Introduction

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Introduction to Machine Learning

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What is Machine Learning?

DeepBlue (1997)
handcrafted artificial intelligence
beats chess world champion

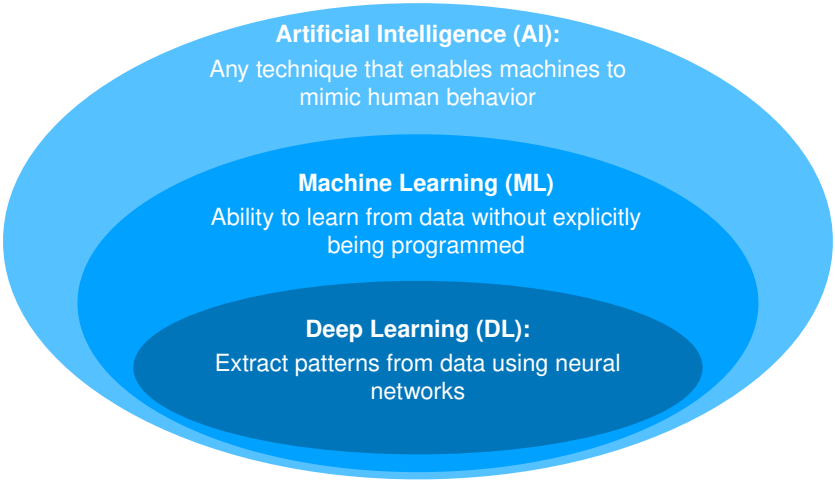
AlphaGo (2016)
artificial intelligence trained with Machine Learning beats Go world champion

Instead of listing out the rules, let machines automatically learn how input data is correlated with a given task/objective/outcome. “Learning is any process by which a system improves performance from experience. **Machine Learning is concerned with computer programs that automatically improve their performance through experience**”, H. Simon

What is Machine Learning?

- The term “Machine Learning” appears in the 1960s in the field of Artificial Intelligence (Computer Science), but important concepts existed already before.
  Samuel, A. (1959). "Some Studies in Machine Learning Using the Game of Checkers".
  `https://doi.org/10.1147/Frd.33.0210`, Schmidhuber, J. (2015). Deep learning in neural networks: An overview `http://dx.doi.org/10.1016/j.neunet.2014.09.003`.
- Machine Learning shares with Statistics the goal of learning from data.
  $\Rightarrow$ Alternative term: Statistical Learning.
- Machine Learning started to flourish in the 1990s
  and gained a lot of popularity since 2010.
- Some say we are now in the Third AI Summer `https://vimeo.com/389560858`
- Machine Learning searches for artificially intelligent algorithms that improve with experience: “A computer program is said to learn from experience E with respect to some class of tasks T and performance measure P if its performance at tasks in T, as measured by P, improves with experience E.” Mitchell, T. (1997). Machine Learning.

What is Machine Learning?



modified slide of Alexandre Alahi

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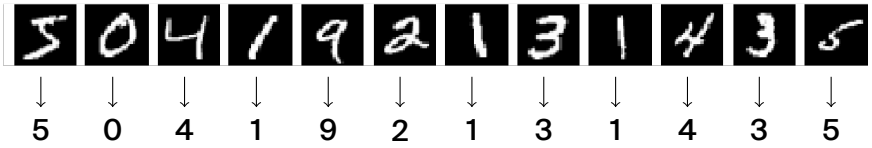
Examples: Recognition of Handwritten Digits

input: gray scale images (28 x 28 pixels)



desired output: digit class

learning task: learn to imitate humans,
given 60'000 examples of images with labels (i.e. corresponding digit class).

`https://www.kaggle.com/c/digit-recognizer/overview`

Examples: Object Recognition

input: color images

mite container ship motor scooter leopard grille mushroom cherry Madagascar cat

desired output: class label

learning task: learn to imitate humans,
given many examples of images with labels (i.e. corresponding object class).

