



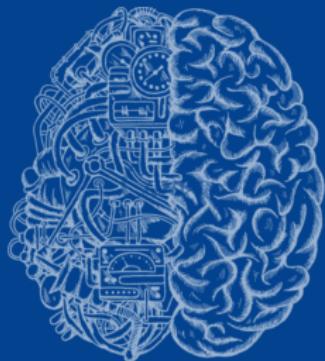
AARHUS
UNIVERSITY
SCHOOL OF ENGINEERING



LESSON 1: Introduction



SPRING 2020



Undervisere

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Eksamens

Formel beskrivelse fra kursuskatalogen

Prøveform

- ▶ Hjemmeopgave.

Bedømmelse

- ▶ Godkendt/Ikke godkendt, ingen censur.

Forudsætninger for prøvedeltagelse

- ▶ "For at kunne bestå kurset skal der i løbet af semesteret være afleveret et antal obligatoriske opgaver samt deltaget i obligatoriske præsentationer. Der vil være deadlines for afleveringen af de enkelte opgaver."

Bemærkninger

- ▶ "Beståelsen af kurset sker på baggrund af én samlet vurdering af de afleverede opgaver og præsentationer, hvor der vil blive lagt vægt på, om den studerende opfylder punkterne i kvalifikationsbeskrivelsen. Bedømmelsen foretages kun af eksaminator (underviser)."

Reeksamen

- ▶ "Næste ordinære eksamenstermin. Samme procedure som ved den ordinære eksamen. Der skal afleveres nye opgaver til eksaminationen."

Eksamensform

Afleveringer og evalueringer

Eksamensform, godkendelsesfag via:

- ▶ et sæt obligatoriske skriftlige gruppe-opgaver med afleveringsdeadlines (**O1/O2/O3/O4**),
- ▶ en poster-session, med aflevering af poster og mundtlig præsentation af poster,
- ▶ en mundtlig gennemgang af den sidste afleveringsopgave (**O4/slut-journal**) med alle medlemmer i ITMAL gruppen, samt evaluering af hver gruppemedlems bidrag.

=> Endelig godkendelse af kurset sker på en samlet vurdering af de tre punkter ovenfor.

Opgaveafleveringer: O1, O2, O3 og O4

O1: Opgavesæt fra L01+L02+..

O2: Opgavesæt fra ..

O3: Opgavesæt fra ..

O4: slut-journal, et mini-projekt:

- ▶ For the final journal, you must design and implement a full machine learning system. You have relative free hands...

Criterions [extract]:

- ▶ Data must be split in a training-test set...
- ▶ Your machine learning algorithm must be described in depth...
- ▶ The system must be evaluated via a suitable performance metric...

NOTE₀: Afleveringsformat i PDF.

NOTE₁: O4 vil blive specifieret på BB.

NOTE₂: O4 konflikt med BA projekter, BA deadline 27/05?

Læringsmål

Når kurset er afsluttet forventes det at den studerende kan:

- ▶ **ITMAL generelt:**
 - ▶ **Redegøre** for de væsentligste begreber i machine learning terminologi samt principperne i en machine learning pipeline.
 - ▶ **Anvende** metoder til analyse af data, bl.a. med henblik på valg af machine learning model.
- ▶ **ITMAL i relation til praktiske projekter:**
 - ▶ **Anvende** udvalgte machine learning teknikker i praktiske opgaver og projekter.
 - ▶ **Anvende** udvalgte kodebiblioteker (frameworks) og udviklingsværktøjer til machine learning.
- ▶ **ML Data og algoritmer:**
 - ▶ **Beskrive** betydningen af datakvalitet i machine learning, samt anvende udvalgte databehandlingsteknikker til at forbedre kvaliteten af datagrundlaget.
 - ▶ **Sammenligne og vurdere** forskellige algoritmer og teknikers anvendelighed i forbindelse med praktiske projekter.

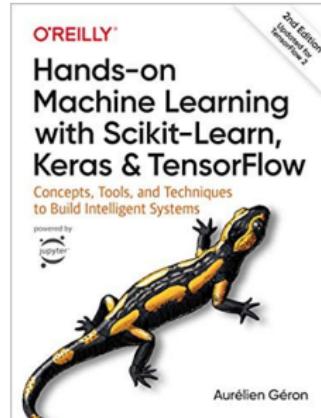
Læringsmål

Indhold på kursushjemmesiden

- ▶ Generelle machine learning koncepter.
- ▶ Machine learning frameworks (biblioteker til Python).
- ▶ Introduktion til diverse specifikke machine learning algoritmer, herunder f.eks. lineær/logistisk regression og neurale netværk.
- ▶ Dimensionsreduktion og visualisering.
- ▶ Clustering
- ▶ Datakvalitet og Big data.
- ▶ ~~Næivé/Bådysk's klassifikation,~~
- ▶ ~~Bølgeprædiktionsmodel,~~
- ▶ ~~Høftvwærdesunderstøttelse.~~

Litteratur

"Hands-On Machine Learning with Scikit-Learn, Keras, and TensorFlow",
Aurélien Géron, O'Reilly, 2019, (Second Edition)



Hands-On Machine Learning with Scikit-Learn, Keras, and TensorFlow
by Aurélien Géron

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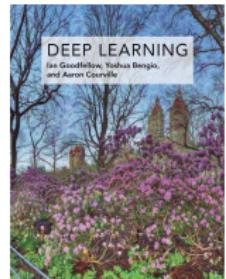
September 2019: Second Edition

Revision History for the Second Edition

2019-09-05: First Release
2019-10-11: Second Release

See <http://oreilly.com/catalog/errata.csp?isbn=9781492032649> for release details.

- ▶ [HOML] → udtales som (Brian) Holm!
- ▶ Ref. til sidetal er for 2.Ed / *Second Release*.
- ▶ Plus yderligere materiale (brug links i BB).



