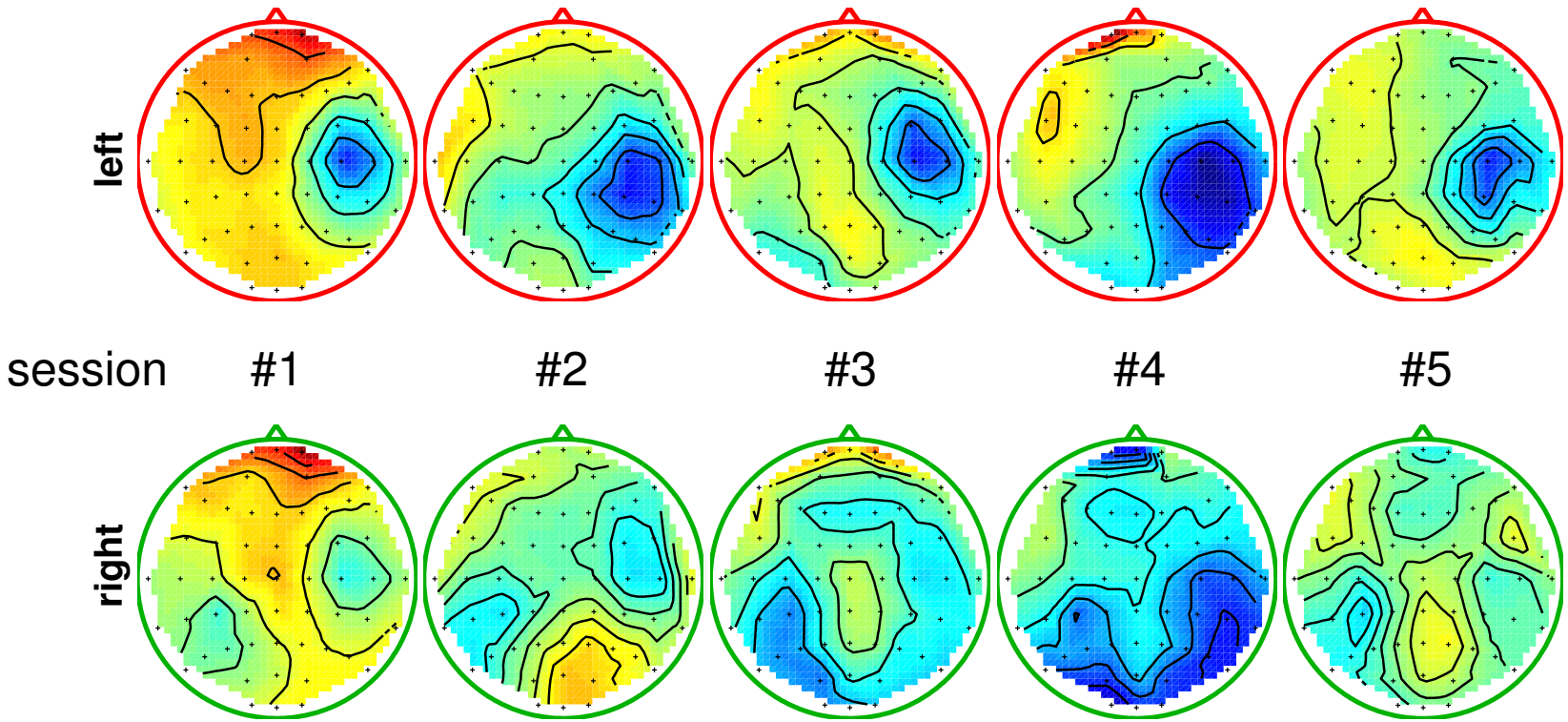
- EEG-based Brain Computer Interfaces
- Network security
- Big Data
- Image analysis
- Quantum chemistry: Prediction of atomic properties
- Optimization of windmills
- Theoretical work