`https://image-net.org`, `https://devopedia.org/imagenet`

Where Do Labels Come From?

https://ghostwork.info/

Examples: Cancer Detection

input: images

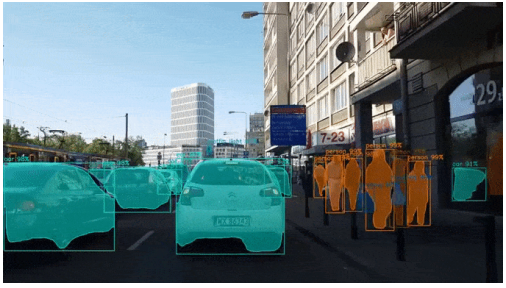
desired output:
yes, if there is at least one pixel of tumor tissue on the image, otherwise **no**.

learning task: learn to imitate doctors,
given many examples of images with labels (i.e. tumor yes or no).

`https://www.kaggle.com/c/histopathologic-cancer-detection/overview`

Examples: Image Segmentation

input: color images or videos



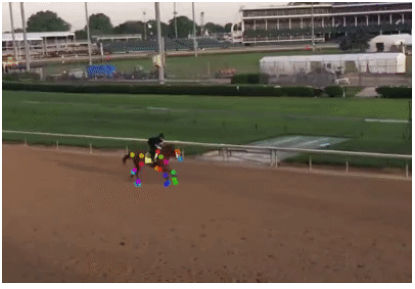
desired output: assign pixels to objects

learning task: learn to imitate humans,
given many examples of images with labels for every pixels.

`https://github.com/matterport/Mask_RCNN`, `https://github.com/facebookresearch/detectron2`

Examples: Pose Estimation

input: color images or videos



desired output: coordinates of body parts

learning task: learn to imitate humans,
given many examples of images with labels (i.e. corresponding coordinates).

`http://www.mousemotorlab.org/deeplabcut/`

Examples: Machine Translation

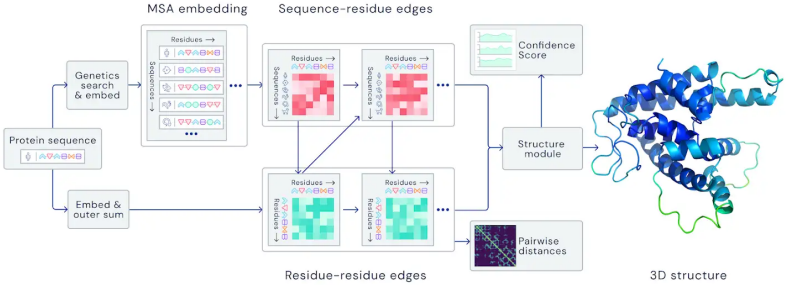
Parteichefin Kipping warnt vor Abschottung - und kritisiert indirekt ihre Genossin Wagenknecht. Die Linken-Bundesvorsitzende Katja Kipping hat ihre Partei aufgefordert, sich in der Frage zwischen Abschottung oder Solidarität eindeutig zu positionieren. Zum Auftakt des Europaparteitags in Bonn sagte Kipping: "Im Sinne dieser Eindeutigkeit sagte ich auch: Europa ist längst ein Kontinent der Einwanderung." Das "Recht auf weltweite Bewegungs- und Auswanderungsfreiheit" sei "ein hohes Gut", Menschenrechte unteilbar. Indirekt widersprach Kipping damit auch der Fraktionsvorsitzenden Sahra Wagenknecht, die immer wieder Vorbehalte gegen eine zu flüchtlingsfreundliche Politik geäußert und deshalb auch Kanzlerin Angela Merkel (CDU) mehrfach kritisiert hatte. Wagenknecht ist als bekannteste Politikerin der Linken bereits seit mehreren Wochen erkrankt. Sie nimmt deshalb auch nicht an dem Parteitag in Bonn teil. Der Parteitag spendete ihr Genesungswünsche. Die Bundestagsfraktion hatte einen gegen sie wegen der Kontroversen um die Flüchtlingspolitik geplanten Aufstand Anfang Januar abgeblasen. Kipping sagte vor den Delegierten in Bonn weiter: "Während Trump, Salvini, Orban und Typen wie Seehofer eine Internationale der Mauerbauer schmieden, setzen wir auf internationale Solidarität." Dies sei für die Linkspartei "auch eine Lehre aus der historischen Erfahrung eines Staatssozialismus, der glaubte, mit Mauern und Stacheldraht überleben zu können". Auf eine andere EU hinzuarbeiten, sei die größere Liebeserklärung an Europa als zuzulassen, dass die EU bleibe wie sie ist, erklärte die Parteivorsitzende. Denn der jetzige Zustand spielt den Rechten und Marktradikalen in die Hände.

