VIBE PROJECT

Virtual Biomedical and STEM/STEAM Education

2021-1-HU01-KA220-HED-000032251

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PÉCSI TUDOMÁNYEGYETEM UNIVERSITY OF PÉCS

U.PORTO

Politechnika Śląska

DEX innovation centre

VIBE PROJECT

PATTERN RECOGNITION IN BIOMEDICAL ENGINEERING

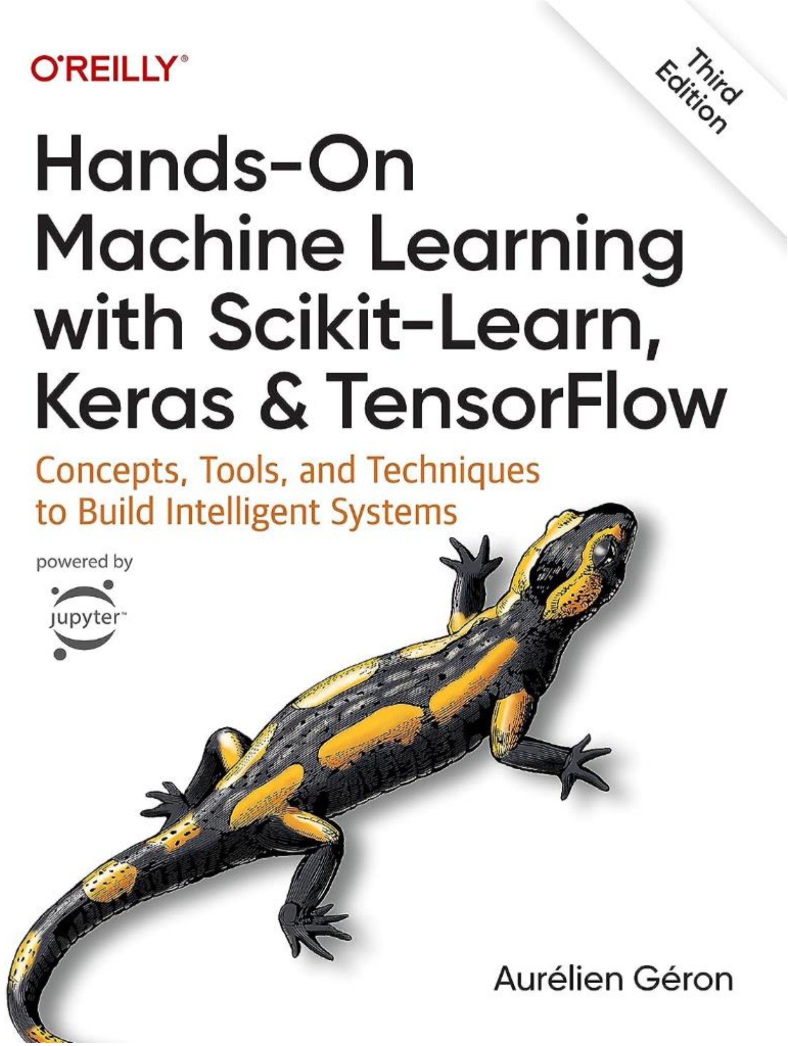
CONVOLUTIONAL NEURAL NETWORKS & DEEP LEARNING ALGORITHMS

Convolutional Neural Networks (CNN) & Deep Learning (DL) Algorithms.

Paweł Kostka

Department of Medical Informatics and Artificial Intelligence,
Faculty of Biomedical Engineering (BE),
Silesian University of Technology (SUT)

For you to recommend as a basic, essential 1st. textbook, even a “Bible” of machine learning, including neural networks, written by a guru and fascinator of this area:



