

Neurocomputing

Introduction

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Source: https://data-science-blog.com/blog/2018/05/14/machine-learningvs-deep-learning-wo-liegt-der-unterschied

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• The term **Artificial Intelligence** was coined by John McCarthy at the Dartmouth Summer Research Project on Artificial Intelligence in **1956**.

The study is to proceed on the basis of the conjecture that every aspect of learning or any other feature of intelligence can in principle be so precisely described that a machine can be made to simulate it.

• Good old-fashion AI approaches (GOFAI) were purely symbolic (logical systems, knowledge-based) systems) or using linear neural networks.

They were able to play checkers, prove mathematical theorems, make simple conversations (ELIZA), translate languages...



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- Machine learning (ML) is a branch of AI that focuses on learning from examples (data-driven).
- ML algorithms include:
 - Neural Networks (multi-layer perceptrons)
 - Statistical analysis (Bayesian modeling, PCA)
 - Clustering algorithms (k-means, GMM, spectral clustering)
 - Support vector machines
 - Decision trees, random forests
- Other names: big data, data science, operational research, pattern recognition...



Source: https://data-science-blog.com/blog/2018/05/14/machine-learningvs-deep-learning-wo-liegt-der-unterschied

- **Deep Learning** is a recent re-branding of neural
- Deep learning focuses on learning high-level representations of the data, using:
 - Deep neural networks (DNN)
 - Convolutional neural networks (CNN)
 - Recurrent neural networks (RNN)
 - Generative models (GAN, VAE)
 - Deep reinforcement learning (DQN, PPO, AlphaGo)
 - Transformers
 - Graph neural networks



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- Neurocomputing is at the intersection between computational neuroscience and artificial neural networks (deep learning).
- Computational neuroscience studies the functioning of the brain through detailed models.
- Neurocomputing aims at bringing the mechanisms underlying human cognition into artificial intelligence.

AI hypes and AI winters



Classification of ML techniques

- **Supervised learning**: The program is trained on a pre-defined set of training examples and used to make correct predictions when given new data.
- **Unsupervised learning**: The program is given a bunch of data and must find patterns and relationships therein.
- **Reinforcement learning**: The program explores its environment by producing actions and receiving rewards.



But also:

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• Self-supervised learning, self-taught learning, developmental learning...

Source: http://www.isaziconsulting.co.za/machinelearning.html

1- Supervised learning

Supervised Learning



reduces its **prediction error** on the training data.

 $\theta^* = \mathrm{ar}$

Source: Andrew Ng, Stanford CS229, https://see.stanford.edu/materials/aimlcs229/cs229notes1.pdf

- When learning is successful, the model can be used on novel examples (generalisation).
- The modality of the inputs and outputs does not really matter:
 - Image → Label : image classification
 - Image \rightarrow Image : semantic segmentation
 - Speech → Text : **speech recognition**
 - Text \rightarrow Speech : **speech synthesis**

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• **Supervised learning** consists in presenting a dataset of input and output samples (or examples) $(x_i, t_i)_{i=1}^N$ to a parameterized model.

 $y_i = f_{ heta}(x_i)$

• The goal of learning is to adapt the parameters θ , so that the model

$$\displaystyle {\mathop{\mathrm{gmin}}} \sum_{i=1}^N ||t_i-y_i||$$

Supervised learning : regression



Supervised learning : regression



Supervised learning : regression



Supervised learning : classification



Supervised learning : classification



Supervised learning : classification



The artificial neuron

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• A single artificial neuron is able to solve linear classification/regression problems:



$$y=f(\sum_{i=1}^d w_i\,x_i+b)$$

• A neuron integrates inputs x_i by multiplying them with weights w_i , adds a bias b and transforms the result into an output y using a transfer function (or activation function) f.

b)

Artificial Neural Network

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• A neural network (NN) is able to solve non-linear classification/regression problems by combining many artificial neurons.



Classical approach to pattern recognition







Deep Learning approach to pattern recognition

• End-to-end learning: the NN is trained directly on the raw data (pixels, sounds, text) and solves a nonlinear classification/regression problem.





Convolutional neural networks

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- A convolutional neural network (CNN) is a cascade of convolution and pooling operations, extracting layer by layer increasingly complex features.
- It can be trained on huge datasets of annotated examples.



Albelwi S, Mahmood A. 2017. A Framework for Designing the Architectures of Deep Convolutional Neural Networks. Entropy 19:242. doi:10.3390/e19060242

Handwriting recognition

- The MNIST database is the simplest benchmark for object recognition (> 99.5 %).
- One of the early functional CNN was LeNet5, able to classify digits.