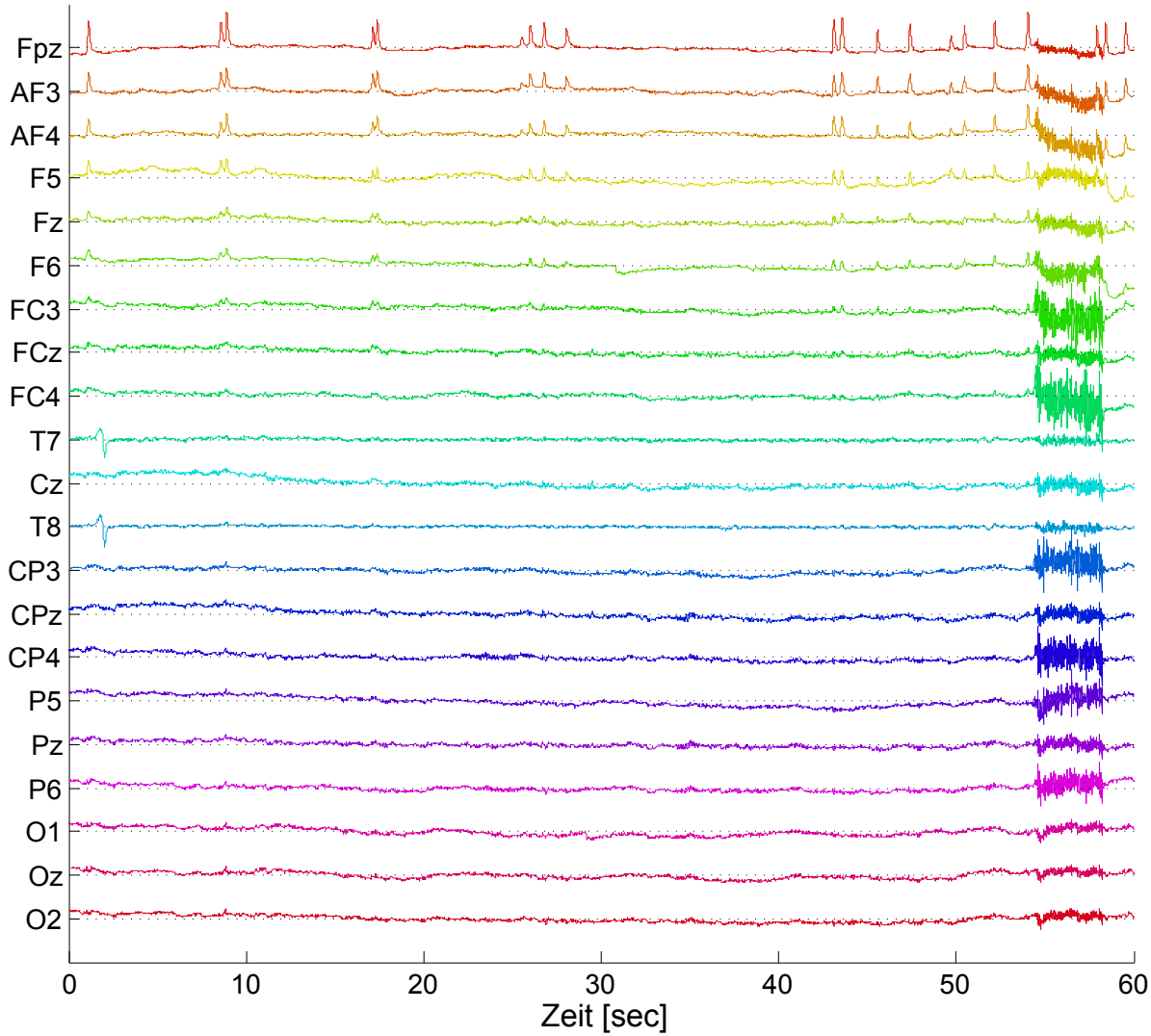
Example 1: Predict cancer stadium from medical images