Aurélien Geron

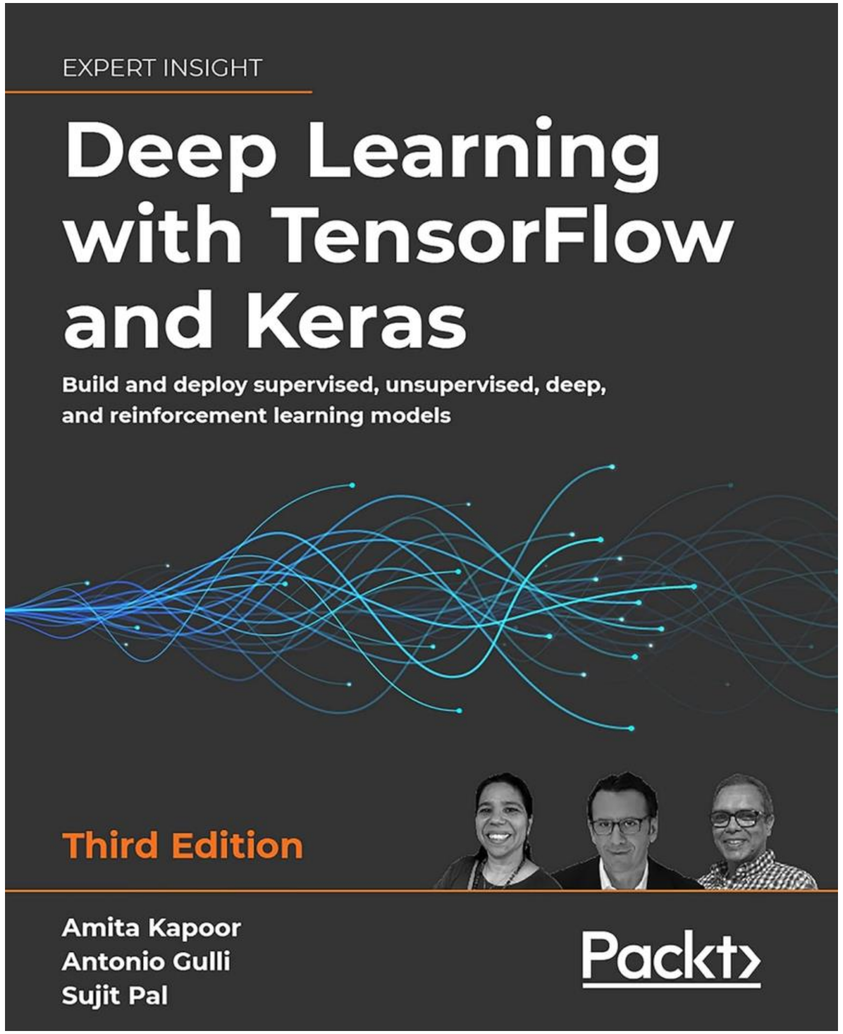
https://github.com/ageron

Lecturers and bloggers of specialized websites draw material from this book and Github repository. What is beautiful and builds the development of this discipline is a „Community”, that shares its experiences and projects even GitHub (like this above) with code examples for free.
Examples of Data Science community sites with projects & data sets:

- https://keras.io/examples/
- https://www.kaggle.com/datasets

Source: https://www.oreilly.com/library/view/hands-on-machine-learning/9781098125967/

For you to recommend as a basic, essential 2nd. textbook, even a “Bible” of machine learning, including neural networks, written by a gurus and fascinators of this area:



https://www.amazon.com/Deep-Learning-TensorFlow-Keras-reinforcement/dp/1803232919

https://github.com/PacktPublishing/Deep-Learning-with-TensorFlow-and-Keras-3rd-edition

