Neural Networks and Learning Systems
TBMI26 / 732A55
2022

Lecture 1
Introduction

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Course information

- All information will be available on Lisam
- Lectures will pre-recorded and available on Teams

- You must register for classes on Lisam (Signup)
  - Chose group A, B , or C for classes
  - Do not change group!

- Laboratory exercises will be done at home with scheduled supervision on Teams
  - Dual occasions for each lab. You may chose occasion (Wed or Thu)

Staff

- **Examiner:** Magnus Borga, IMT (magnus.borga@liu.se)
- **Course admin:** David Abramian, IMT (david.abramian@liu.se)

- Lectures:
  - Magnus Borga
  - Anders Eklund
- Classes:
  - David Abramiam
  - Martin Hultman
  - Iulian Tampu
- Laboratory exercises:
  - Martin Hultman
  - David Abramiam
  - Iulian Tampu
  - Stina Mauritzon

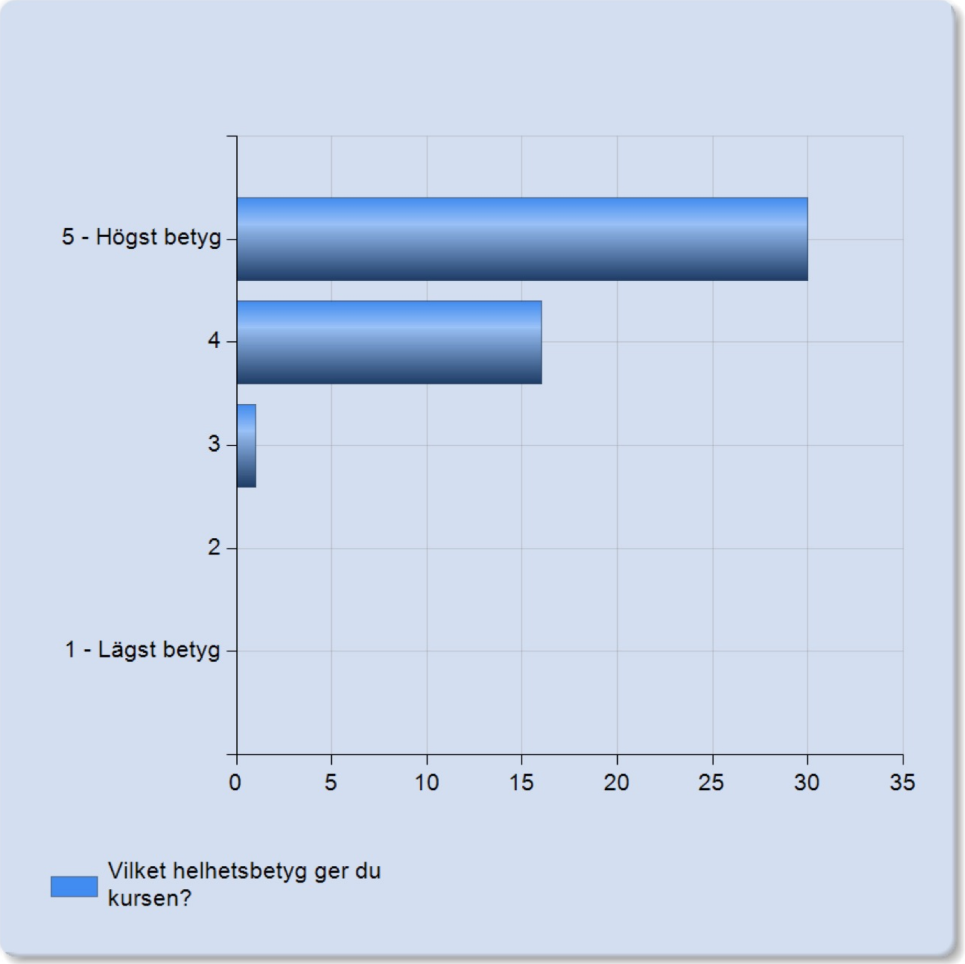
Course evaluation and development

9. Vilket helhetsbetyg ger du kursen?

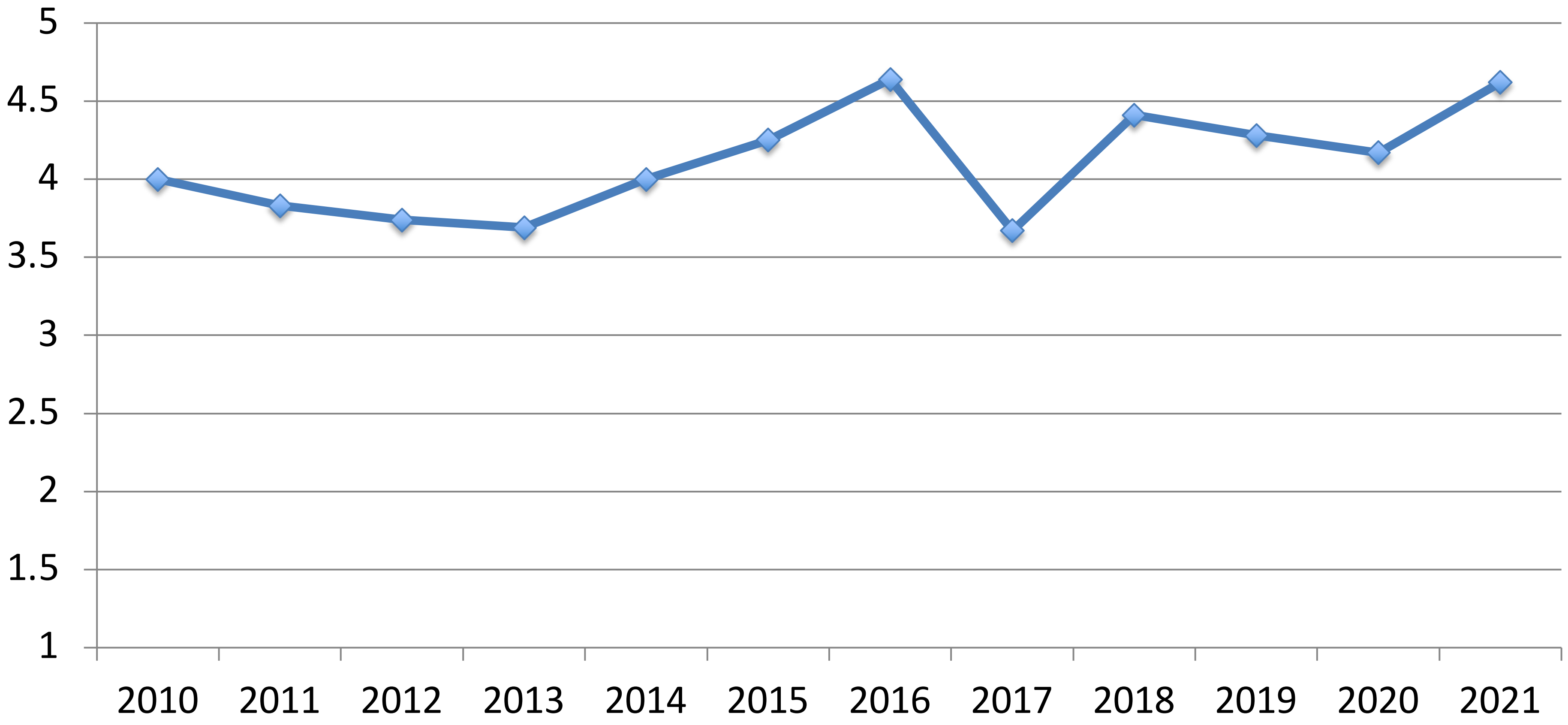
Vilket helhetsbetyg ger du kursen?	Antal svar
5 - Högst betyg	30 (64%)
4	16 (34%)
3	1 (2%)
2	0 (0%)
1 - Lägst betyg	0 (0%)
Summa	47 (100%)

Average score 2021: 4.62

Course evaluation 2021



Overall credit over time



Course evaluation and development

Changes 2022

- All laboratory exercises are now in Python
- Hybrid mode
  - Lectures and lab supervision in distance mode
  - Classes and exam on campus

The Course - Overview

- 9 lectures
- 9 lessons (classes)
- 4 assignments
- 1 written exam

Mandatory

- Course language is English.

The Course - Lectures

PPT lectures, handouts on course page

1. Introduction
2. Supervised learning - Linear classification
3. Neural networks
4. Deep learning
5. Generative Adversarial Networks
6. Ensemble learning & Boosting methods
7. Reinforcement learning
8. Unsupervised learning – Dimensionality reduction, Clustering
9. Kernel methods

Lectures in distance mode

- Lectures will be pre-recorded and published on Lisam
- Please email questions to the lecturer (me or Anders)
  - magnus.borga@liu.se
  - anders.eklund@liu.se
- Questions and answers will be published in the Lecture folder on Lisam

The Course - Lessons

- Pen & paper exercises
- Complementary presentations
- Preparations and help with lab assignments
- Choose group (A,B, or C) on Lisam and follow that group

The Course - Assignments

- 4 laboratory exercises/assignments:
  1. Pattern recognition using linear classifiers and neural networks
  2. Deep learning
  3. Face recognition in images using Boosting techniques
  4. Reinforcement learning
- Programming in Python
- Assignments are done in pairs. (Not more than 2 students together!)
- Supervision in Teams
  - time scheduled ("LA" in schedule) –

- Deadlines for <u>written reports</u>.
- Late reports may not be corrected until next re-exam (June/August).