Example 2: Alleviate non-stationarities for Brain-Computer-Interfaces

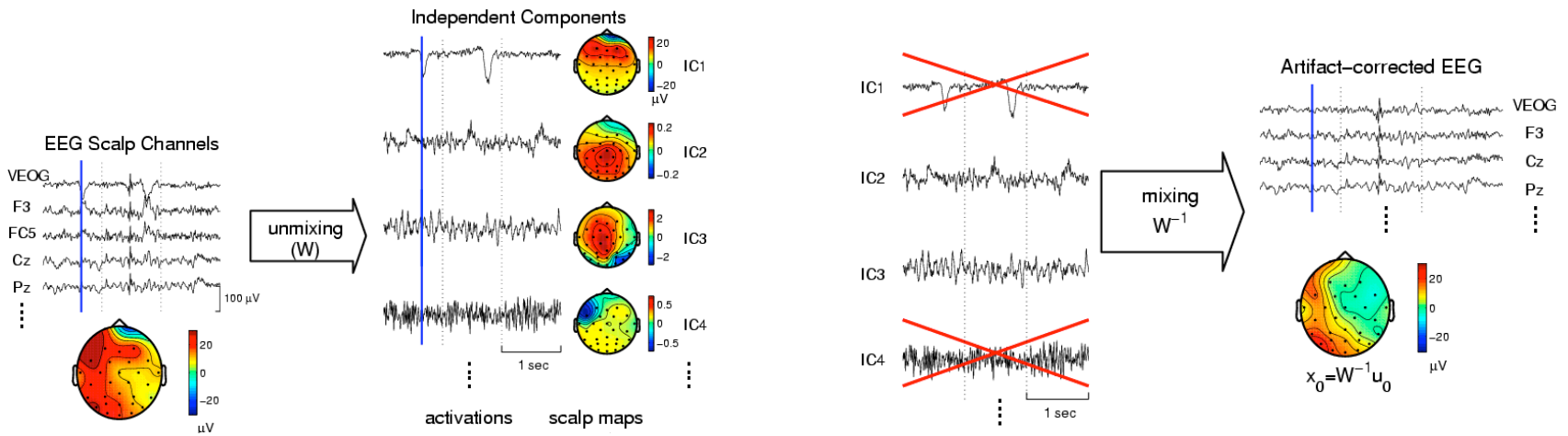


Example 3: Remove artifacts from EEG



Example 3: Remove artifacts from EEG

Procedure: Decompose the EEG into statistically independent sources using Independent Component Analysis (ICA)