Syllabus

Uge	Dato	Lektion	Emne	Opgave	Underviser	Kommentar
5	28/01-2020	Lo1	Intro		CEF	
6	04/02-2020	Lo2	Klassifikation		CEF	
7	11/02-2020	Lo3	TBD		CEF	
8	18/02-2020	Lo4	Regression	O1(20/2)	PAH	
9	25/02-2020	Lo5	Unsupervised learning I		PAH	
10	03/03-2020	Lo6	Data analyse		PAH	
11	10/03-2020	Lo7	Neurale netværk	O2 (11/3)	PAH+CEF	
12	17/03-2020		Træning og generalisering		CEF	
13	24/03-2020	Lo8	Optimering og søgning		CEF	
14	31/03-2020	Lo9	Probabilistiske modeller		PAH	
15	07/04-2020	L10	Unsupervised learning II	O3 (8/4)	PAH	Påske (ingen undervisning)
16	14/04-2020	L11	Deep learning		CEF	
17	21/04-2020	L12	J3 projekt			
18	28/04-2020	L13	J3 projekt			
19	05/05-2020	L14	J3 projekt	O4 (5/5) Poster(4/5)		Poster-session
20	12/05-2020					Mundtlige præsentationer af O4

ITMAL Nomenklatur

- [HOML]: Hands-On Machine Learning bog, aka (B.)Holm.
- [GITHOML]: Git repository for [HOML].
- [GITMAL]: Git repository for ITMAL kursus opgaver,
(bruges evt. slet ikke)
- [G]: ITMAL gruppe, med tre studerende, (evt. fire).
- [SG]: ITMAL super-gruppe, ved nogle af opgaverne.
- [O1]: opgavesæt 1, osv. (O2/O3/O4).
- [L01]: Lektion 1, osv.

NOTE: se fuld liste på '*BB | Kursusinfo | Kursusforkortelser*'.

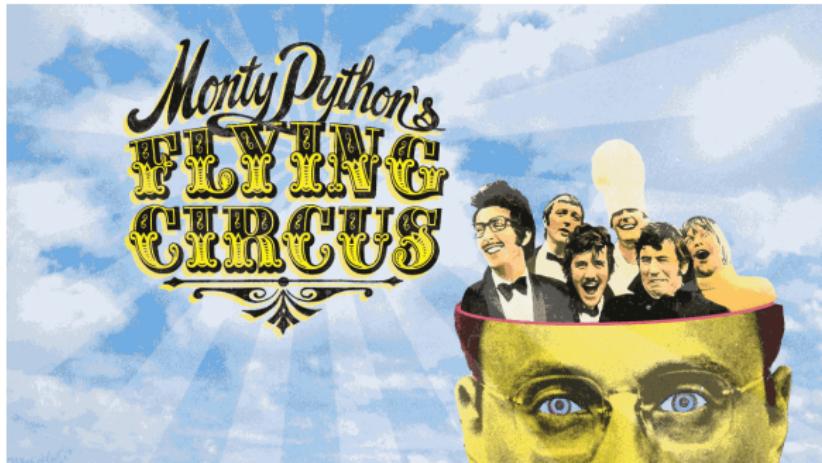
Monty Python's FLYING CIRCUS

END Kursus intro/
BEGIN Python intro



python Introduction

- ▶ Python is an **interpreted** high-level programming language for general-purpose programming. Created by **Guido van Rossum** and first released in 1991, Python has a design philosophy that emphasizes **code readability**, notably using significant whitespace. It provides constructs that enable clear programming on both small and large scales.
- ▶ Python features a **dynamic type system and automatic memory management**. It supports multiple programming paradigms, including **object-oriented, imperative, functional and procedural**, and has a large and comprehensive standard library.
- ▶ Python interpreters are available for many operating systems.



Anaconda and Jupyter Introduction



- ▶ **Anaconda:** a python distribution [<https://www.anaconda.com>].
- ▶ **Jupyter notebook:** interactive python development environment (GUI IDE), distributed with the Anaconda package.
- ▶ Jupyter is an anagram of: Julia, Python, and R.
- ▶ Jupyter notebook method:
 - ✓ polyglot environment, mixing source code, markdown test and formulas (LaTeX),
 - ✓ interactive/explorativt/trial-and-error environment,
 - ÷ not good at source-code level debugging.
- ▶ Other IDE's:
 - ▶ Spyder (Anaconda),
 - ▶ VSCode (Microsoft),
 - ▶ and many others...

Scikit-learn Introduction

- ▶ Scikit-learn: a framework (API + website) for machine Learning in python.
- ▶ <http://scikit-learn.org>
- ▶ <git@github.com:scikit-learn/scikit-learn.git>

The screenshot shows the official scikit-learn website. At the top, there's a navigation bar with links for 'Install', 'User Guide', 'API', 'Examples', and 'More'. Below the header, the main title 'scikit-learn' is displayed in large letters, followed by the subtitle 'Machine Learning in Python'. A search bar and a 'Go' button are on the right. Below the title, there are three orange buttons: 'Getting Started', 'What's New in 0.22.1', and 'GitHub'. To the right, there's a list of bullet points highlighting the project's features:

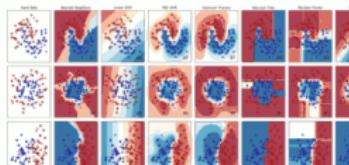
- Simple and efficient tools for predictive data analysis
- Accessible to everybody, and reusable in various contexts
- Built on NumPy, SciPy, and matplotlib
- Open source, commercially usable - BSD license

Classification

Identifying which category an object belongs to.

Applications: Spam detection, image recognition.

Algorithms: SVM, nearest neighbors, random forest, and more...

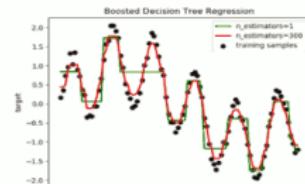


Regression

Predicting a continuous-valued attribute associated with an object.

Applications: Drug response, Stock prices.

Algorithms: SVR, nearest neighbors, random forest, and more...



Clustering

Automatic grouping of similar objects into sets.

Applications: Customer segmentation, Grouping experiment outcomes

Algorithms: K-Means, spectral clustering, mean-shift, and more...