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1998)

LeCun et al. (1998). Gradient-Based Learning Applied to Document Recognition (Proc. IEEE

ImageNet recognition challenge

• The ImageNet challenge was a benchmark for computer vision algorithms, providing millions of annotated images for object recognition, detection and segmentation.

Object recognition

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Object detection



Object segmentation



AlexNet

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- achieve.

• Classical computer vision methods obtained moderate results, with error rates around 30%.

• In 2012, Alex Krizhevsky, Ilya Sutskever and Geoffrey E. Hinton (Uni Toronto) used a CNN (**AlexNet**) without any preprocessing, using directly images as inputs.

• To the big surprise of everybody, they won with an error rate of 15%, half of what other methods could

• Since then, everybody uses deep neural networks for object recognition.

• The deep learning hype had just begun...

Computer vision

Natural language processing

Speech processing

Robotics, control

Object detection

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Classification, easy these days

Object detection, still a lot harder

Object detection

- It turns out object detection is both a classification (what) and regression (where) problem.
- Neural networks can be trained to do it given enough annotated data.



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regression (where) problem. d data.

Object detection



Semantic segmentation

• Classes can be predicted at the pixel level, allowing semantic segmentation.



Badrinarayanan, Handa and Cipolla (2015). "SegNet: A Deep Convolutional Encoder-Decoder Architecture for Robust Semantic Pixel-Wise Labelling." arXiv:1505.07293

Semantic segmentation



Dave2 : NVIDIA's self-driving car



Dave2 : NVIDIA's self-driving car



Facial recognition





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- 4030 users to train **DeepFace**.
- with humans.

• Facebook used 4.4 million annotated faces from

Accuracy of 97.35% for recognizing faces, on par

• Used now to recognize new faces from single examples (transfer learning, one-shot learning).

Recurrent neural networks

Recurrent neural networks



Source: C. Olah



- A **recurrent neural network** (RNN) uses it previous output as an additional input (*context*).
- The inputs are integrated over time to deliver a response at the correct moment.
- This allows to deal with time series (texts, videos) without increasing the input dimensions.
- The input to the RNN can even be the output of a pre-trained CNN.
- The most efficient RNN is called **LSTM** (Long shortterm memory networks) (Hochreiter and Schmidhuber, 1997).

Natural Language Processing : Automatic word/sentence completion



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Natural Language Processing : Text Generation

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PANDARUS: Characters or words are fed one by one into a Alas, I think he shall be come approached and LSTM. the day When little srain would be attain'd into being • The desired output is the next character or word in never fed, the text. And who is but a chain and subjects of his death, • Example: I should not sleep. Inputs: To, be, or, not, to Second Senator: They are away this miseries, produced upon my • Output: **be** soul, Breaking and strongly should be buried, when I • The text on the left was generated by a LSTM perish having read the entire writings of William The earth and thoughts of many states. Shakespeare. DUKE VINCENTIO: • Each generated word is used as the next input. Well, your wit is in the care of side and that.

http://karpathy.github.io/2015/05/21/rnn-effectiveness

Natural Language Processing : text translation





- Two LSTM can be stacked to perform sequence-to-sequence translation (seq2seq).
- One is the encoder, the other the decoder.

Natural Language Processing : Google Neural Machine Translation



- Same idea, but with much more layers...
- Can translate any pair of languages!

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Transformers

1 - Semi-supervised training on large amounts of text (books, wikipedia..etc).



Source: https://jalammar.github.io/illustrated-bert/

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2 - Supervised training on a specific task with a labeled dataset.

GPT - Generative Pre-trained Transformer

• GPT can be fine-tuned (transfer learning) to perform machine translation.

Training Dataset

I	am	а	student	<to-fr></to-fr>	je	suis	étudiant
let	them	eat	cake	<to-fr></to-fr>	Qu'ils	mangent	de
good	morning	<to-fr></to-fr>	Bonjour				



Source: https://jalammar.github.io/illustrated-gpt2/

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GPT - Generative Pre-trained Transformer

• GPT can be fine-tuned to summarize Wikipedia articles.