Example 3: Remove artifacts from EEG

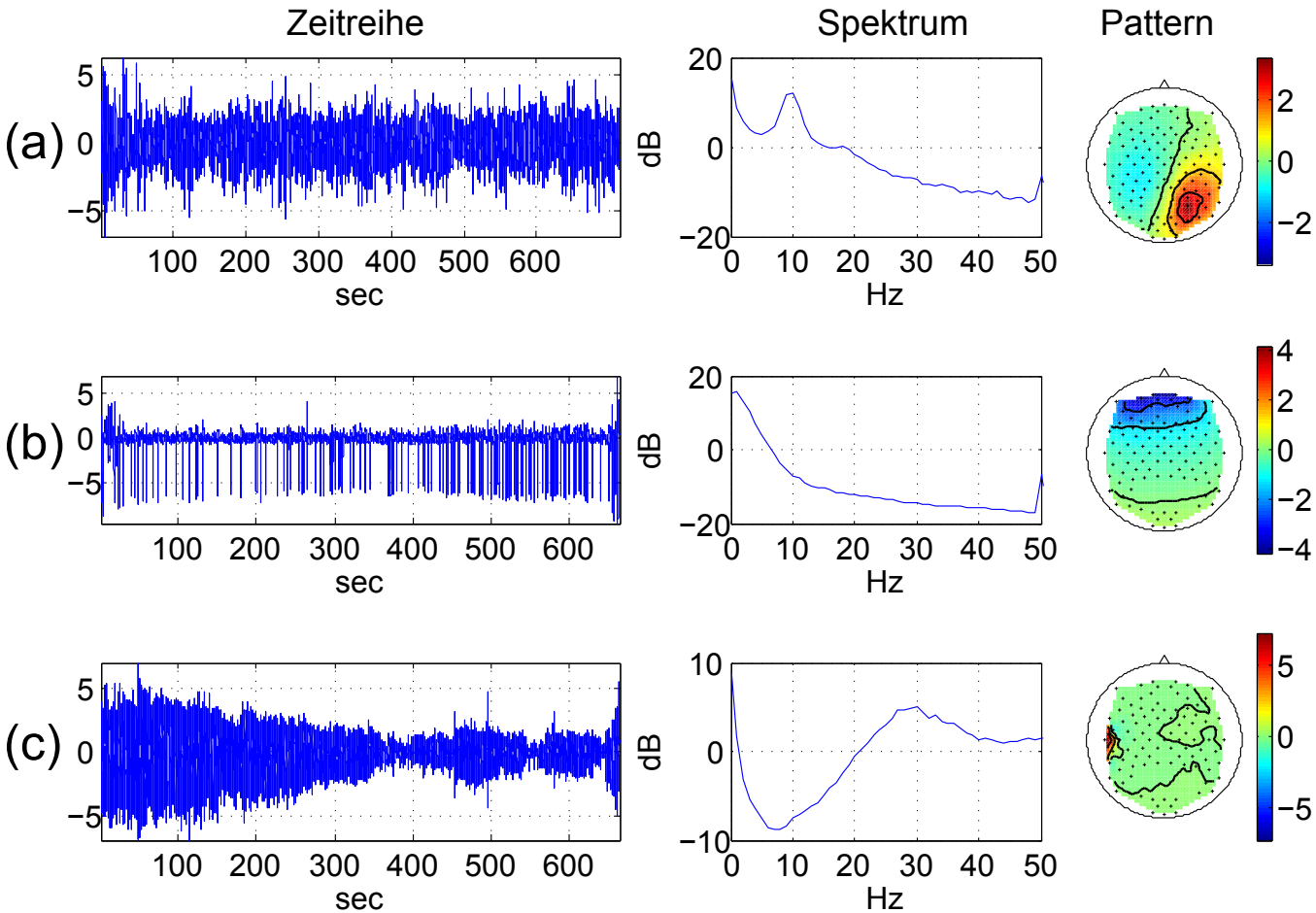
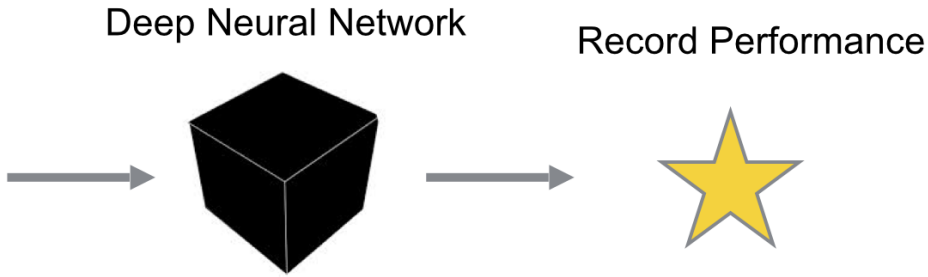


Figure: (a) Neuronal acitivity. (b) Eye artifact. (c) Muscle artifact.