K-means clustering on the digits dataset (PCA-reduced data)
Centroids are marked with white cross



Vores videnskabelige framework

Sat sammen...



Gode hjælpe og dokumentations-systemer..

Alternativer kunne være...



Anaconda and Jupyter Demo

The screenshot shows a Jupyter Notebook interface running on a local host at port 8888. The title bar indicates the notebook is titled "jupyter demo (autosaved)". The menu bar includes File, Edit, View, Insert, Cell, Kernel, Widgets, Help, Trusted, and Python 3. Below the menu is a toolbar with various icons for file operations like saving, opening, and running cells. The main content area displays a notebook page with the following structure:

- L01**
- Mini Python Demo**
- REVISIONS**

2019-0128	CEF, Initial.
2019-0806	CEF, E19 ITMAL update.
- Mini Python/Jupyter notebook demo**
- Text: Build-in python array an Numpy arrays...
- Code cell (In [79]):

```
# import clause, imports numpy as the name 'np'
import numpy as np

# python build-in array
x = [[1, 2, 3], [4, 5, 6]]

# print using print-f-syntax, prefeed againts say print('x =
print(f'x = {x}')
print()
```

Anaconda and Jupyter Demo: Highlights...

- ▶ Polyglot miljø:
 - ▶ lidt ala Matlab IDE,
 - ▶ markdown (HTML+LaTeX)-og-Python-i-een = polyglot,
 - ▶ alt kører i browser, lokalt eller på server.
- ▶ Quickstart:
 - ▶ åbn via `http://localhost:8888` (efter launch),
 - ▶ ENTER på celle: editer celle,
 - ▶ CTRL+ENTER: kør celle,
 - ▶ SHIFT+TAB: hjælp på funktion,
 - ▶ TAB: tab-completion.
- ▶ Magics:
 - ▶ nulstil vars: `%reset -f`,
 - ▶ inline plots: `%matplotlib inline`.
- ▶ Hints:
 - ▶ Pas på globale vars (igen scopes ml. `.ipynb` celler),
 - ▶ Brug menu 'Help' og
find shortcuts i 'open command palette'n,
 - ▶ Hvis du er C++ haj: alt er anderledes!

Q: L01/modules_and_classes.ipynb

Modules and Packages...

The screenshot shows a Jupyter Notebook interface with the following content:

ITMAL Exercise

REVISIONS

2018-1219	CEF, initial.
2018-0206	CEF, updated and spell checked.
2018-0207	CEF, made Qh optional.
2018-0208	CEF, added PYTHONPATH for windows.
2018-0212	CEF, small mod in itmalutils/utils.
2019-0820	CEF, updated.

Python Basics

Modules and Packages in Python

Reuse of code in Jupyter notebooks can be done by either including a raw python source as a magic command

```
%load filename.py
```

but this just pastes the source into the notebook and creates all kinds of pains regarding code maintenance.

A better way is to use a python **module**. A module consists simply (and pythonic) of a directory with a module `init` file in it (possibly empty)

```
libitm/_init_.py
```

Q: L01/modules_and_classes.ipynb

Python classes...

The screenshot shows a Jupyter Notebook interface with the title bar "modules_and_classes" and the URL "localhost:8888/notebook". The notebook contains the following content:

Classes in Python

Good news: Python got classes. Bad news: they are somewhat obscure compared to C++ classes.

Though we will not use object-oriented programming in Python intensively, we still need some basic understanding of Python classes. Let's just dig into a class-demo, here is `MyClass` in Python

```
class MyClass:  
    myvar = "blah"  
  
    def myfun(self):  
        print("This is a message inside the class.")  
  
myobjectx = MyClass()
```

Q: Extend the class with some public and private functions and member variables

How are private function and member variables represented in python classes?

What is the meaning of `self` in python classes?

What happens to a function inside a class if you forget `self` in the parameter list, like `def myfun():` instead of `def myfun(self):`?

[OPTIONAL] What does 'class' and 'instance variables' in python correspond to in C++? Maybe you can figure it out, I did not really get it reading, say this tutorial

<https://www.digitalocean.com/community/tutorials/understanding-class-and-instance-variables-in-python-3>

In []: # TODO: Qe...

END Python intro/BEGIN ML intro



Klassisk maskinlæring årgang 1992

Pattern recognition, machine vision, neural networks...

612 Recognition and Interpretation

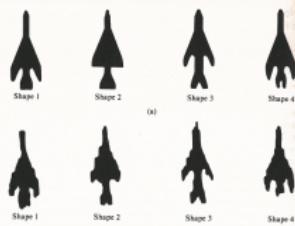


Figure 9.18. (a) Reference shapes and (b) typical noisy shapes used in training the neural network of Fig. 9.19. (From Gopas et al. [1990].)

Pattern vectors were generated by computing the normalized signatures of the shapes (see Section 8.1.3) and then obtaining 48 uniformly spaced samples of each signature. The resulting 48 48-dimensional vectors were the inputs to the three-layer feedforward neural network shown in Fig. 9.19. The number of neuron nodes in the first layer was chosen to be 48, which corresponds to the dimensionality of the input pattern vectors. The 4 neurons in the third (output) layer correspond to the number of pattern classes, and the number of neurons in the middle layer was heuristically specified as 26 (\approx the average of the number of neurons in the input and output layers). There are no known rules for specifying the number of neurons in the internal layers of a neural network, so this number generally is based either on experience or simply chosen arbitrarily and then refined by testing. In the output layer, the neurons from top to bottom in this case represent classes $a_{i,j} = 1, 2, 3$, and 4, respectively. After the network structure has been set, activation functions have to be selected for each unit and layer. All activation functions were selected to satisfy Eq. (9.3-50) so that, according to the earlier discussion, Eqs. (9.3-72) and (9.3-73) apply.