Course literature

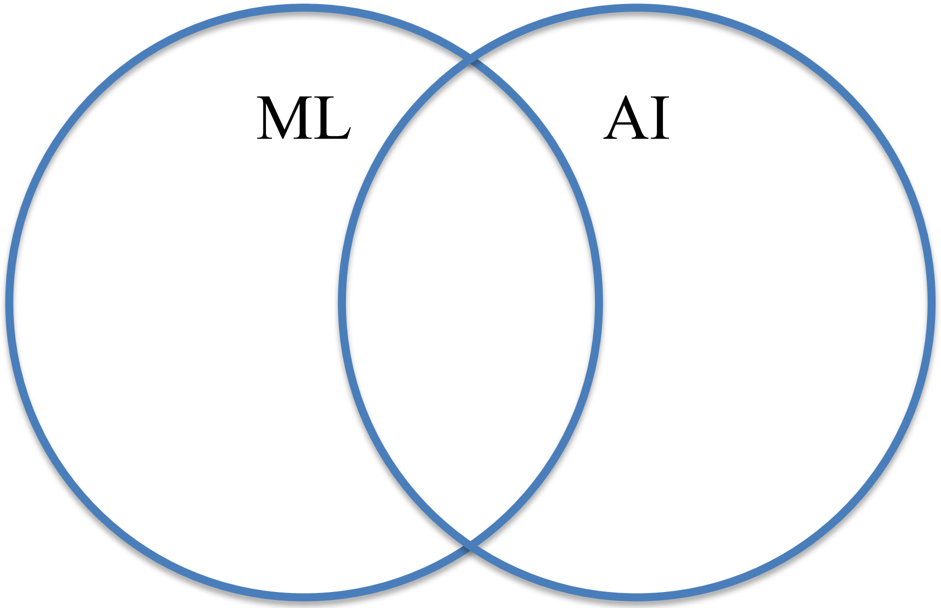
- Lecture notes
- Exercise collection
- Assignments

- Additional links in lecture notes (not required reading)

What is machine learning?

The ability of a system to <u>learn from data</u> and <u>generalize</u> to new data

ML vs AI



- AI aims at simulating “intelligent” behaviour, but not necessarily by learning
- ML does not always aim at doing something “intelligent”

How can a machine learn?

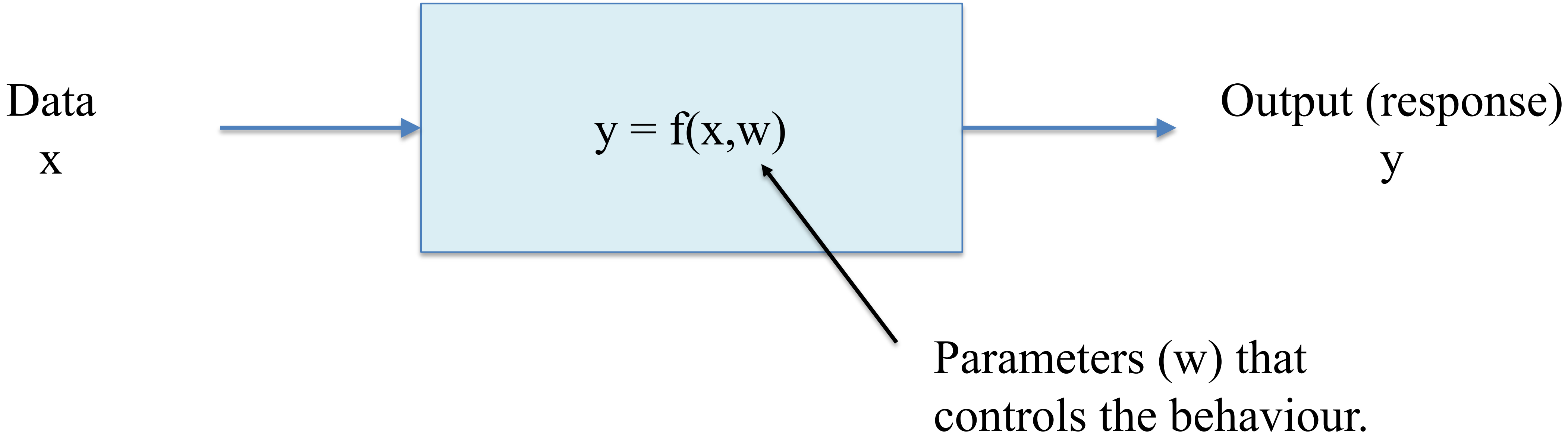
Learning: ”Any relatively permanent change in behaviour resulting from past experience.”

(Encyclopaedia Britannica 1964)

- The ”behaviour” of the machine is determined by its parameters.
- “past experience” is previously observed data.

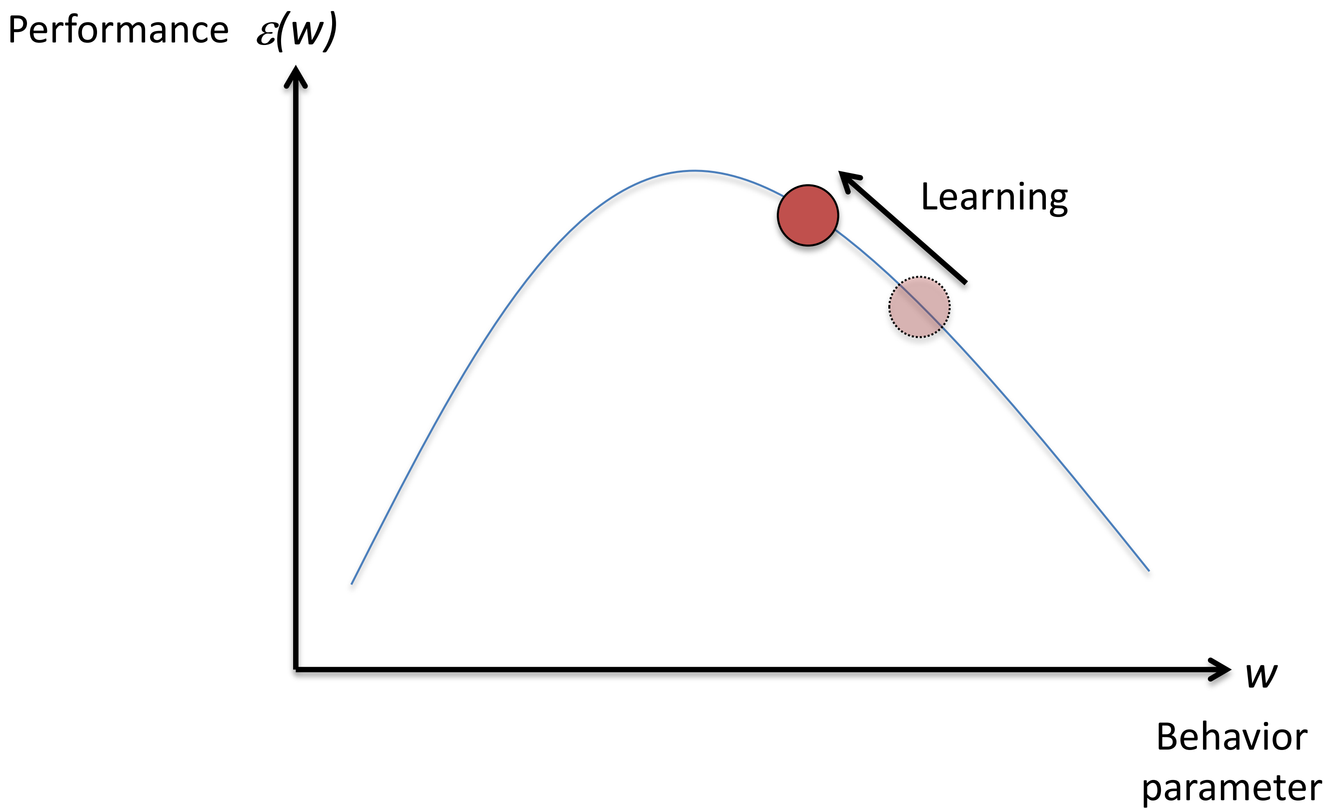
- Machine learning = changing parameter values (behaviour) as a result of observed data (experience).