Example 4: Understanding Deep Neural Networks

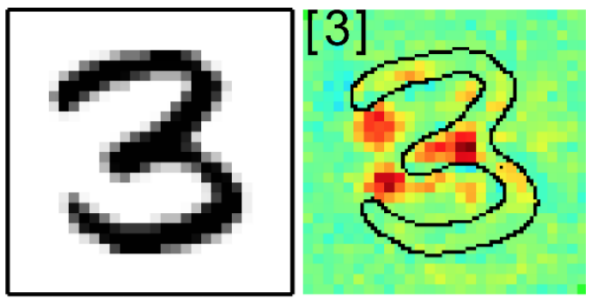
14.2 Million images, 22.000 classes



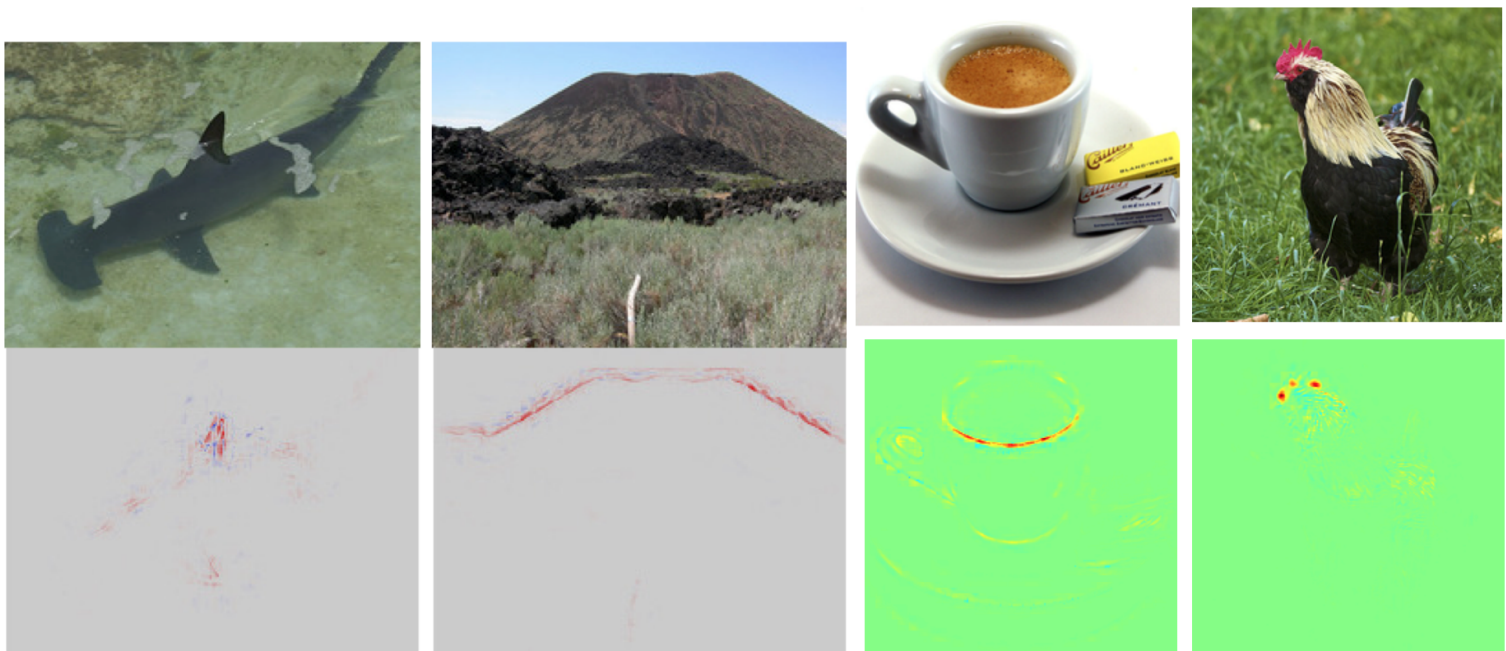
BUT why ?

What makes the DNN "think" that an image belongs to a certain category ?

Why is a 3 classified as 3 ?