La présidente de gauche Katja Kipping a demandé à son parti de se positionner clairement sur la question du cloisonnement ou de la solidarité. En prélude à la journée de l'appartement européen à Bonn, Kipping a déclaré : "Dans le sens de cette clarté, j'ai également dit que l'Europe était depuis longtemps un continent d'immigration". Le "droit à la liberté de circulation et d'émigration dans le monde" est "un bien précieux", les droits de l'homme indivisibles. Kipping contredit ainsi indirectement le président du groupe Sahra Wagenknecht, qui avait toujours exprimé des réserves sur une politique trop favorable aux réfugiés et avait donc critiqué à plusieurs reprises la chancelière Angela Merkel (CDU). Wagenknecht, la politicienne la plus connue de la gauche, est malade depuis plusieurs semaines. Elle ne participe donc pas non plus au congrès du parti à Bonn. Le congrès du parti lui a adressé ses vœux de rétablissement. Le groupe du Bundestag avait fait sauter un soulèvement prévu contre lui au début du mois de janvier en raison des controverses sur la politique des réfugiés. Kipping a ajouté devant les délégués à Bonn : "Alors que Trump, Salvini, Orban et des types comme Seehofer forgent une Internationale des constructeurs de murs, nous misons sur la solidarité internationale". Pour le parti de gauche, "c'est aussi une leçon de l'expérience historique d'un socialisme d'État qui croyait pouvoir survivre avec des murs et des fils barbelés". Travailler vers une autre UE est une plus grande déclaration d'amour à l'Europe que de permettre à l'UE de rester telle qu'elle est, a déclaré la présidente du parti. Car la situation actuelle fait le jeu de la droite et des radicaux du marché.

`http://www.statmt.org/wmt19/index.html` (Microsoft Research Asia: Multi-Agent Dual Learning)

Examples: Protein Folding

input: protein amino acid sequence



desired output: 3D structure of the protein

learning task: learn to imitate the laborious task of 3D reconstruction (X-ray crystallography) from many examples of protein sequences with known 3D structure.

`https://deepmind.com/research/case-studies/alphafold`

Examples: Image Generation

optional input: high level aspects, e.g. hair color, facial expression, gender, age

desired output: realistically looking images

learning task: learn to generate realistic photos, given many examples of photos.

`https://github.com/NVlabs/stylegan`, `https://thispersondoesnotexist.com/`

Examples: Image Generation

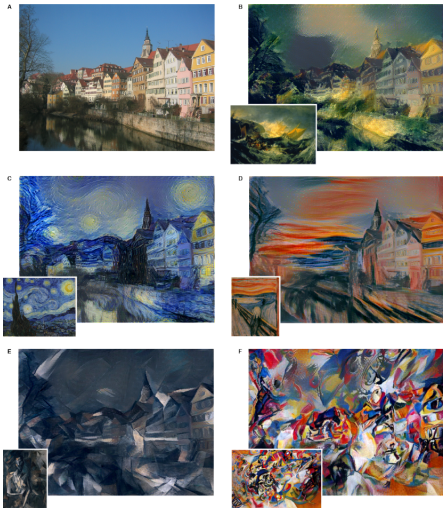
input: some text, e.g. “A blue jay standing on a large basket of rainbow macarons.”

desired output: realistically looking images

learning task: learn to generate realistic photos, given many examples of photos.