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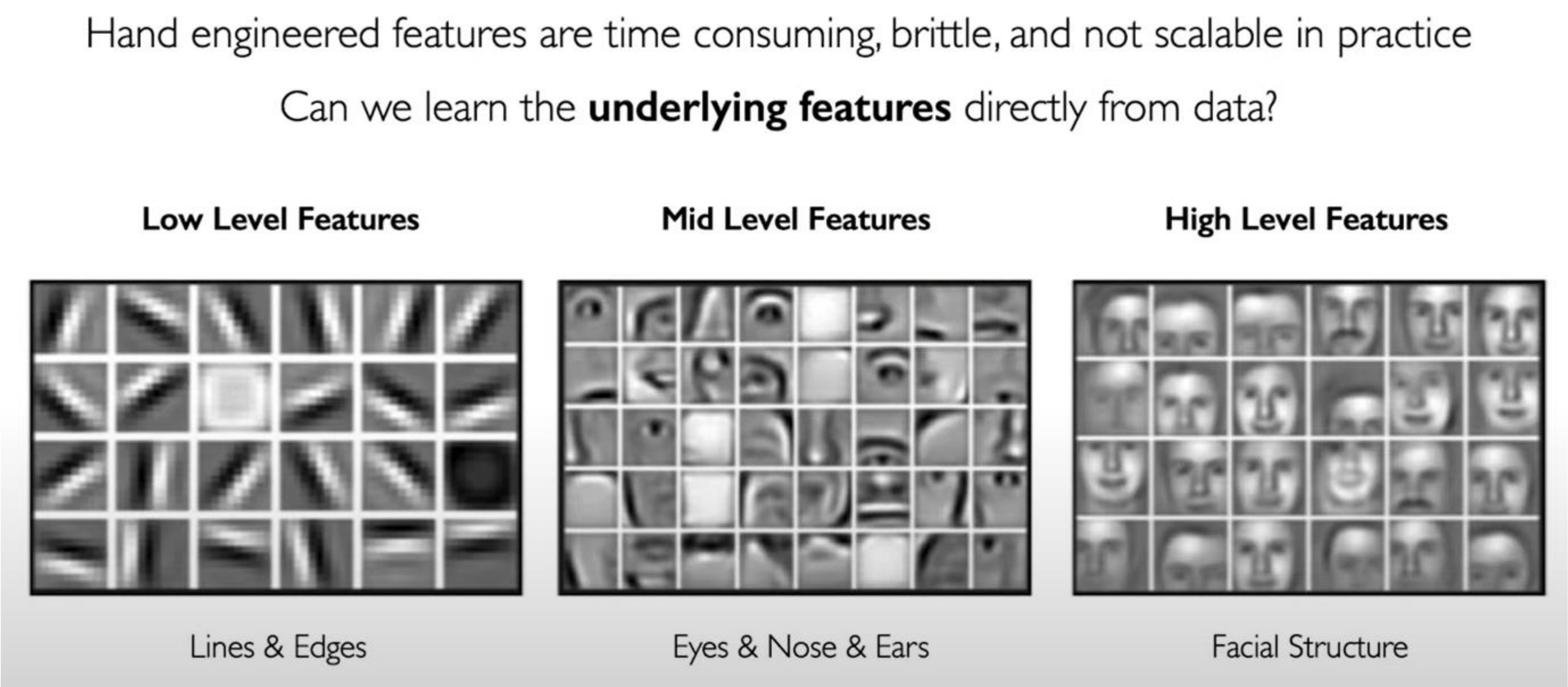
Why and What is Deep Learning (DL) ?