The training process was divided in two parts. In the first part, the weights were initialized to small random values with zero mean, and the network was

9.3 Decision-Theoretic Methods 613

then trained with pattern vectors corresponding to noise-free samples like the shapes shown in Fig. 9.18(a). The output nodes were monitored during training. The network was said to have learned the shapes for all four classes if, given, for any training pattern from class $a_{i,j}$, the elements of the output layer yielded $O_j \geq 0.95$ and $O_q \leq 0.05$, for $q = 1, 2, \dots, N_O$, $q \neq i$. In other words, for any pattern of class $a_{i,j}$, the output unit corresponding to that class had to be high (≥ 0.95) while, simultaneously, the output of all other nodes had to be low (≤ 0.05).

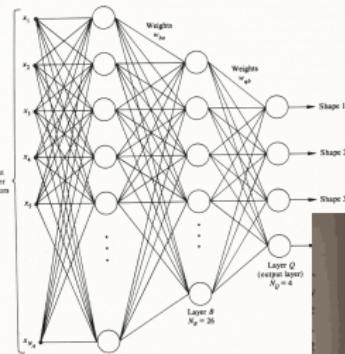
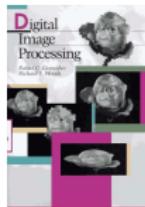


Figure 9.19. Three-layer neural network used to recognize the shapes in Fig. 9.18.

- ▶ Indeholder allerede det 'meste' ML,
- ▶ ML "vintre og somre":
90'erne=sommer,
00'erne=vinter



Digital Image Processing,
Gonzalez and Woods,
1992

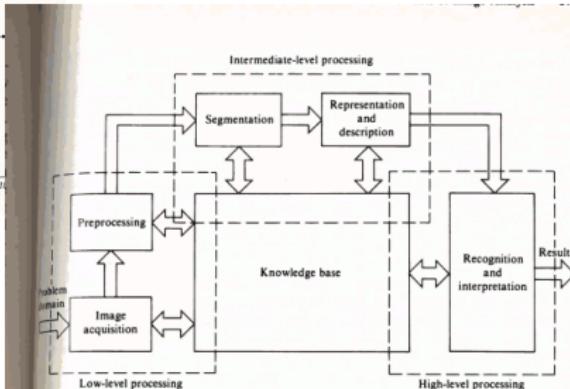
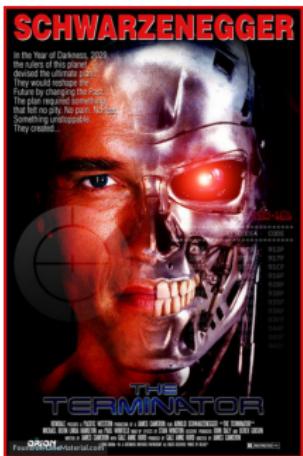


Figure 9.1. Elements of image analysis.

dark theater from bright sunlight. The (intelligent) process of finding an unoccupied seat cannot begin until a suitable image is available. The process

Moderne maskinlæring, renæssancen

SciFi:



Real:



Apple's Siri



IBM's Watson



Tesla's selvkørende bil

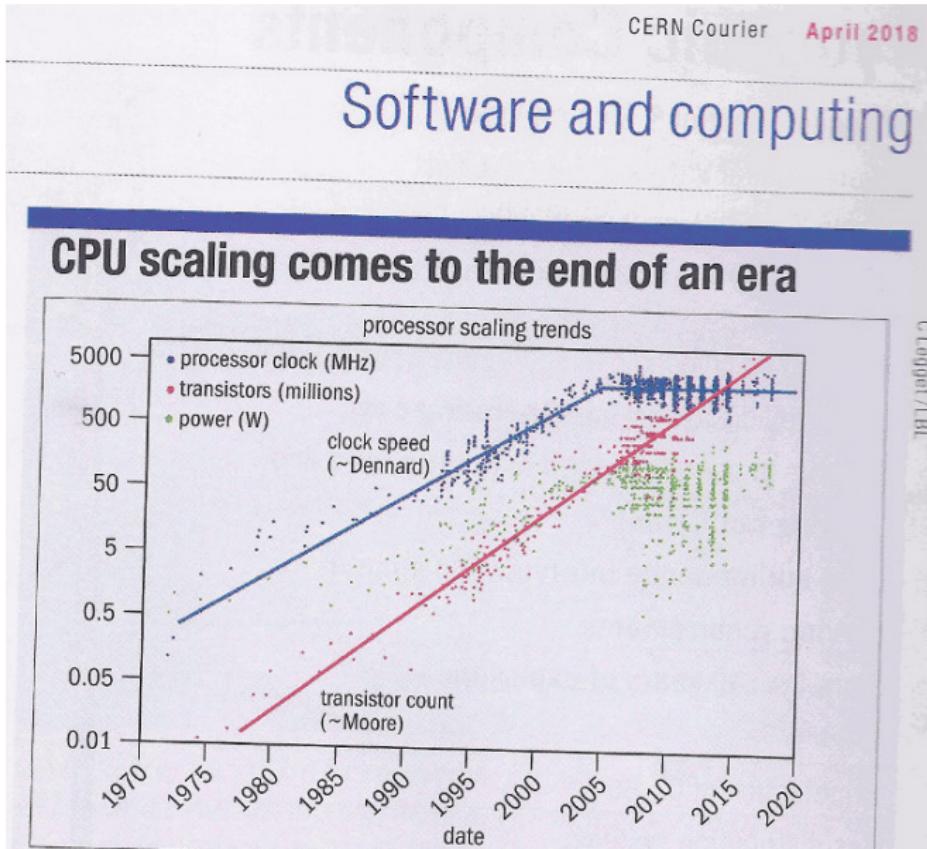
Moderne maskinlæring

Diskussion: hvad er ML for Jer?

- ▶ hvad kender I af ML systemer?
- ▶ hvilke ML systemer anvender I allerede nu?
- ▶ ...og andre ML relaterede kommentarer!