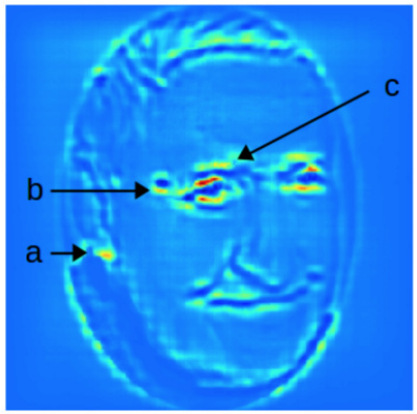


Example 4: Understanding Deep Neural Networks

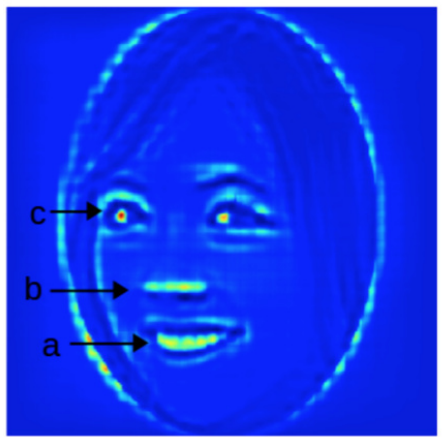


Example 4: Understanding Deep Neural Networks

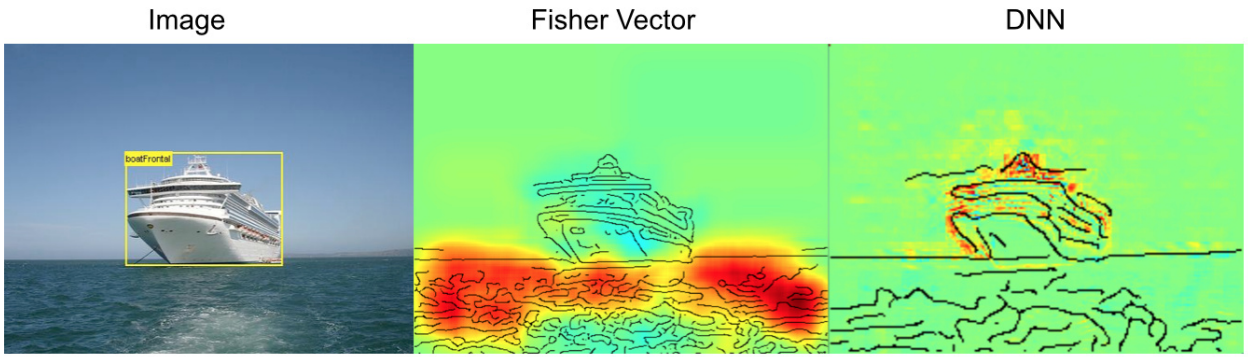
What makes
you look old ?

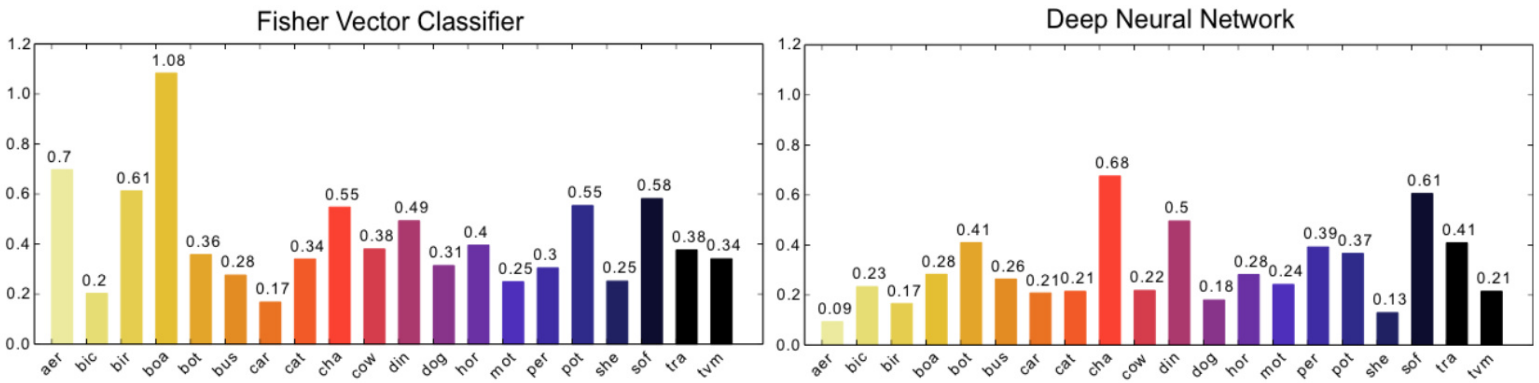


What makes
you look attractive ?