`https://imagen.research.google/`, `https://openai.com/dall-e-2/`

Examples: Style Transfer



input: one content image (top left) and one style image (small images)

desired output: an image with desired content and style

learning task: there is no classical learning task here, but rather a creative use of a machine learning model (convolutional neural network).

`https://arxiv.org/abs/1508.06576v2`

Examples: Text Generation

optional input: e.g. start of phrase, context.

Machine learning is not that new. As early as 2006, one team found a way to automatically analyze the social media profiles of millions of people to determine the personalities of them, including the people who liked and commented on the content of a particular post. The technology was so impressive that other companies started experimenting with similar approaches , including a company called DeepMind that won a Google award for its work. But there is a serious problem here , and it is the fundamental lack of interest among academics and the media in solving the problem of social media data in general.

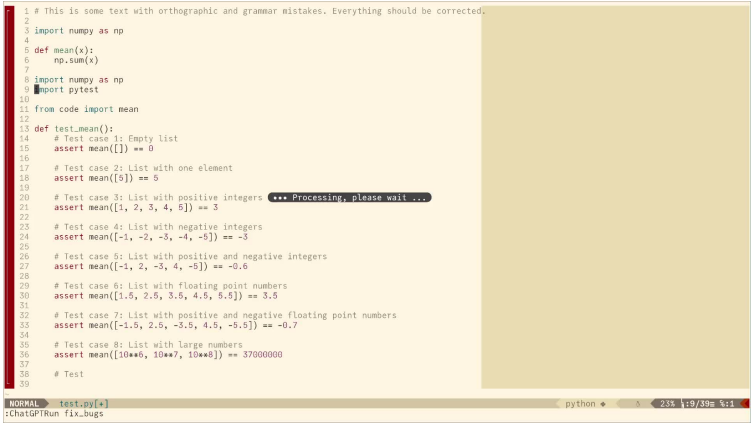
desired output: sensible text

learning task: learn to generate sensible text, given many examples of texts.

`https://github.com/huggingface/transformers`

Examples: GPT

Generative Transformer-based model pre-trained to predict the next token in a document. https://arxiv.org/abs/2303.08774. Example: Assistance in editor:



Examples: GPT

Example: Counterfactual reasoning.

Assume I had special boots which allowed me to walk 1000 meters per second with little effort. What would I do to visit my grandmother who lives at the other end of the continent?

Answer by `https://perplexity.ai`:

Assuming you had special boots that allowed you to walk 1000 meters per second with little effort, you would be able to travel 3,600,000 meters (3600 kilometers) in an hour. To visit your grandmother who lives at the other end of the continent, you would need to know the exact location of your grandmother and the distance between you and her. Assuming you are in the United States, and your grandmother is in Italy, you would need to travel approximately 7,000 kilometers. With your special boots, you would be able to reach your grandmother's location in less than 2 hours. However, it is important to note that traveling at such high speeds can be dangerous and may cause harm to yourself and others around you. Therefore, it is not recommended to travel at such high speeds without proper safety precautions and training.

Examples: Theorem Proving

input: mathematical axioms and theorems (goals)

```
cnf(sos01,axiom, ( product(A,A) = A )).
cnf(sos02,axiom, ( product(A,product(B,C)) = product(product(A,B),product(A,C)) )).
...
cnf(goals,negated_conjecture, ( product(product(product(x0,x1),x1),product(x0,x2)) !=
product(product(x0,x1),product(product(x1,x0),x2)) )).
```

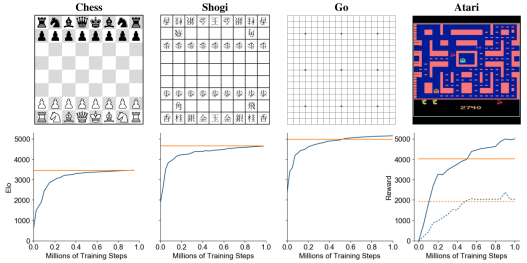
desired output: steps to prove the theorem from the axioms

learning task: learn solving strategies by trial-and-error on many examples of axioms and theorems.