Source: https://jalammar.github.io/illustrated-gpt2/

JOR TAN		Read	Edit	View history	Search Wikipedia	
Positronic brain						
From Wikipedia, the free encyclopedia						
(Redirected from Positronic robot)						
This article is about a fictional technological device. For the man	facturing company based in Sp	vingfield	, Missu	ouni, see Pos	itronic (company).	
This article needs additional citation sources. Unsourced material may be of Find sources: "Providence brain" – news - new messared	a for verification. Please help i hallenged and removed. spepers - books - scholar - JSTOR (J	mprove (wy 2008)	this art	icle by addin	g citations to reliable to remove this template	
A positronic brain is a fictional technological device, originally conc	eived by science fiction writer Is	aac Asir	nov.11	21 It function	s as a central processing u	nit (CPU)
rebots, and, in some unspecified way, provides them with a logar	IMMAF	Y	When	Asimov wrot	e his first robot stories in 1	939 and 1
"Runaround", by Asimov, elaborates on the concept, in the context of	This fictional Three Laws of Rot	otics.	e popu	lar science s	o the concept. The short st	lony
Contents (hide)						
1 Conceptual overview						
2 In Allen's trilogy 3 Belarances in other fiction and time						
3.1 Abbott and Costello Go To Mars						
3.2 The Avergers						
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3.7 Dicentennial Man						
3.8 Buck Rogers in the 25th Century						
3.9 Mystery Science Theater 3000 3.10 Spectreman						
3.11 Stellaris						
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5 External links						
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Asimov remained vague about the technical details of positronic bra	ns except to assert that their su	bstructur	re was	formed from	an alloy of platinum and in	idium, Th
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Try transformers at https://huggingface.co

pip install transformers





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Github copilot

- Github and OpenAI trained a GPT-3-like architecture on the available open source code.
- Copilot is able to "autocomplete" the code based on a simple comment/docstring.

https://copilot.github.com/

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Voice recognition





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- CNNs are not limited to images, voice signals can also be recognized using their mel-spectrum.
- Siri, Alexa, Google now, etc. use recurrent CNNs to recognize vocal commands and respond.
- **DeepSpeech** from Baidu is one of the state-of-theart approach.

2 - Unsupervised learning

Unsupervised learning

• In unsupervised learning, only raw input data is provided to the algorithm, which has to analyze the statistical properties of the data.



https://learn.g2.com/supervised-vs-unsupervised-learning

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• The goal of **unsupervised learning** is to build a model or find useful representations of the data, for

finding groups of similar data and model their density (clustering).

reduce the redundancy of the input dimensions (dimensionality reduction).

finding good explanations / representations of the data (latent data modeling).

generate new data (generative models).

Clustering: learning topologies in film preferences



Dimensionality reduction: finding the right latent space

- Images have a lot of dimensions (pixels), most of which are redundant.
- Dimensionality reduction techniques allow to reduce this number of dimensions by projecting the data into a **latent space**.
- Autoencoders are NN that learn to reproduce their inputs by compressing information through a bottleneck.



https://hackernoon.com/autoencoders-deep-learning-bits-1-11731e200694

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Reconstructed input

Dimensionality reduction: visualization

• If the latent space has two or three dimensions, you can use dimensionality reduction to visualize your data.



https://hackernoon.com/latent-space-visualization-deep-learning-bits-2-bd09a46920df

- Classical machine learning algorithms include PCA (principal component analysis) or t-SNE.
- NN autoencoders can also be used for visualization, e.g. UMAP.

Feature extraction: self-taught learning

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• Pretrain a neural network on huge unlabeled datasets (e.g. Youtube videos) before applying it to smalldata supervised problems.



Generative models

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• If the latent space is well organized, you can even sample from it to generate new images using variational autoencoders (VAE).

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DeepFake



DeepFake

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• During training, each autoencoder learns to reproduce the face of one person.



Original Face B

• When generating the deepfake, the decoder of person B is used on the encoder of person A.



Generative Adversarial Networks



- A Generative Adversarial Network (GAN) is composed of two networks:
 - The generator learns to produce realistic images.
 - The **discriminator** learn to differentiate real data from generated data.
- Both compete to reach a Nash equilibrium:

$$\min_{G} \max_{D} V(D,G) = \mathbb{E}_{x \sim P_{ ext{data}}(x)}[\log D(x)] +$$

 $\mathbb{E}_{z\sim P_z(z)}[\log(1-D(G(z)))]$

DCGAN : Deep convolutional GAN

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Discriminator



cGAN : conditional GAN for image synthesis



Text description	This bird is blue with white and has a very short beak	This bird has wings that are brown and has a yellow belly	A white bird with a black crown and yellow beak	This bird is white, black, and brown in color, with a brown beak	
Stage-I images			THE NAME		
Stage-II images					

This flower has small, round violet petals with a dark purple center



The bird has small beak, with reddish brown crown and gray belly

This is a small, black bird with a white breast and white on the wingbars.