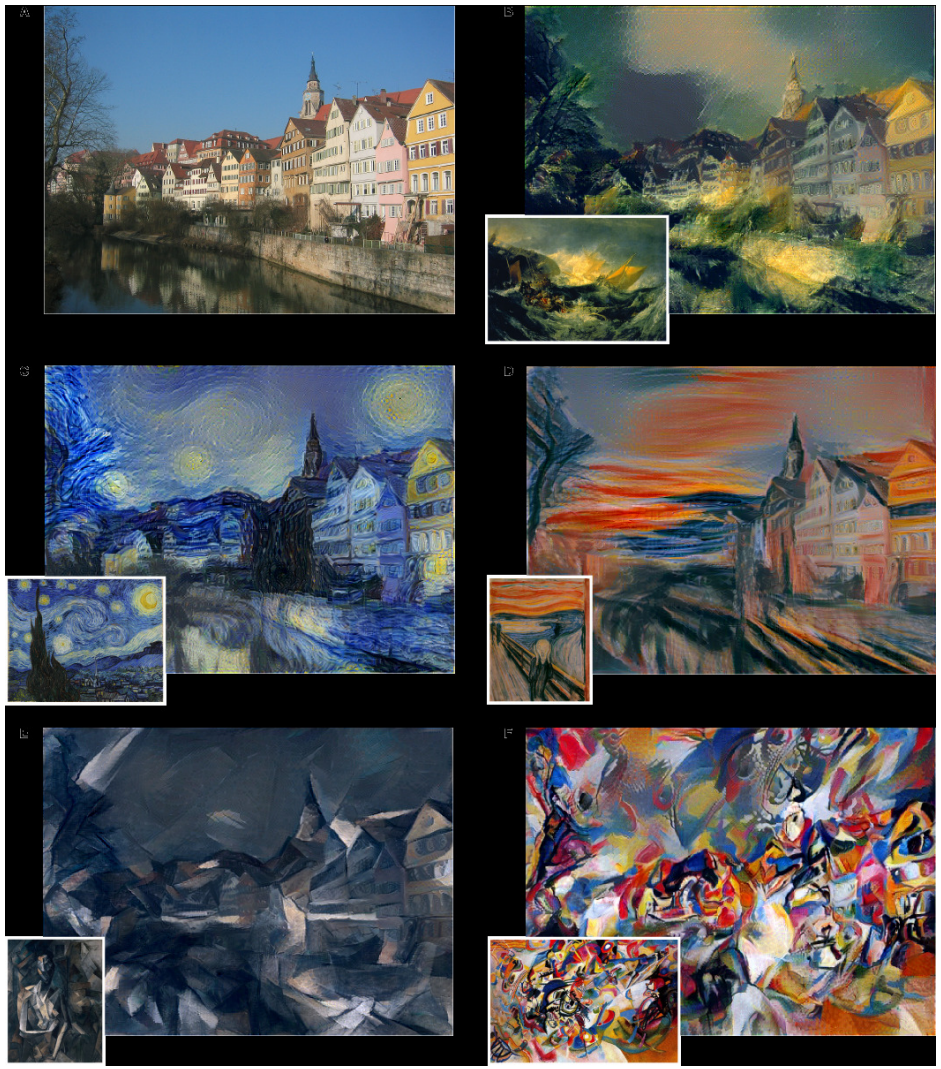
Example 4: Understanding Deep Neural Networks





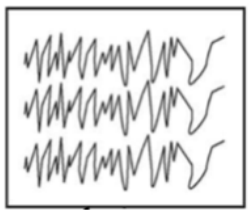
Large values indicate importance of context

Example 5: Data Manipulation

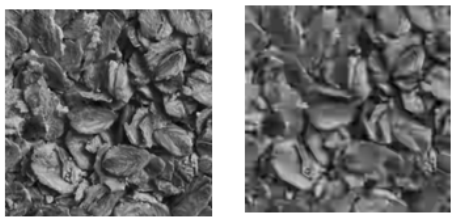


Example 6: Quality Assessment

"More Brain in Video Coding"



EEG Signal



wahrgenommene Qualität

Wieso EEG ?
- Objektiv
- Unbiased
- Schnell
- Direkt
- Genauer ?