Moderne maskinlæring

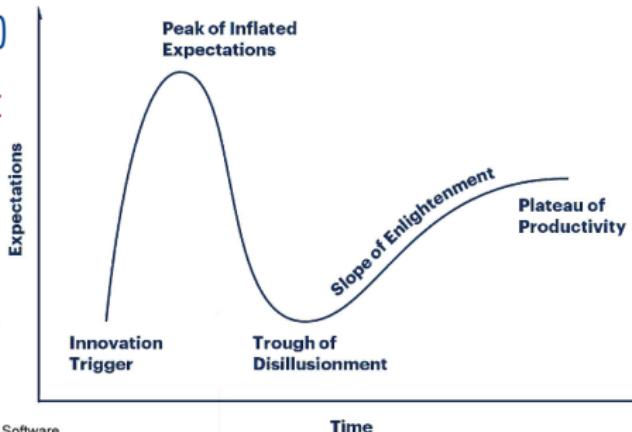
Eksponentiel udvikling og Moore's Lov



Moderne maskinlæring

Forskelse på ML og AI (artificial intelligence)

- ▶ Er det skrevet i **PowerPoint**
så er det **AI**.
- ▶ Er det skrevet i **Python**
så er det **ML**.



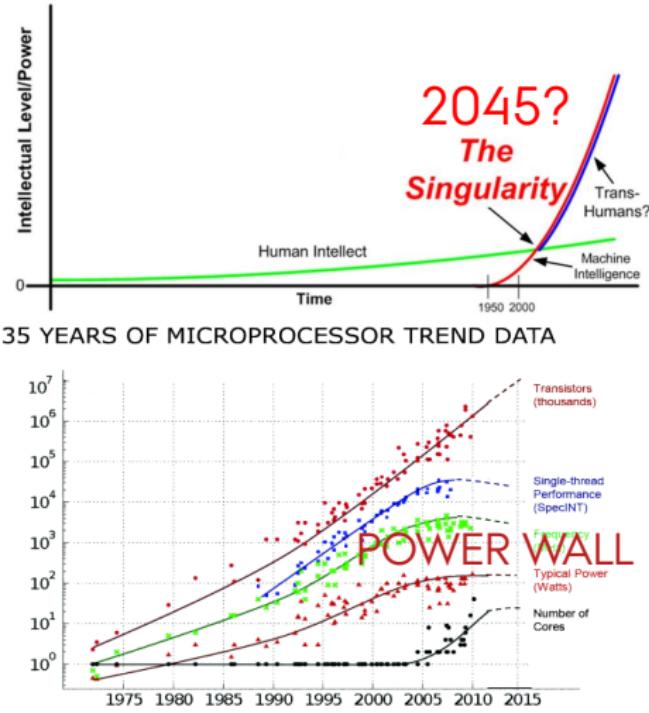
*Data is not information,
information is not knowledge,
knowledge is not understanding,
understanding is not wisdom*
- Cliff Stoll

As of July 2018

Moderne maskinlæring

Forskelse på Sci-Fi og Science

- ▶ Har seks årtiers forskning i AI led til ingenting?
- ▶ Forstår vi hjernen, cognition, menneskelig intelligens?
- ▶ Vil eksponentiel udvikling give os ægte AI?
(Ray Kurzweil, Singularity)
- ▶ Hvor er alle android, cyborg eller HAL-9000'erne i vores hverdag?



Original data collected and plotted by M. Horowitz, F. Labonte, O. Shacham, K. Olukotun, L. Hammond and C. Batten
Dotted line extrapolations by C. Moore

Fra klassisk til moderne maskinlæring

Stadig pattern recognition, machine vision, neural networks...

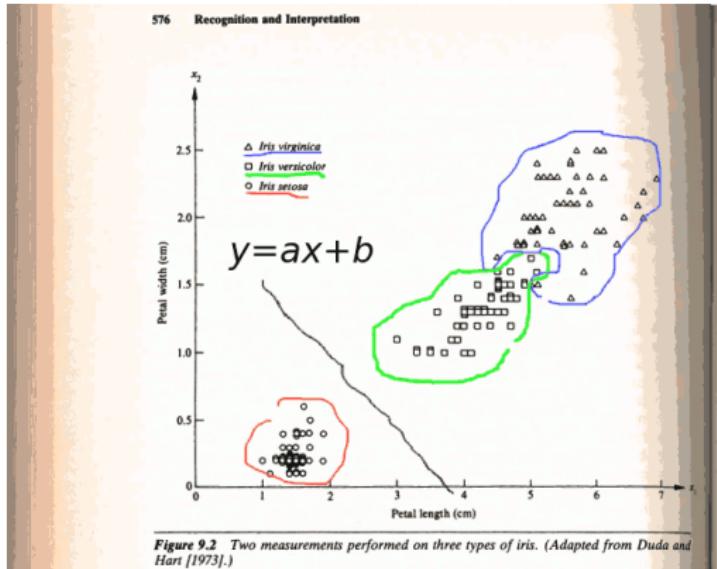
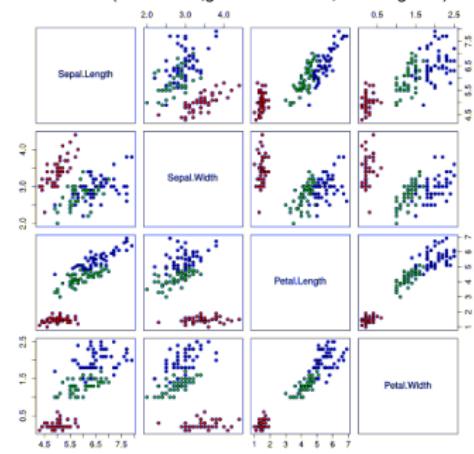


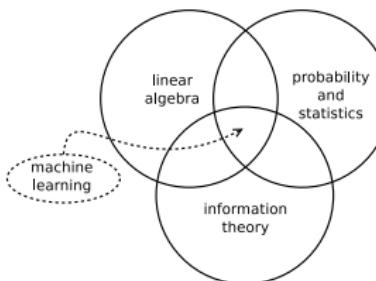
Figure 9.2 Two measurements performed on three types of iris. (Adapted from Duda and Hart [1973].)