Machine Learning



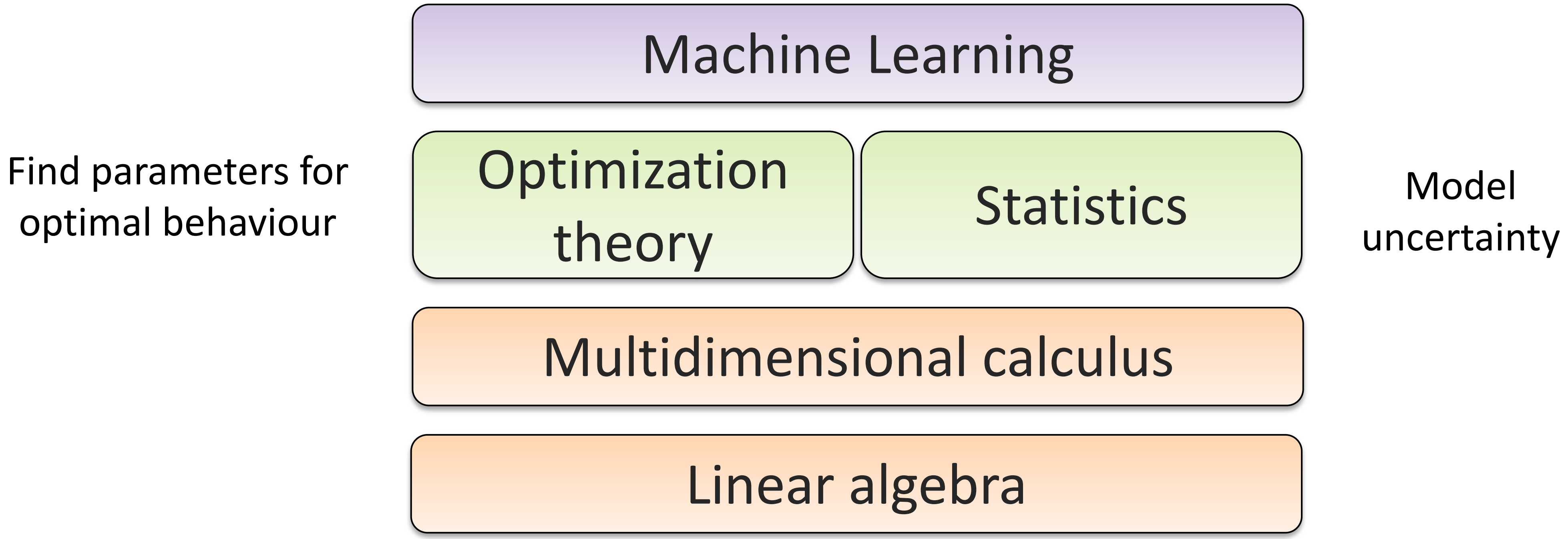
Machine learning: The system changes its parameters (w) in order to improve its performance

Learning = optimization of performance



What is being learnt depends on how we define <u>performance</u>!

Mathematical foundations of machine learning



Prerequisites

- Linear algebra
  - Vectors, scalar products, eigenvectors and eigenvalues
- Multidimensional calculus
  - Gradients, partial derivatives
- Mathematical statistics
  - Mean, variance, covariance, correlation, Gaussian distribution,
- Programming
  - Some programming experience
  - Matlab and Python experience helps a lot

Why machine learning?

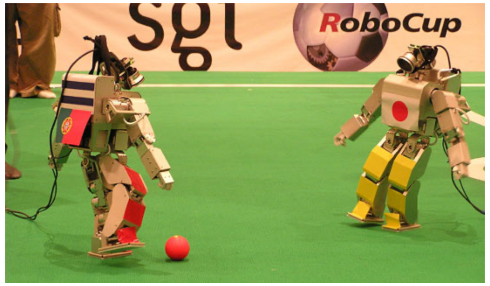
- Algorithm too complex for a human to design, but we can easily provide examples of what the algorithm should do.

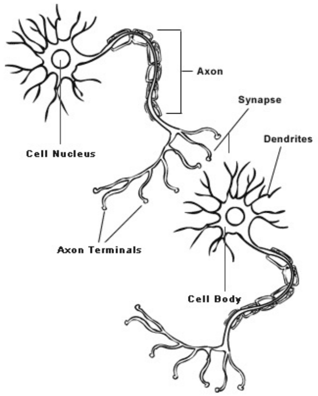
- Relationships in high-dimensional data too complex for a human to see, but a computer can find these.

- The computer should learn and adapt continuously to new situations.

Applications of machine learning

- Pattern and speech recognition
- Robots & autonomous systems
- Big data
- Expert systems & decision support
- Games
- Models of the brain





Three main categories of machine learning methods

- **Supervised learning (predictive)**

  Learn to generalize and classify new data based on labelled training data.
  - Pattern recognition
  - Classification
  - Regression

- **Unsupervised learning (descriptive**)

  Discover structure and relationships in complex high-dimensional data.

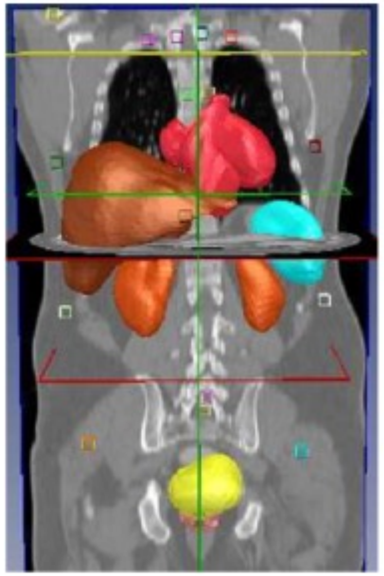
- **Reinforcement learning (active)**

  Generate policies/strategies that lead to a (possibly delayed) reward. Learning by doing.

Pattern recognition examples

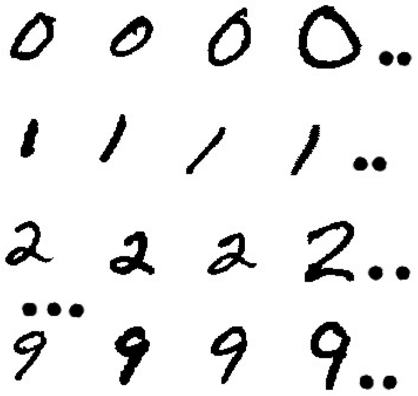
Face recognition

Organ segmentation

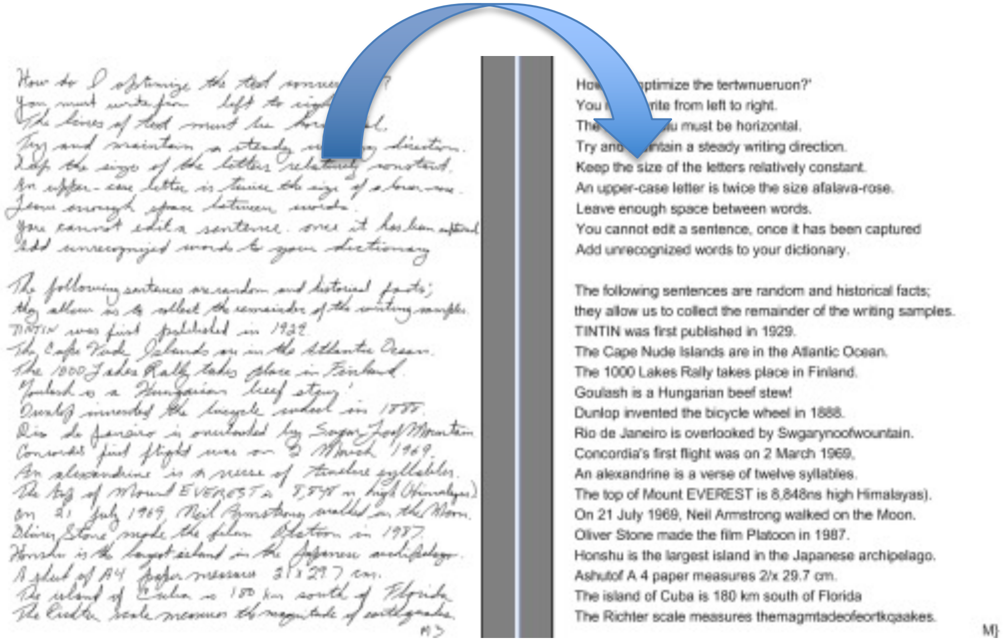


Pattern recognition examples

Optical Character Recognition (OCR)