`http://www.tptp.org/`, `https://deepmind.com/research/publications/Training-a-First-Order-Theorem-Prover-from-Synthetic-Data`

Examples: Games

input: rules of a game



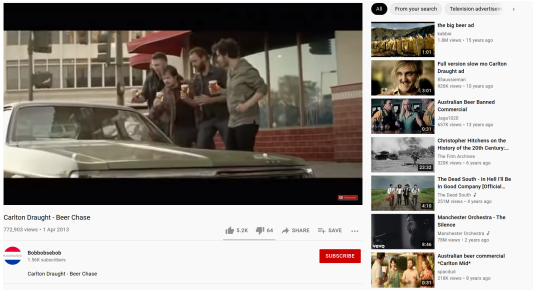
desired output: winning policy

learning task: learn winning strategies by trial-and-error from many games of the computer playing against itself.

`https://arxiv.org/abs/1911.08265`

Examples: Advertisement

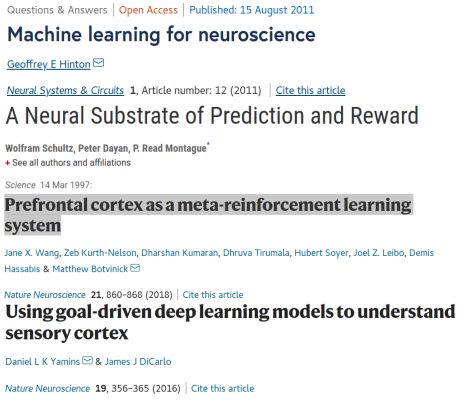
input: user profile (currently viewed page & history)



desired output: attractive suggestions

learning task: learn by trial-and-error to display the suggestions that users will select with high probability.

Examples: Machine Learning as Models of Brain Function



Questions & Answers | Open Access | Published: 15 August 2011

Machine learning for neuroscience

Geoffrey E Hinton

Neural Systems & Circuits **1**, Article number: 12 (2011) | Cite this article

A Neural Substrate of Prediction and Reward

Wolfram Schultz, Peter Dayan, P. Read Montague*

+ See all authors and affiliations

Science 14 Mar 1997:

Prefrontal cortex as a meta-reinforcement learning system

Jane X. Wang, Zeb Kurth-Nelson, Dharshan Kumaran, Dhruva Tirumala, Hubert Soyer, Joel Z. Leibo, Demis Hassabis & Matthew Botvinick

Nature Neuroscience **21**, 860–868 (2018) | Cite this article

Using goal-driven deep learning models to understand sensory cortex

Daniel L K Yamins & James J DiCarlo

Nature Neuroscience **19**, 356–365 (2016) | Cite this article

- https://neuralsystemsandcircuits.biomedcentral.com/articles/10.1186/2042-1001-1-12
- https://www.pdn.cam.ac.uk/system/files/documents/1997-science.pdf
- https://www.biorxiv.org/content/biorxiv/early/2018/04/13/295964.full.pdf
- http://brainmind.umin.jp/PDF/wt17/Yamins3.pdf

Other Links

Competitions

https://www.kaggle.com/

https://dreamchallenges.org/

Notable Companies

https://www.amazon.science/

https://ai.facebook.com/

https://ai.google/

https://deepmind.com/

https://machinelearning.apple.com/

https://openai.com/

Datasets

https://www.datasetlist.com/

https://registry.opendata.aws/

https://www.kaggle.com/

https://www.openml.org/

State-of-the-Art Research

https://paperswithcode.com/sota

Books

https://people.eecs.berkeley.edu/~russell/hc.html

https://en.wikipedia.org/wiki/The_Age_of_Surveillance_Capitalism

https://ghostwork.info/

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Tasks

- **supervised learning**: predict a class label (**classification**) or real values (**regression**) from an input. Training data: input X, output y.
- **unsupervised learning**: discover good features for representing or visualizing the input data or for generating examples similar to the input data. Training data: input X.
- **reinforcement learning**: discover what action should be performed next (a policy) in order to maximize the eventual payoff. Training data is obtained by interacting with an environment and observing reward.