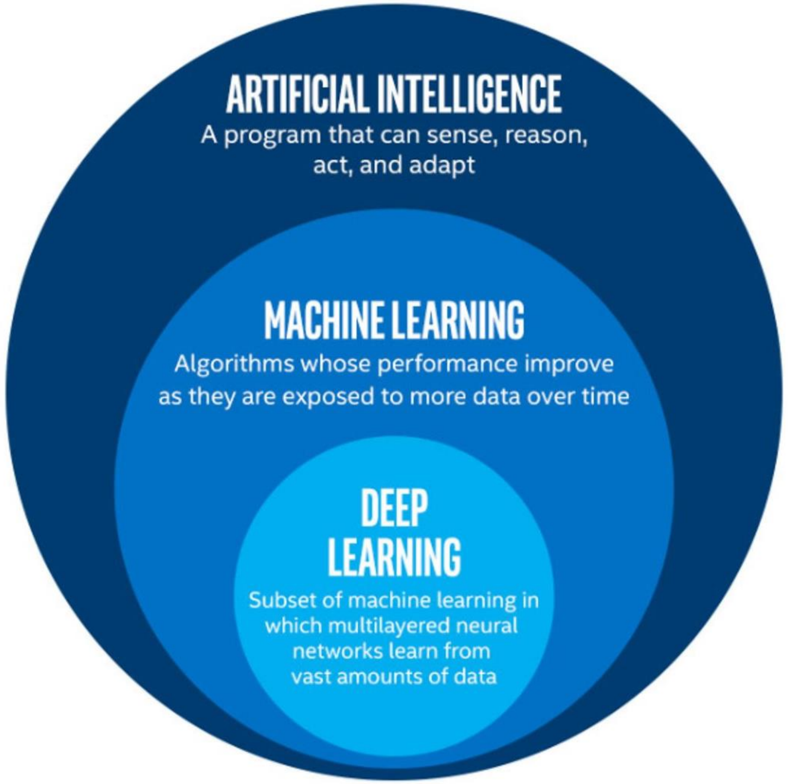


An illustration drawing, demonstrating the idea of autonomous feature extraction by DL.

Source: https://www.kdnuggets.com/2016/08/brohrer-convolutional-neural-networks-explanation.html/2

Features extraction conducted by DL is the key

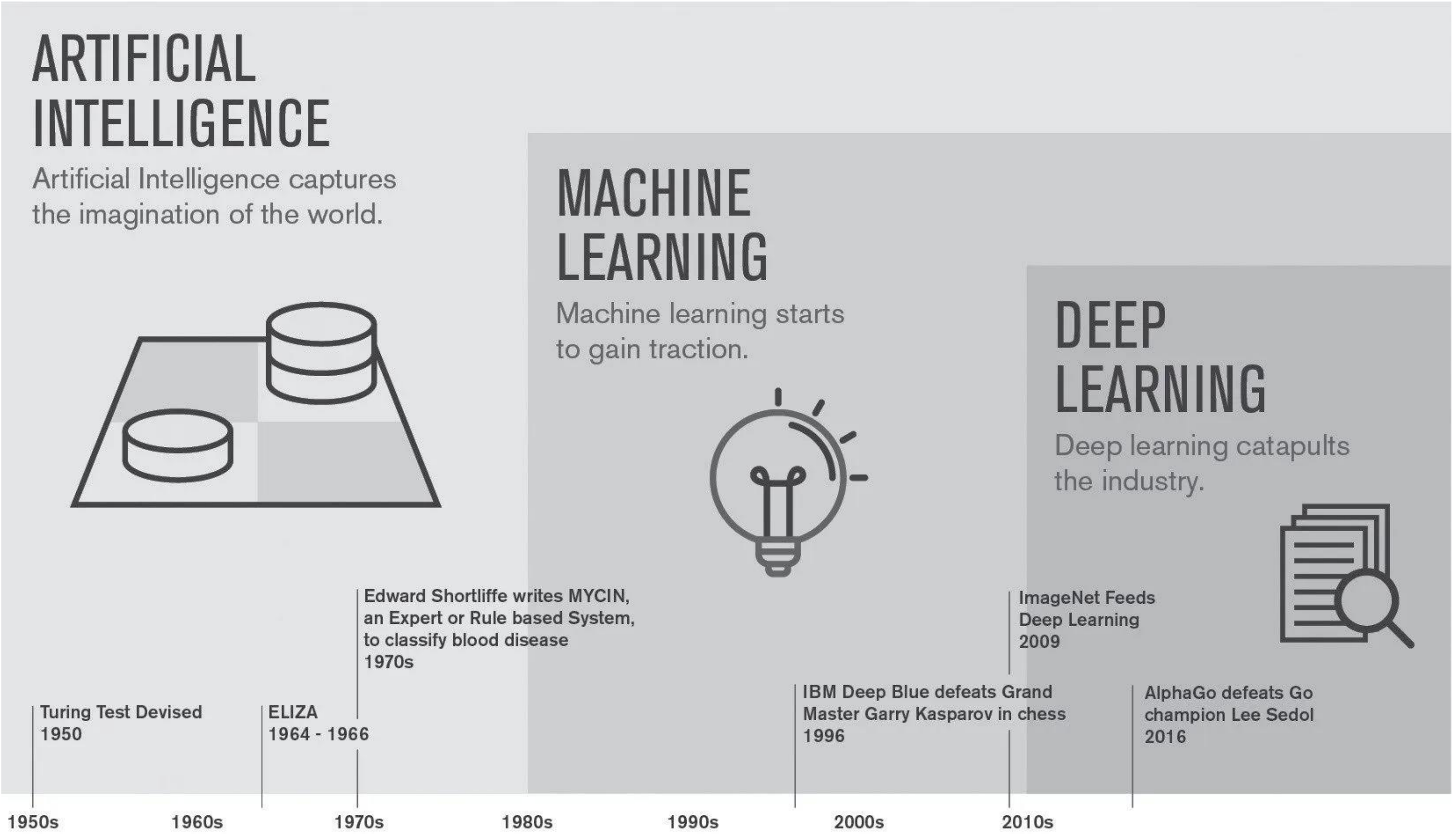
What is Deep Learning (DL) ?