Source: http://blog.damiles.com

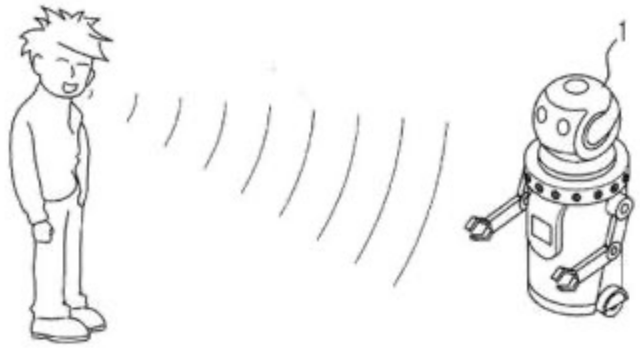


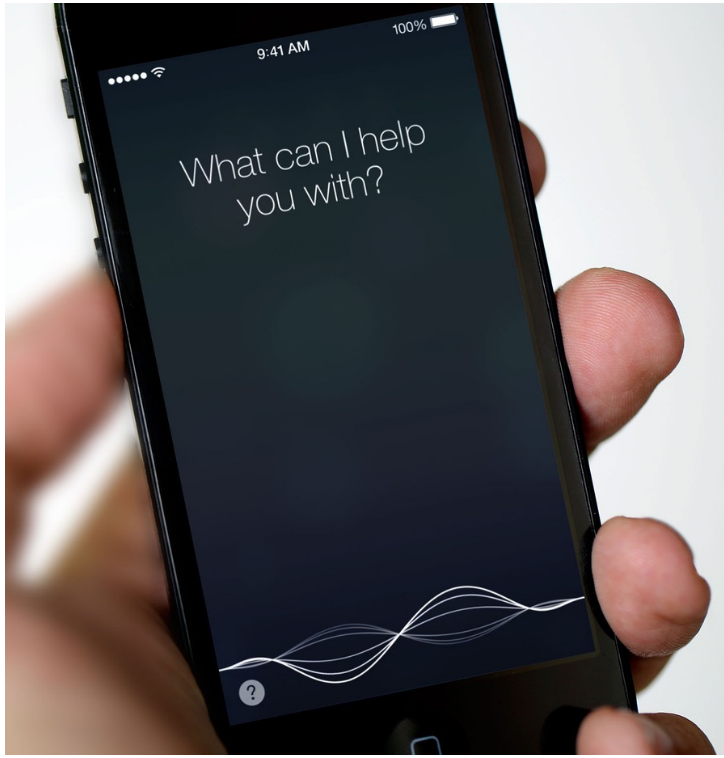
Pattern recognition examples

Xbox Kinect – Pose estimation

Pattern recognition examples

Speech recognition





Pattern recognition examples

Game positions

Spam filters

#1
100% satisfied
4U
Accept credit cards
Act Now!
Additional Income
Affordable
All natural

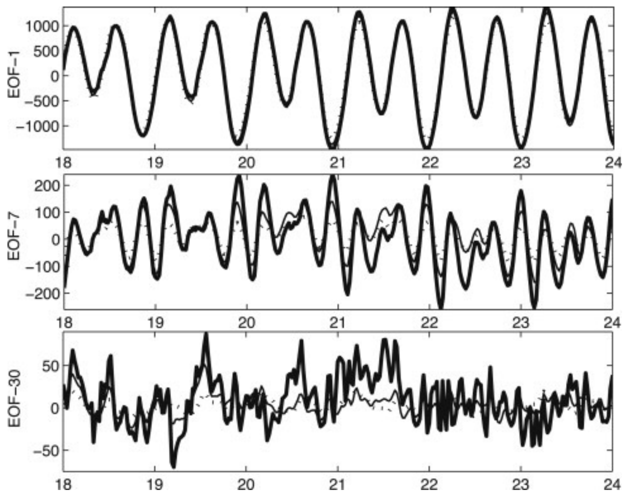
Movie & music recommendation

Spotify

Regression examples

Prediction and forecasting

Weather and natural phenomena



Financial markets

Features

- A feature is a measurement or scalar number that describes some aspect of a phenomenon or object
  - Size, length, shape, velocity
  - Intensity and color (RGB)
  - Position (x,y)
  - Signal frequency
  - Sensor measurements (e.g., temperature)
  - Game piece present at certain location (yes/no)
  - Word present in an email (yes/no)

- Feature extraction is the process of measuring features from data.

Features – Iris dataset


Iris setosa


Iris versicolor


Iris virginica

Fisher's Iris Data

Sepal Length	Sepal Width	Petal Length	Petal Width	Species
5.7	4.4	1.5	0.4	*I. setosa*
5.8	2.6	4.0	1.2	*I. versicolor*
5.8	2.7	5.1	1.9	*I. virginica*

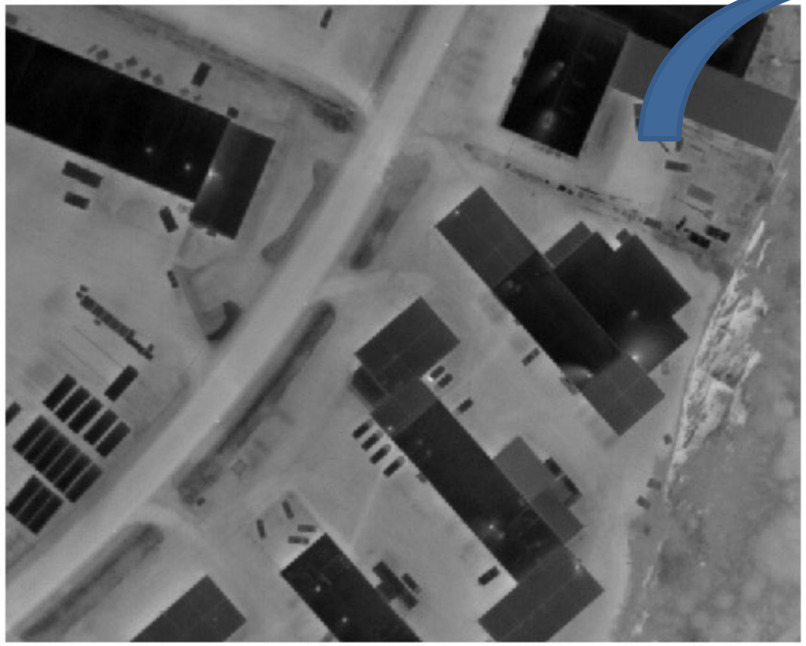
From Wikipedia

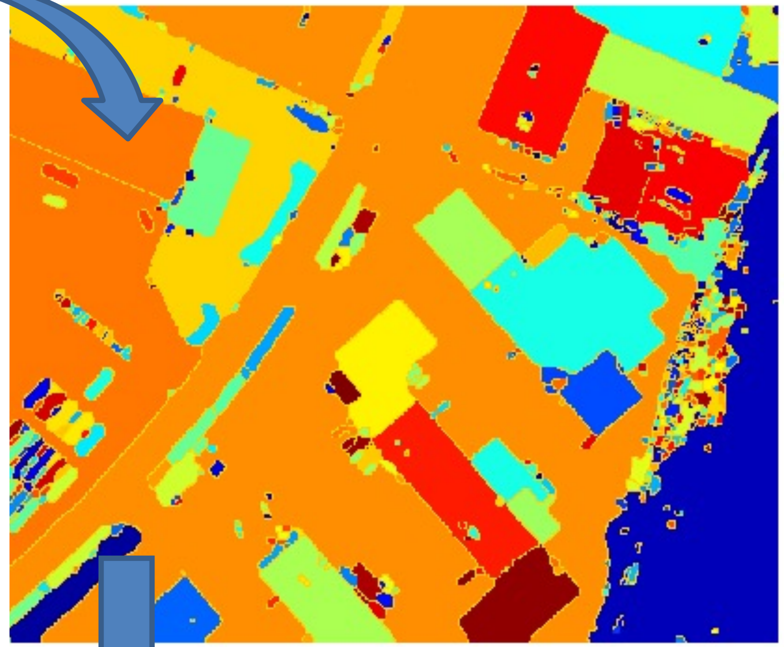
Feature vectors:

$$\mathbf{x}_1 = \begin{bmatrix} 5.7 \\ 4.4 \\ 1.5 \\ 0.4 \end{bmatrix} \quad \mathbf{x}_2 = \begin{bmatrix} 5.8 \\ 2.6 \\ 4.0 \\ 1.2 \end{bmatrix} \quad \mathbf{x}_3 = \begin{bmatrix} 5.8 \\ 2.7 \\ 5.1 \\ 1.9 \end{bmatrix}$$

Features – Image classification

Watershed transform

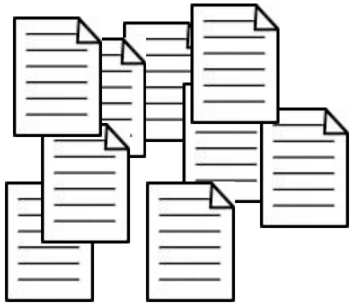




Extract intensity & shape features

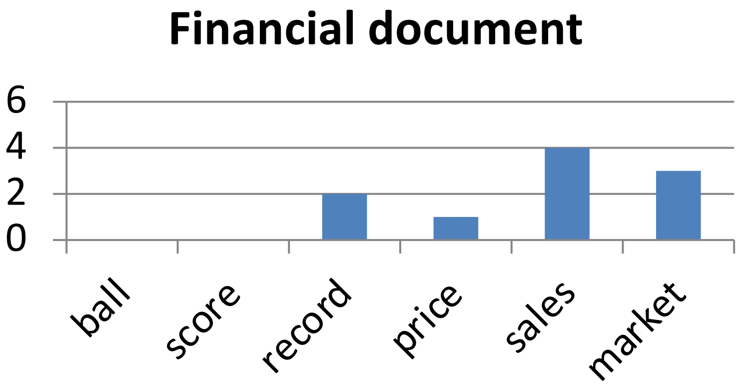
$$\mathbf{x} = \begin{bmatrix} \text{Mean intensity} \\ \text{Std intensity} \\ \text{Border regularity} \\ \text{Compactness} \end{bmatrix}$$