- ▶ ikke-nyt₁: matematik,
- ▶ ikke-nyt₂: algoritmer,
- ▶ nyt₁: meget mere data og flere dimensioner, f.eks. 4D til 784D,
- ▶ nyt₂: hurtigere hardware (og parallelitet).

Machine learning baggrund

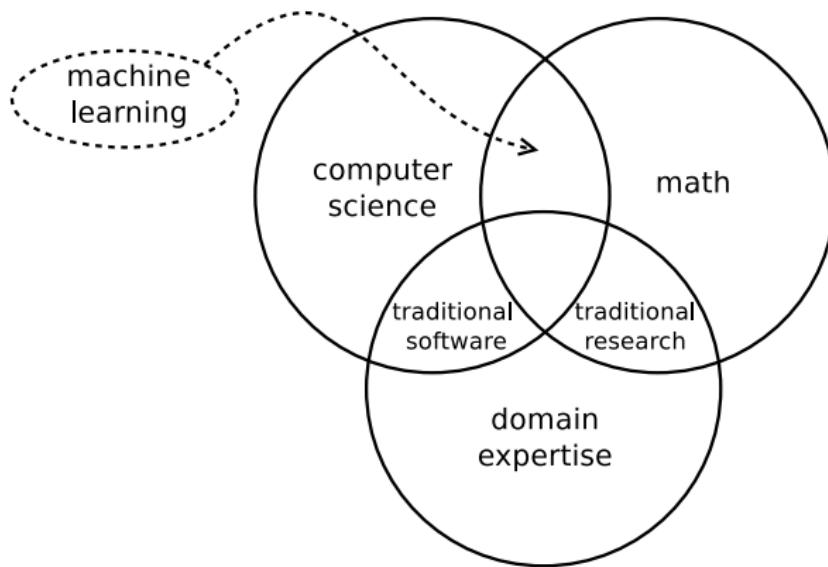
Machine learning: matematisk baggrund



- ▶ Lineær algebra, læs løbende op:
 - ▶ norm (afstand),
 - ▶ matrix algebra (mest multiplikation),
 - ▶ least-square closed solution, $(\mathbf{X}^T \mathbf{X})^{-1} \mathbf{X}^T \mathbf{y}$,
 - ▶ nabla operator, $\nabla_{\mathbf{w}} = [\frac{\partial}{\partial w_1}, \frac{\partial}{\partial w_2} \dots]$.
- ▶ Sandsynlighedsregning, læs løbende op:
 - ▶ multivariate mean, variance,
 - ▶ multivariate Gaussisk distribution,
 - ▶ (Bayes',)
- ▶ Informationsteori: vi navigere (mest) udenom entropi og andre informations-teori elementer i dette kursus.

Machine learning baggrund

Machine learning: ekspertise



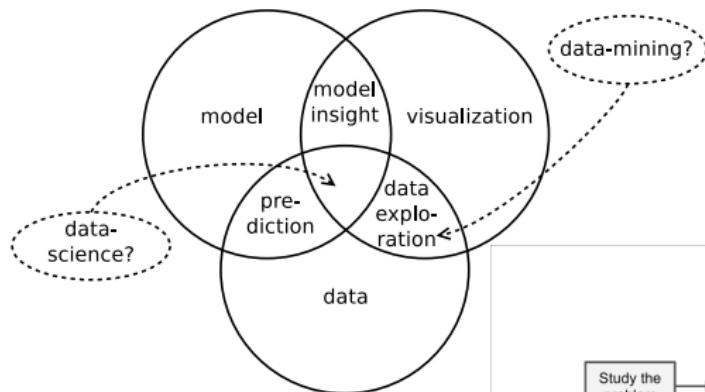
- ▶ ML ekspert er computer science og matematik ekspert.
- ▶ ML ekspert er IKKE (nødvendigvis) domæne ekspert!

NOTE:

[\[https://imarticus.org/what-are-the-skills-you-need-to-become-a-machine-learning-engineer/\]](https://imarticus.org/what-are-the-skills-you-need-to-become-a-machine-learning-engineer/)

Machine learning baggrund

Machine learning: data science ekspert



- ▶ fra white-box domæne ekspert til black-box ML data scientist,
- ▶ stadig polytekniker:
 - ▶ math- og computer science,
 - ▶ pattern-recognition,
 - ▶ neurocomputation,
 - ▶ datamining,
 - ▶ visualization,
 - ▶ etc..