Source: https://carpentries-incubator.github.io/machine-learning-novice-sklearn/aio/index.html

DL is able to automatically extract useful patterns (features) from raw data

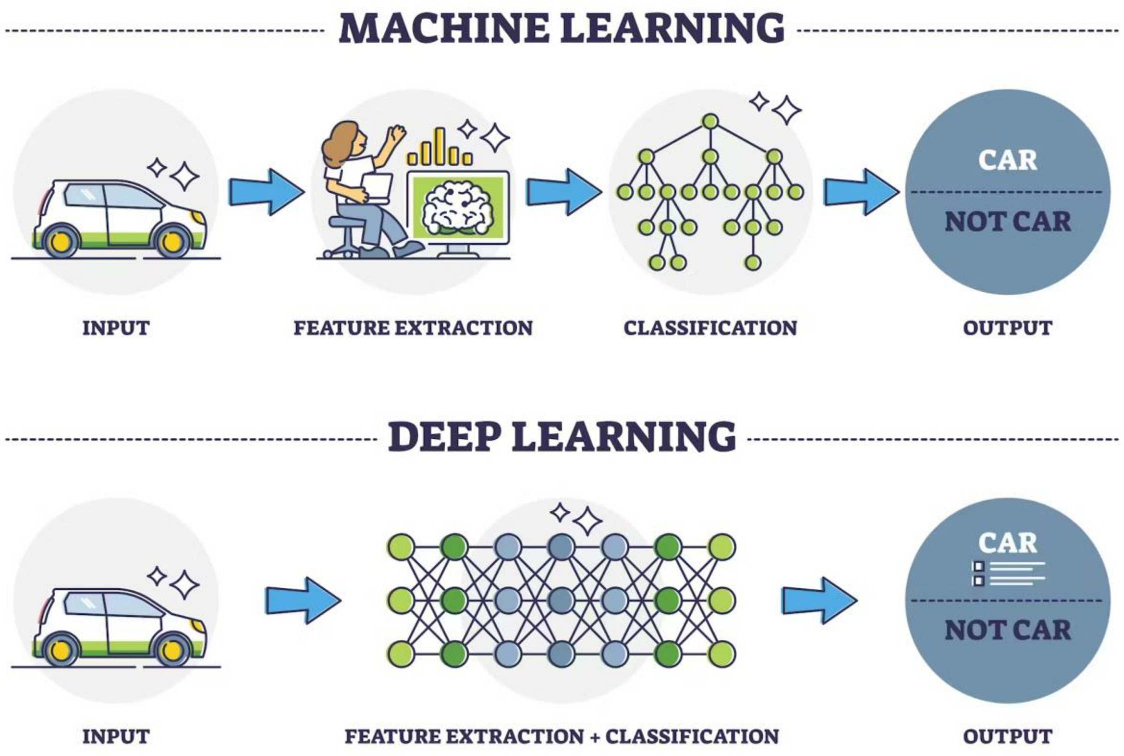
What is Deep Learning (DL)? Initial examples.