This bird is white black and yellow in color, with a short black beak







pix2pix : Image translation



Source: https://phillipi.github.io/pix2pix/

BW to Color



output





output

CycleGAN : Monet Paintings to Photo

Input

Output



Source: https://github.com/junyanz/CycleGAN

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Input

Output

CycleGAN : Neural Style Transfer

Input

Monet

Van Gogh



Source: https://github.com/junyanz/CycleGAN

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Cezanne

Ukiyo-e

CycleGAN : Object Transfiguration





Output



horse \rightarrow zebra





 $zebra \rightarrow horse$







apple \rightarrow orange





orange \rightarrow apple

Source: https://github.com/junyanz/CycleGAN

















3 - Deep Reinforcement Learning

Reinforcement learning



- **Supervised learning** allows to learn complex input/output mappings, given there is enough data.
- Sometimes we do not know the correct output, only whether the proposed output is correct or not (partial feedback).
- **Reinforcement Learning** (RL) can be used to learn by trial and error an optimal policy $\pi(s, a)$.
- Each action (=output) is associated to a **reward**.
- The goal of the system is to find a policy that maximizes the sum of the rewards on the longterm (return).

• See the deep reinforcement learning course:

https://www.tu-

$$R(s_t,a_t) = \sum_{k=0}^\infty \gamma^k \, r_{t+k+1}$$

```
chemnitz.de/informatik/KI/edu/deeprl/
```

DQN : learning to play Atari games



- A CNN takes raw images as inputs and outputs the probabilities of taking particular actions.
- Learning is only based on trial and error: what happens if I do that?
- The goal is simply to maximize the final score.

es of taking particular actions. that?

DQN : learning to play Atari games



AlphaStar : learning to play Starcraft II



https://deepmind.com/blog/alphastar-mastering-real-time-strategy-game-starcraft-ii/

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Google Deepmind - AlphaGo





- In 2015, Google Deepmind surprised everyone by publishing **AlphaGo**, a Go AI able to beat the world's best players, including Lee Sedol in 2016, 19 times world champion.
- The RL agent discovers new strategies by using self-play: during the games against Lee Sedol, it was able to use **novel** moves which were never played before and surprised its opponent.
- The new version **AlphaZero** also plays chess and sokoban at the master level.

Parkour

DeepMi	nd Learns Parkour		



Dexterity



Autonomous driving



Neurocomputing syllabus

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1. Linear learning machines	4. Autoend
 Optimization, Gradient Descent 	• Auto
 Linear regression and classification 	 Vari
 Multi-class classification 	• Res
 Learning theory, Cross-validation 	• Gen
2. Neural networks	5. Recurre
 Multi-layer perceptron 	• RNN
 Backpropagation algorithm 	• LST
 Regularization, Batch Normalization 	• Atte
3. Convolutional neural networks	6. Self-sup
 Convolutional layer, pooling 	• Trar
 Transfer learning 	• Con
 Object detection (Fast-RCNN, YOLO) 	7. Outlook
 Semantic segmentation 	

coders and generative models

- o-encoders
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ent Neural Networks

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pervised learning

- nsformers
- ntrastive learning

Literature

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• **Deep Learning**. Ian Goodfellow, Yoshua Bengio & Aaron Courville, MIT press.

http://www.deeplearningbook.org

• Neural Networks and Learning Machines. Simon Haykin, Pearson International Edition.

http://www.pearsonhighered.com/haykin

• Deep Learning with Python. Francois Chollet, Manning.

https://www.manning.com/books/deep-learning-with-python

• The Elements of Statistical Learning: Data Mining, Inference, and Prediction, Trevor Hastie, Robert *Tibshirani & Jerome Friedman*, Springer.

https://web.stanford.edu/~hastie/ElemStatLearn/printings/ESLII_print12.pdf

• Probabilistic Machine Learning: An introduction, Kevin Murphy, MIT Press, 2022.

https://probml.github.io/pml-book/book1.html

But also

• The machine learning course of Andrew Ng (Stanford at the time) hosted on Coursera is great for beginners:

https://www.coursera.org/learn/machine-learning

• His advanced course on deep learning allows to go further:

https://www.coursera.org/specializations/deep-learning

• The machine learning course on EdX focuses on classical ML methods and is a good complement to this course:

https://www.edx.org/course/machine-learning

• https://medium.com has a lot of excellent blog posts explaining AI-related topics, especially:

https://towardsdatascience.com/

• The d2l.ai online book is a great resource, including programming exercises:

http://d2l.ai/index.html

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