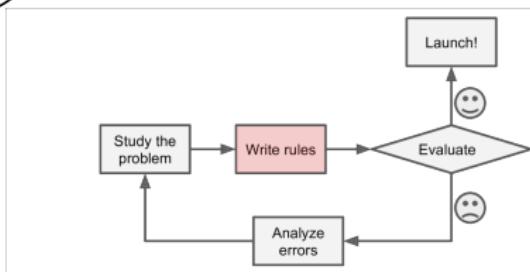


Figure 1-1. The traditional approach

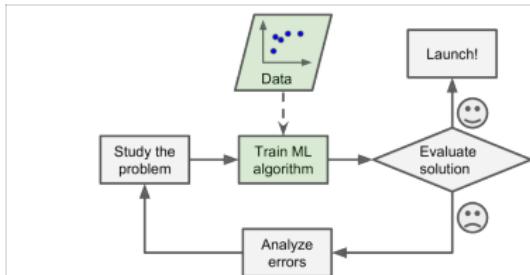
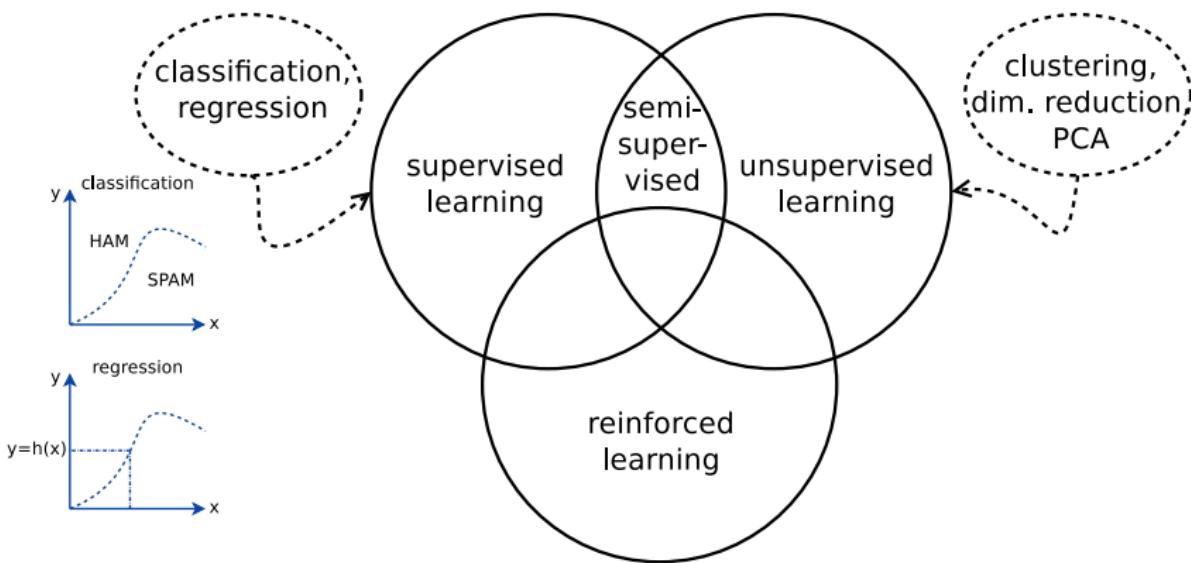


Figure 1-2. Machine Learning approach

Machine learning taksonomi

Machine learning læringsstyper



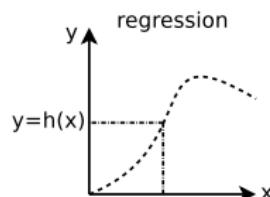
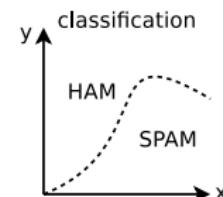
- ▶ I dette kursus:

kun om supervised- og unsupervised-learning.

Et ML end-to-end projekt

Emner fra [HOML] §2 'End-to-end Machine Learning'

- ▶ Læringstyper:
 - ▶ supervised (mest om dette i ITMAL),
 - ▶ unsupervised, [semisupervised], [reinforced learning].
- ▶ Output klasser:
 - ▶ classification (ham/spam),
 - ▶ regression ($h(x) = y$).
- ▶ Læring via data:
 - ▶ batch læring (al data),
 - ▶ [inkrementel læring (on-the-fly)].
- ▶ Prediktions/generaliserings model:
 - ▶ model-based (pattern-detection, byg intern model),
 - ▶ [instance-based (lær al data udenad)],
- ▶ Typiske ML fejl klasser:
 - ▶ for lidt trænings data (small-data, brug cross-validation),
 - ▶ sampling noise, sampling bias (ved manglende stratificering),
 - ▶ outliers og dårlig data (i big-data),
 - ▶ model og algoritme fejl: underfitting/overfitting.



Machine learning terminologi

\mathbf{X}, \mathbf{x} : input data matrix og vektor,

\mathbf{y}, y : output data vektor og skalar,

θ : model parametre,

h : hypothesis funktion; typer af ML algos:

Bayes classifier, k-Nearest Neighbors, Linear Reg., Logistic Reg., SVM, Decision Trees, Random Forest, Neural Networks, k-Means, ...

y_{true} : ground truth, til supervised learning,

y_{pred} : predikteret værdi, aka \hat{y} ,

attribut: data type, f.eks. salgspris, dog anvendes
'feature' typisk i stedet for attribut!

λ , feature: data attribut plus value, f.eks. $\lambda_{\text{salgspris}} = \42 ,

J, L , loss fun.: loss/cost/error/objective funktion, som
minimeres via fitting, jo lavere jo bedre et fit,

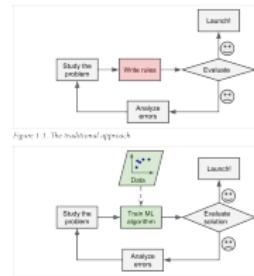
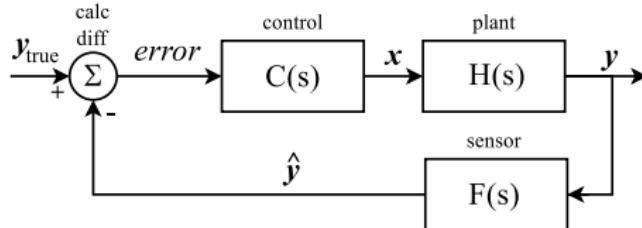
score fun.: score/fitness/goodness funktion, jo højere

performance-
metric bruges typisk efter fit-minimeringen
til model inspektion og eftervalidering.

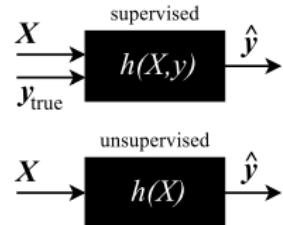
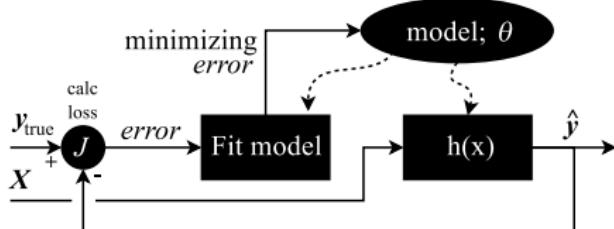
Supervised learning, blok diagram

Fra white-box til black-box

Almindelig white-box negativt feedback control block diagram, som for lineære og tids-uafhængige funktioner kan Laplace analyseres 'i det uendelige':



Supervised machine learning block diagram:



Valg af: model/hypothesis funktion, h , that's is!