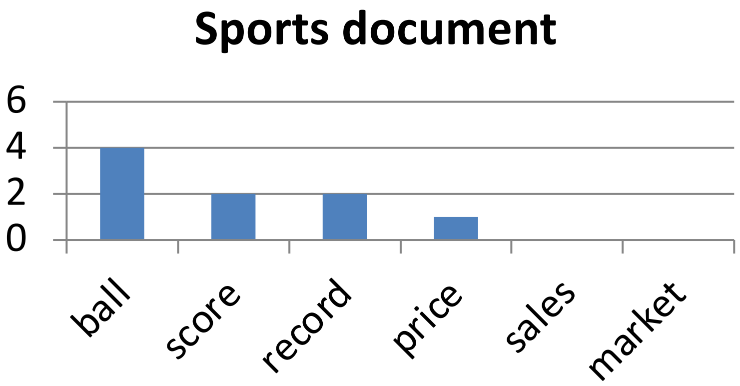
Features – Document analysis



Articles, mail, web pages, ...

Dictionary:
{'ball', 'score', 'record', 'price', 'sales', 'market'}

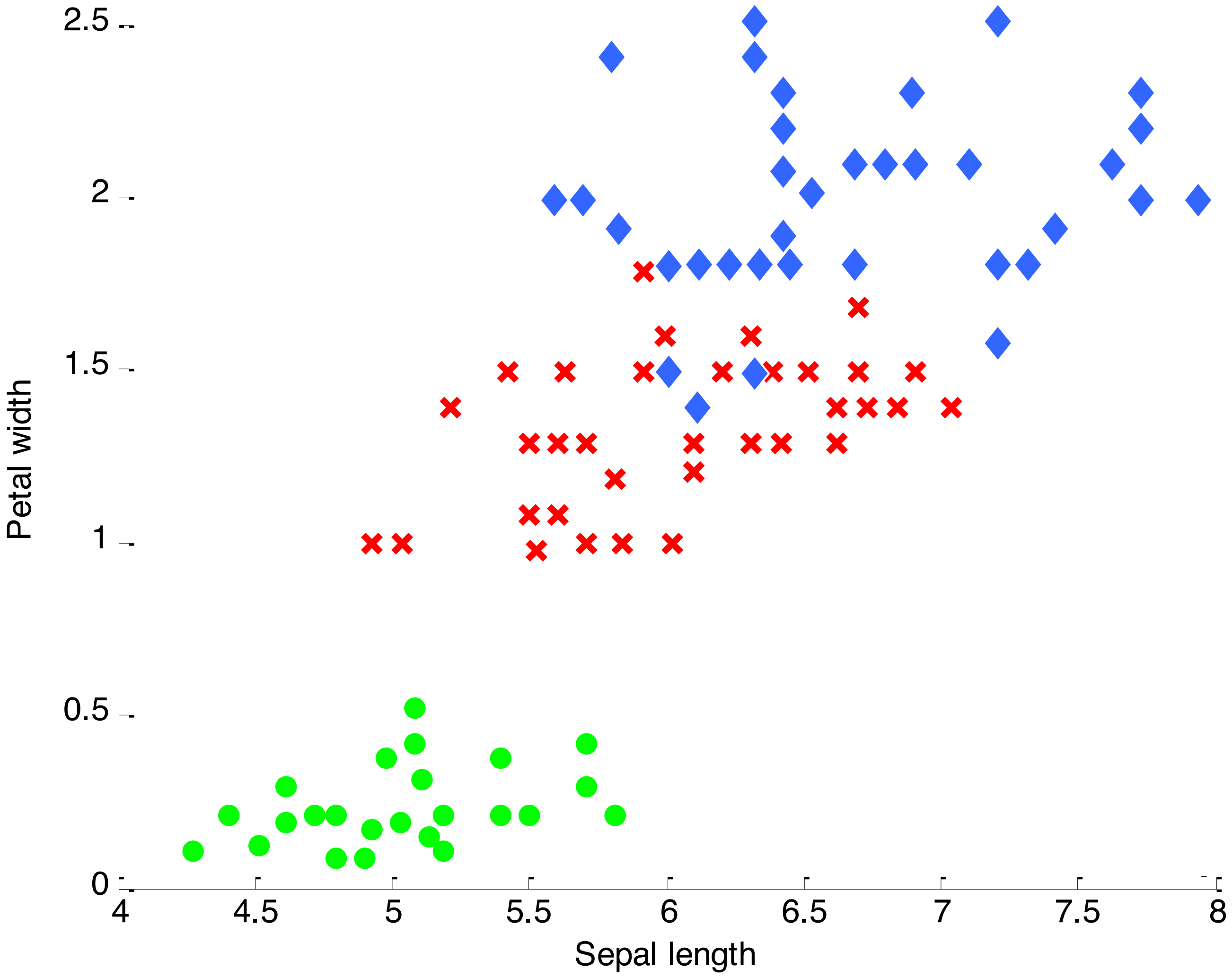




$$\mathbf{x} = \begin{bmatrix} \#'ball' \\ \#'score' \\ \#'record' \\ \#'price' \\ \#'sales' \\ \#'market' \end{bmatrix}$$

Bag-of-words model

Feature space

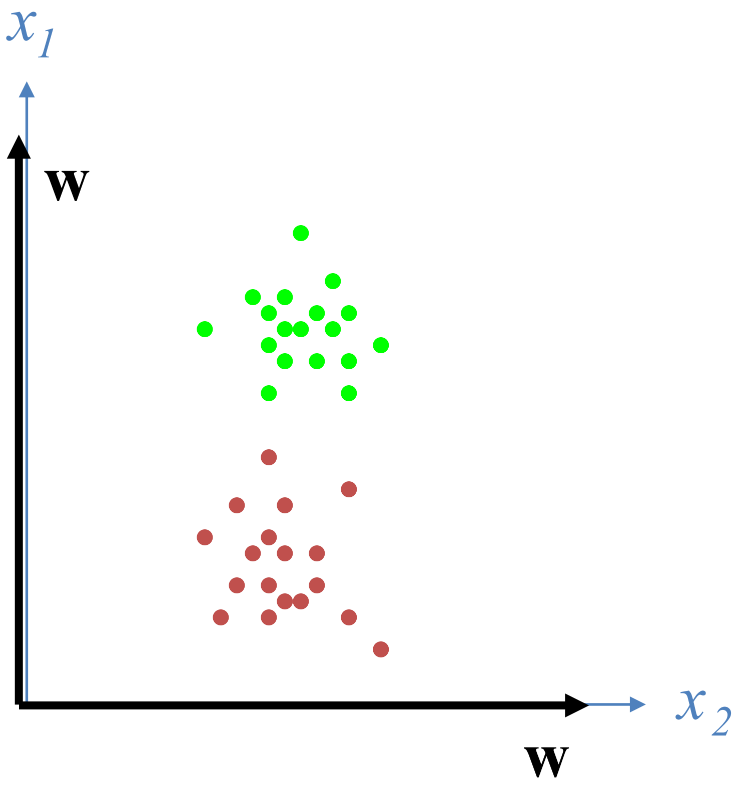


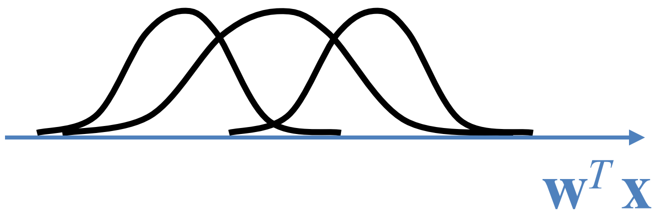
Iris setosa

Iris versicolor

Iris virginica

Representation





Supervised learning

- **Task:** Learn to predict/classify new data from labeled examples.
- **Input:** Training data examples {$\mathbf{x}_i$, y_i}, i=1...N, where $\mathbf{x}_i$ is a feature vector and y_i is a class label in the set Ω.
- **Output:** A function $f(\mathbf{x};w_1,\ldots,w_k) \rightarrow \Omega$

Find a function *f* and adjust the parameters $w_1,\ldots,w_k$ so that new feature vectors are classified correctly. ***Generalization!!***