Research in Machine Learning

Programming

```
def cv(X, y, C, params, loss_function=zero_one_loss, nfolds=10, nrepetitions=5):
    ''' general cross-validation:
            - for arbitrary learning algorithms
            - for arbitrary loss functions
    '''
    d, n = X.shape

    param_names = params[0::2]
    value_ranges = params[1::2]
    combs = list( it.product(*value_ranges) )
    ncombs = len(combs)
    if ncombs == 1:
        cvresult = 0
    else:
        cvresult = np.zeros( [ncombs,nrepetitions,nfolds] )

    totalEvals = ncombs*nrepetitions*nfolds
    evals = 0
    Tstart = time.time()

    print 'starting the cross validation:'
    inds = np.arange(n)
    nperfold = np.ceil( np.float(n)/nfolds )
    for rep in range(nrepetitions):
        # generate a random cval set
        np.random.shuffle(inds)
        for fold in range(nfolds):
            cvtest = inds[nperfold*fold:nperfold*(fold+1)]
            cvtrain = np.setdiff1d(range(n),cvtest)
            for icomb, params in enumerate(combs):
                C.fit(  X[:,cvtrain], y[:,cvtrain], *params)
                C.predict(X[:,cvtest])
                if ncombs == 1:
                    cvresult += loss_function(y[:,cvtest],C.ypred)
                else:
                    cvresult[icomb,rep,fold] = loss_function(y[:,cvtest],C.ypred)
                evals +=1
                Tcurr = time.time()
```

Maths

Theorem 1. *Let A2 hold, $\Delta > 0$, $\alpha > 0$, and $r = \frac{\text{Cardinal of } W_n}{p_n^{1+\alpha}}$ with $W_n = \left\{(i,j)\middle||\Sigma_{ij}^n| > \Delta\right\}$ denote the set of all indices for which the entry in the covariance matrix is larger than Δ.*

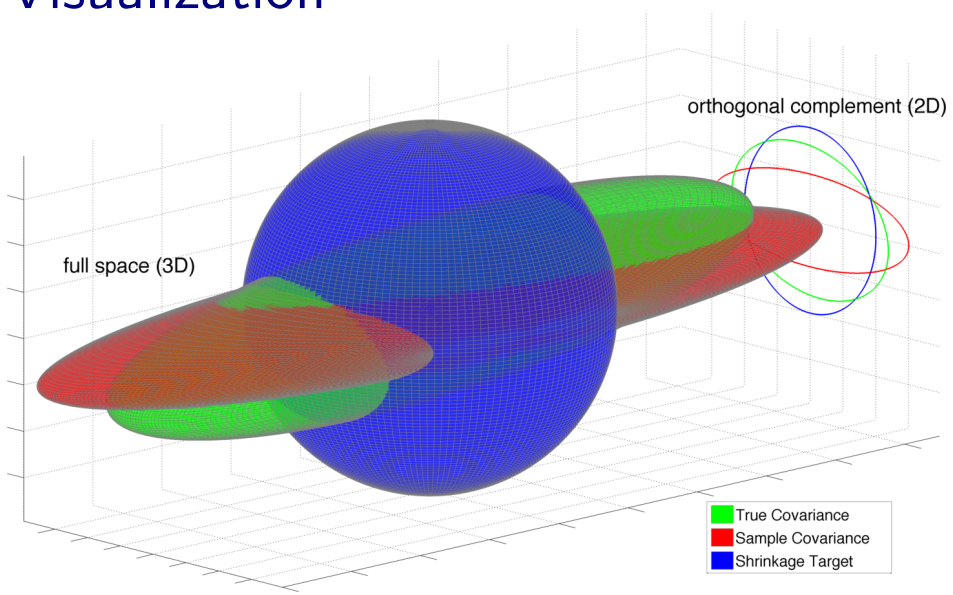
If

$$\lim_{n\to\infty} p_n = \infty,$$

then

$$\lim_{n\to\infty} r = 0.$$

Visualization



Writing/Publishing

Summary

- Cognitive processes:
  Perception, recognition of and inference on semantic concepts
- Cybernetics
  - simple (hardwired) models of cognition
  - inspired by biological organisms
  - modeled motion detection, navigation, ...
  - $\rightarrow$ but what about higher cognitive functions?
- Artificial intelligence
  - adopted ideas from Cybernetics
  - focused on (biologically inspired) models of higher cognition
  - Old AI: rule based systems
  - New AI (machine learning): learns rules from data

Next lecture

Neurons, the computational units of cognitive processes
in biological and artificial systems

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