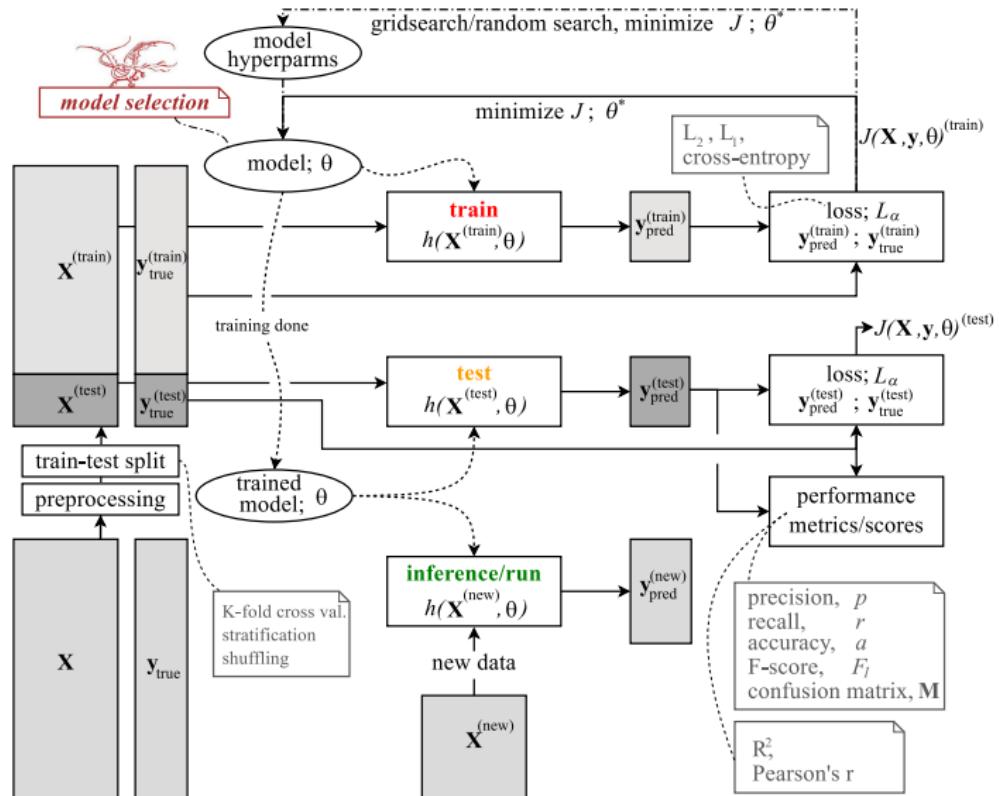
(excl. hyperparametre og valg af loss fun.)

Alt er nu black-box.

Holder ikke, kendskab til
ML algo osv. nødvendig!

Supervised learning, blok diagram

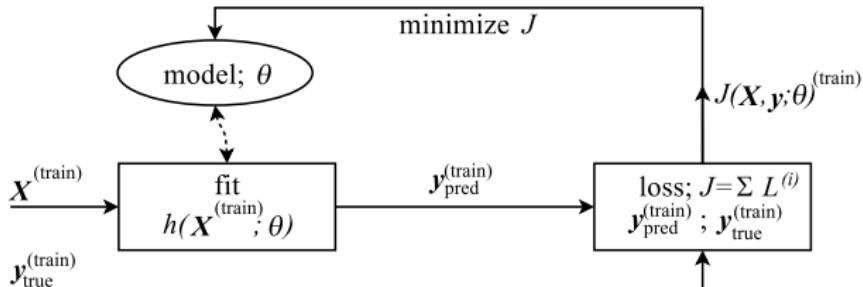
Sneak-preview af 'the full monty'...



NOTE: Kun et preview; vi går igennem detaljerne i figuren i de følgende lektioner.

Q: L01/intro.ipynb

ML supervised learning data flow model: Training (fit).

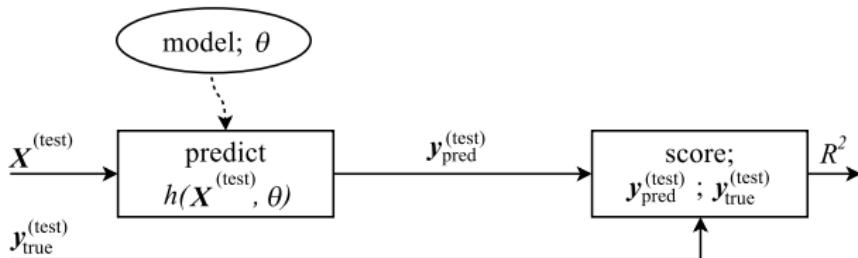


- $\mathbf{X}^{(train)}$: trænings matrix input data,
- $\mathbf{x}^{(train)}$: data input vector; $\mathbf{x} = [x_1, x_2, \dots, x_d]$,
- $\mathbf{y}_{true}^{(train)}$: trænings input ground truth vektor,
- $\mathbf{y}_{pred}^{(train)}$: predikteret værdi for y , aka \hat{y}
- θ : model parametre,
- h : hypothesis funktion, aka. ML algoritmen,
- $L^{(i)}$: loss funktion (individuel), $L^{(i)}(y_{pred}^{(i)}, y_{true}^{(i)})$
- J : loss funktion (summeret), $J = \frac{1}{n} \sum_i L^{(i)}$.

NOTE: med \mathbf{x} havende dimensionalitet d ... mere om denne og loss funktioner i L02.

Q: L01/intro.ipynb

ML supervised learning data flow model: Regression and prediction



Øvelse:

- ▶ træn en lineær regression model,
(Scikit-learn fit-predict interface),
- ▶ gå i detaljen med R^2 score funktionen,
(NOTE: test data er lig train data for denne øvelse),
- ▶ check k-Nearest Neighbors modellen ud på data,
sammenlign kNN-score med lineær regression-score.
- ▶ prøv en neutralt netværks-model på data
(NOTE: den performer ekstrem dårligt!).