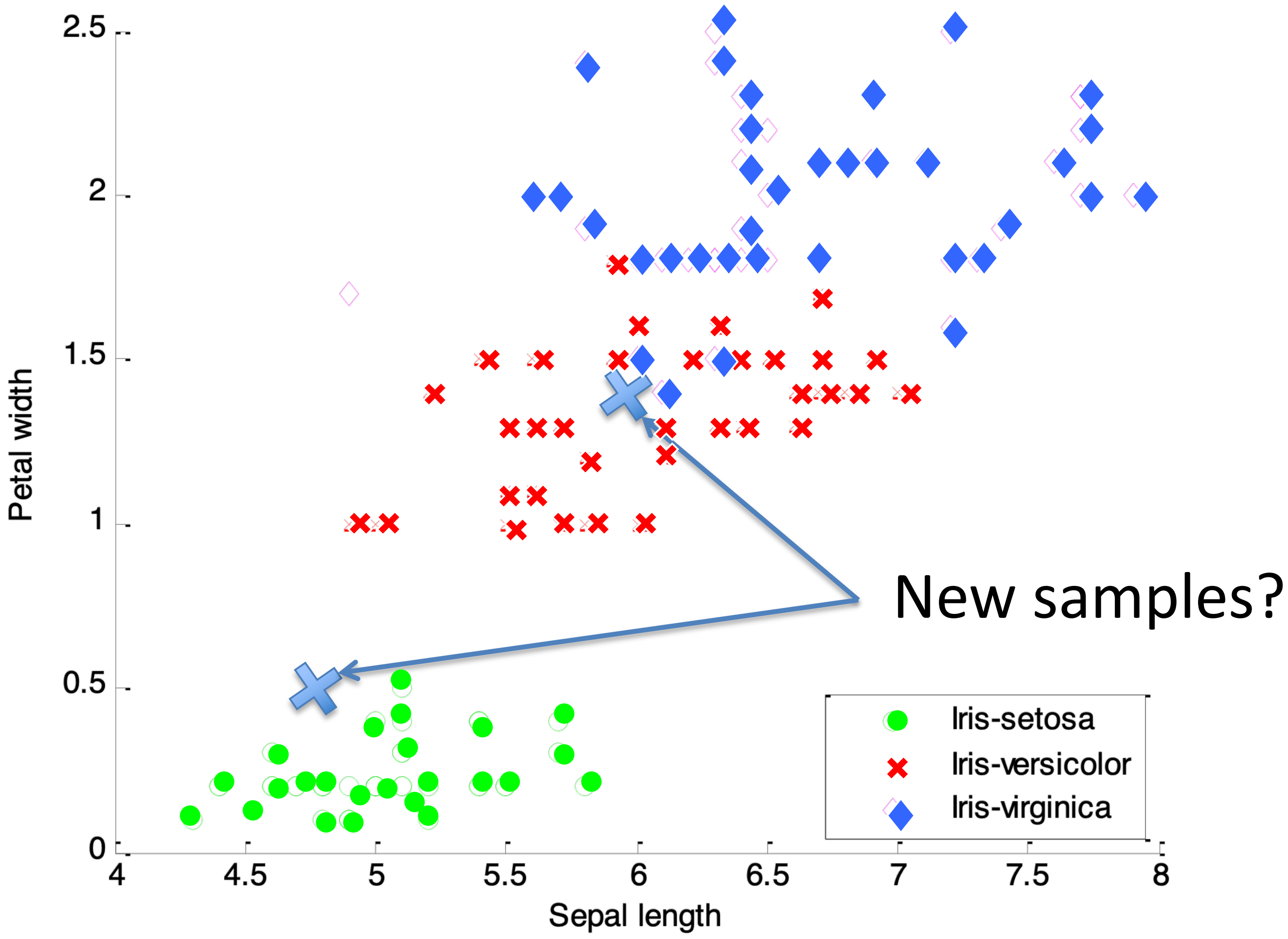
Classification vs. regression vs. ranking

- **Classification**: Select one of a discrete set of classes (the set Ω is discrete).
  - Which horse is going to win this race?
  - Which letter does this image depict?
  - Is this email spam (yes/no)?

- **Regression**: Learn to predict a continuous value ($\Omega = \mathbb{R}$).
  - Learn to predict the temperature tomorrow.
  - What is the *probability* that this image depicts the letter ‘a’?

- **Ranking**: Learn to rank a set of items ($\Omega = \mathbb{R}$).
  - Rank webpages, movies, etc.

Example - Classification



k-Nearest Neighbours (k-NN)

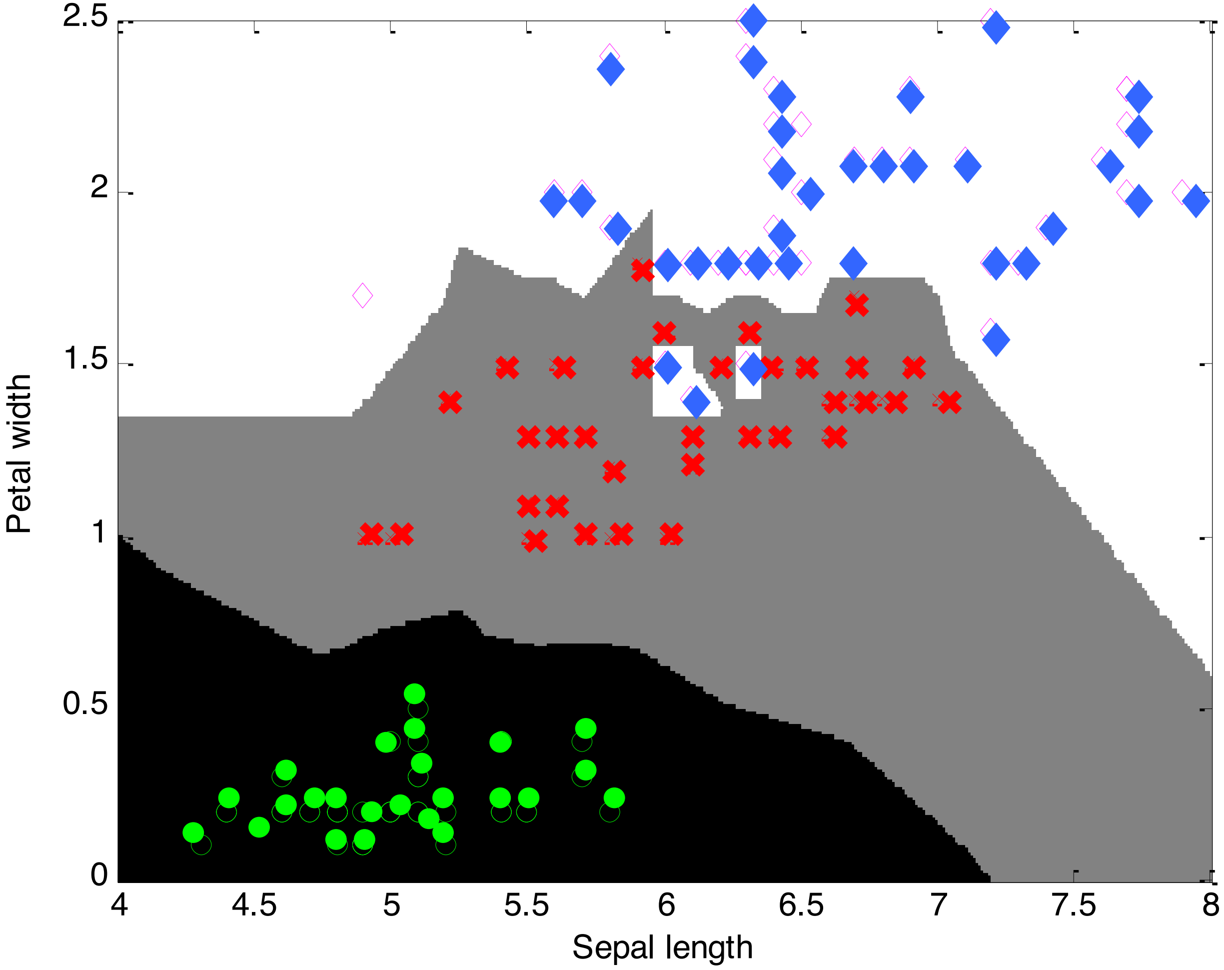
- Save all training data.
- For a new case, find similar examples among the training data.
- Requires a similarity measure (metric), for example the Euclidian distance

$$\|\mathbf{x}-\mathbf{y}\| = \sqrt{\sum_i \left(x_i - y_i\right)^2}$$

- A majority vote among the *k* nearest neighbours decides the class, where *k* can be 1,2,3,4...