Goals

- **Prediction** with highest possible accuracy.
  e.g. "Do we see cancer on this image or not?"
- **Interpretation**.
  e.g. "Which visual features are most indicative of cancer?"
- **Visualization**.
  e.g. "Are some images more similar to each other than to others, i.e. are there some clusters in the data?"
- **Data Generation**.
  e.g. "Can we generate realistically looking artificial histology images?"

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Quiz

1. For digit recognition (MNIST), machine learning models are trained on many examples of (image, digit label) pairs. What kind of machine learning task is this?
   A supervised **B** unsupervised **C** reinforcement
2. What kind of machine learning task is cancer detection?
   A regression **B** classification **C** neither
3. For translation, machine learning models are trained of many examples of (source language, target language) pairs. What kind of machine learning task is this?
   A supervised **B** unsupervised **C** reinforcement
4. What is the primary goal in the above three tasks from the perspective of a post office, medical doctor or internet user?
   A prediction **B** interpretation **C** visualization
5. For theorem proving, machine learning models are given axioms, a theorem and a signal to encourage the machine to find a short number of steps from axioms to theorem. What kind of machine learning task is this?
   A supervised **B** unsupervised **C** reinforcement
6. What kind of machine learning task is digit recognition (MNIST)?
   A regression **B** classification **C** neither

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Logistics

- Lectures on Wednesdays 8h15 - 10h00 in MXF 1
- Exercises on Fridays 15h15 - 17h00 in CM5 (**bring your laptop!**)
- Interactive website with illustrations, code examples and exercises:
  `https://bio322.epfl.ch`
  In the exercise session you should
  - study the illustrations to understand the theory.
  - look at the code examples to prepare for exercises and project.
  - solve the exercises.
- Exercise solutions are uploaded to moodle after the exercise sessions.
- Ask questions on Ed Discussion! (see Moodle)
  Teachers and students can provide answers.

Semester Overview

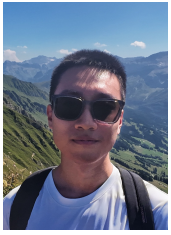
- Week 1: Introduction.
- Weeks 2-10: Supervised Learning
- Weeks 11-12: Unsupervised Learning
- Week 13: Reinforcement Learning
- Week 14: no lecture
- Project in weeks 11-14 (teams of at most 2) (**1/3 Grade**)
- Exam Session in January: Written Exam 180 minutes (**2/3 Grade**)

Project

- The project starts end of November (description and exact date tbd).
- Submission deadline is Friday 20 December 2024 at 18:00.
- You will work in teams of 2 (alone is also possible).
- We will organize a machine learning competition for the best prediction.
- You will hand in the code and a 2 pages written report.

Your Support Team

Lucas Gruaz



Zihan Wu

Simon Crouzet

Nicolás Reátegui

Nayan Adani

Recommended Textbooks

This course is strongly inspired by the first two books.
The other books are a bit more advanced.

- **An Introduction to Statistical Learning**
  `www.statlearning.com`
- **Reinforcement Learning an Introduction**
  `http://incompleteideas.net/book/the-book-2nd.html`
- The Elements of Statistical Learning
  `https://web.stanford.edu/~hastie/ElemStatLearn`
- Bayesian Reasoning and Machine Learning
  `http://web4.cs.ucl.ac.uk/staff/D.Barber/pmwiki/pmwiki.php?n=Brml.HomePage`
- Pattern Recognition and Machine Learning
  `www.microsoft.com/en-us/research/publication/pattern-recognition-machine-learning`