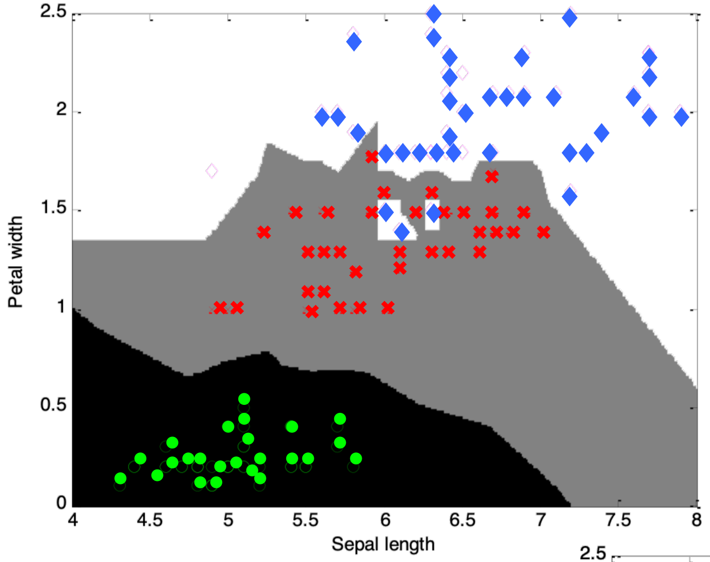
Classification areas

k = 1

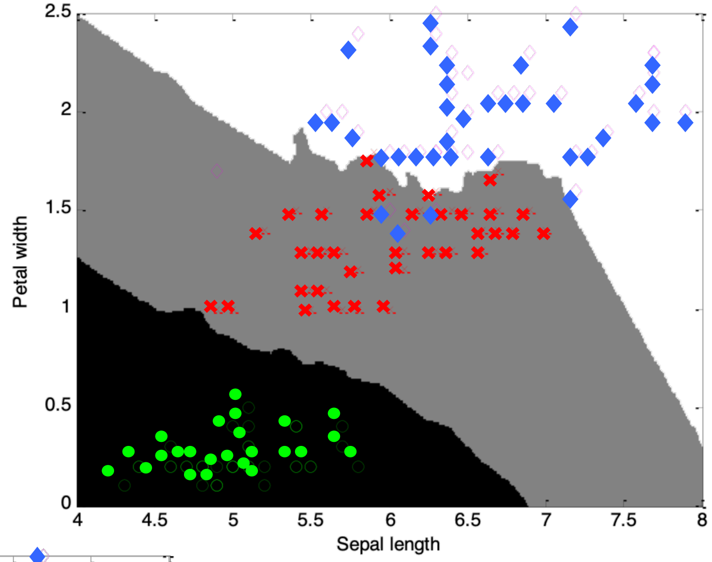


Classification areas

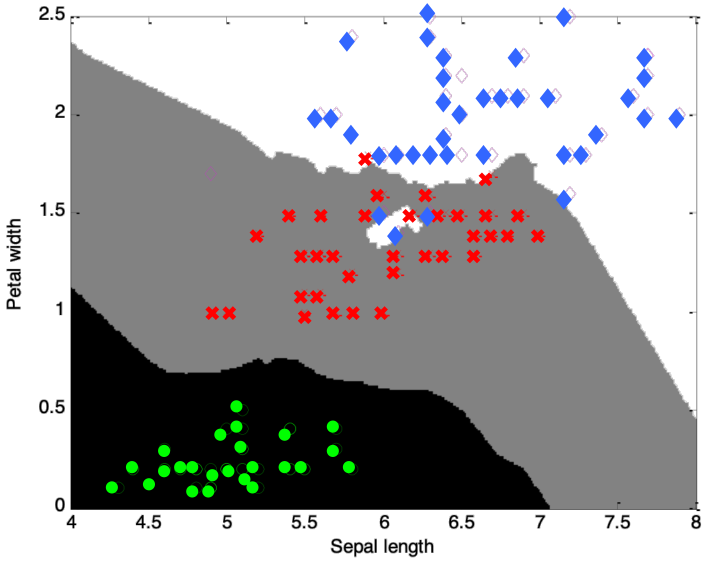
k = 1



k = 7



k = 3



Pros and cons of k-NN

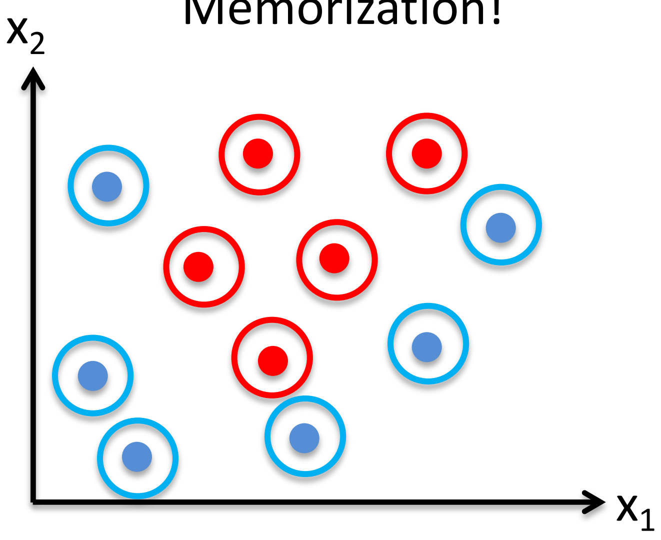
- Very simple – no “training“ or modeling required
- Must store all training data – problem for large data sets:

$$f(\mathbf{x};\underbrace{w_1,\ldots,w_k}_{\text{Parameters equal to training data } \mathbf{x}_i})\rightarrow \Omega$$

- Slow classification for large data sets – must compare new samples with all stored samples.

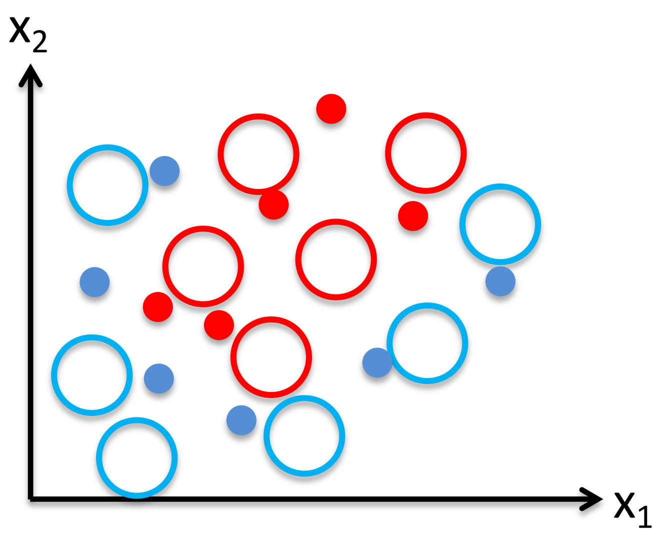
Generalization!

Classifying training data is trivial.
Memorization!



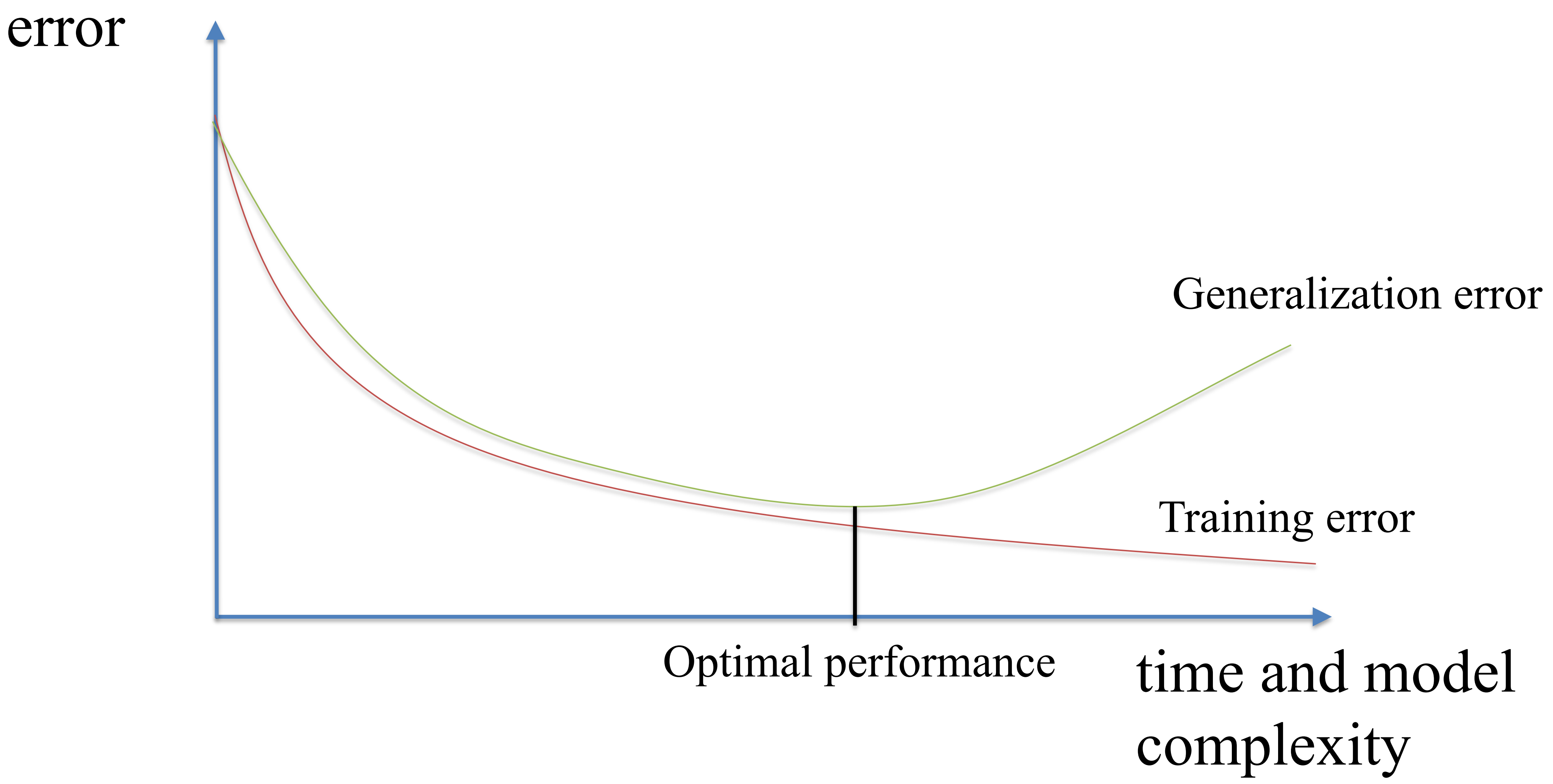
$f(\mathbf{x};w_1,\ldots,w_k) \rightarrow \Omega$

Classifying **new data** is the challenge!



Generalization error!

Overfitting

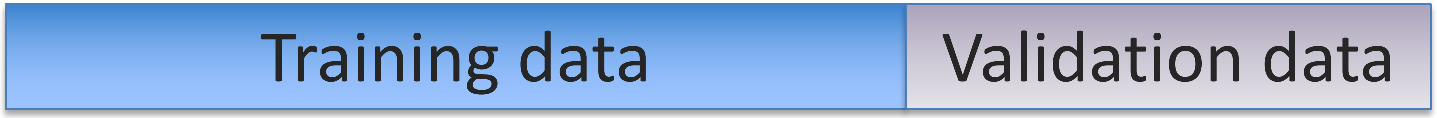


Training data vs. validation data

- A classifier must be able to generalize, i.e., it must be evaluated using previously unseen data.
- Evaluating using training data will give an overly optimistic accuracy.
- Three ways to perform the evaluation:
  - Hold out
  - Cross validation
  - Leave one out

Hold out

- Simplest approach, hold out one part of the entire data set as validation data.



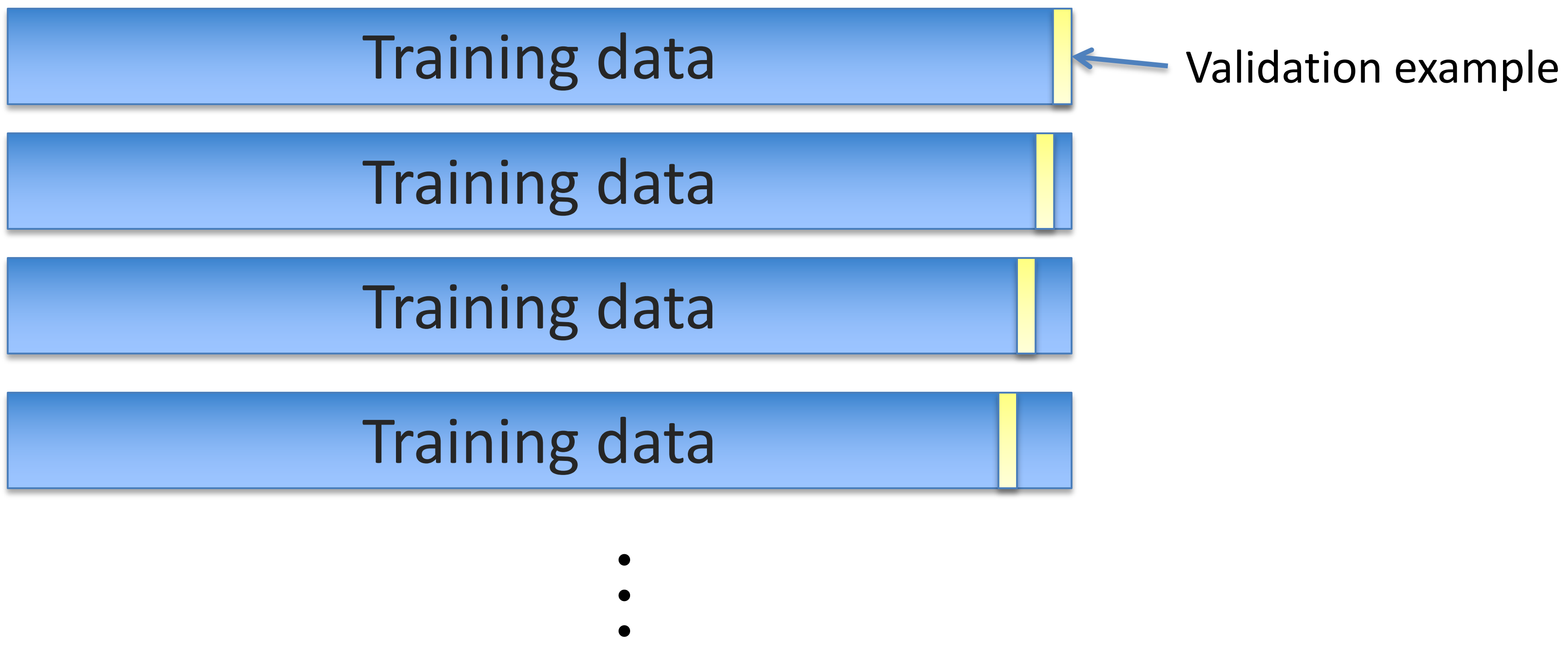
n-fold Cross-Validation

- Divide data set into n segments. Train using n-1 segments and validate using the n:th.
- Example of 3-fold Cross-Validation:

Training data	Training data	Validation data
Training data	Validation data	Training data
Validation data	Training data	Training data

Leave-one-out

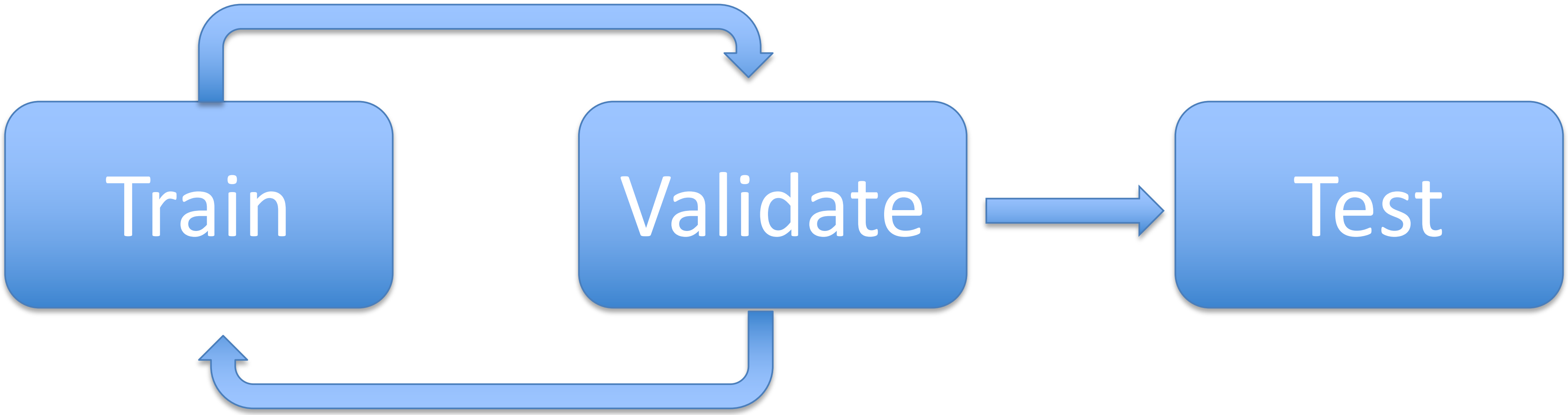
- Extreme case of Cross-Validation: Use all data but one example for training and use the last one to evaluate



How can we find the minimum generalization error?

- What happens if the generalization error is not low enough?
- Modify the classifier (change the model) and train again…
- But – then the validation data is used to select the model!
- How do we know how well the new model generalizes?
- Need new validation data to test the final model – this dataset is called test data.
- Test data must <u>never</u> be used more than once!

Training – Validation –Testing



Evaluating classifiers – The Confusion matrix


Iris setosa


Iris versicolor


Iris virginica

Predicted class

Actual class	Setosa	Versicol.	Virginica
Setosa	50	0	0
Versicol.	0	45	5
Virginica	0	7	43

Accuracy: $$\frac{50+45+43}{150}=92\%$$