Source: https://medium.com/vmacwrites/awesome-ai-the-guide-to-master-artificial-intelligence-a7823611299a

DL is able to automatically extract useful patterns (features) in raw data

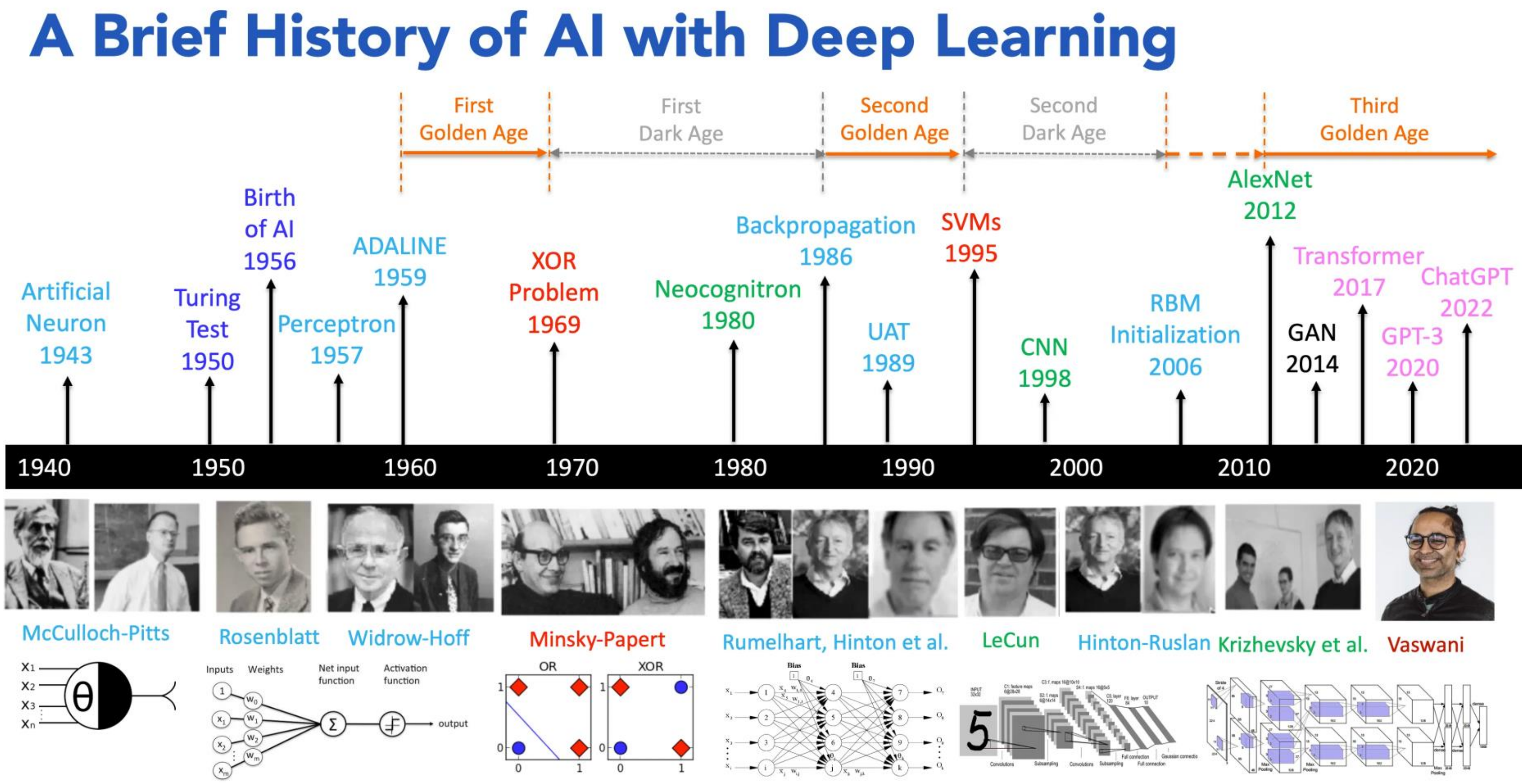
Deep Learning (DL) vs general Machine Learning (ML)?



Source: https://www.turing.com/kb/ultimate-battle-between-deep-learning-and-machine-learning

DL is able to automatically extract useful patterns (features) from raw data, while in classical machine learning, feature extraction was done by an expert human with his methods.

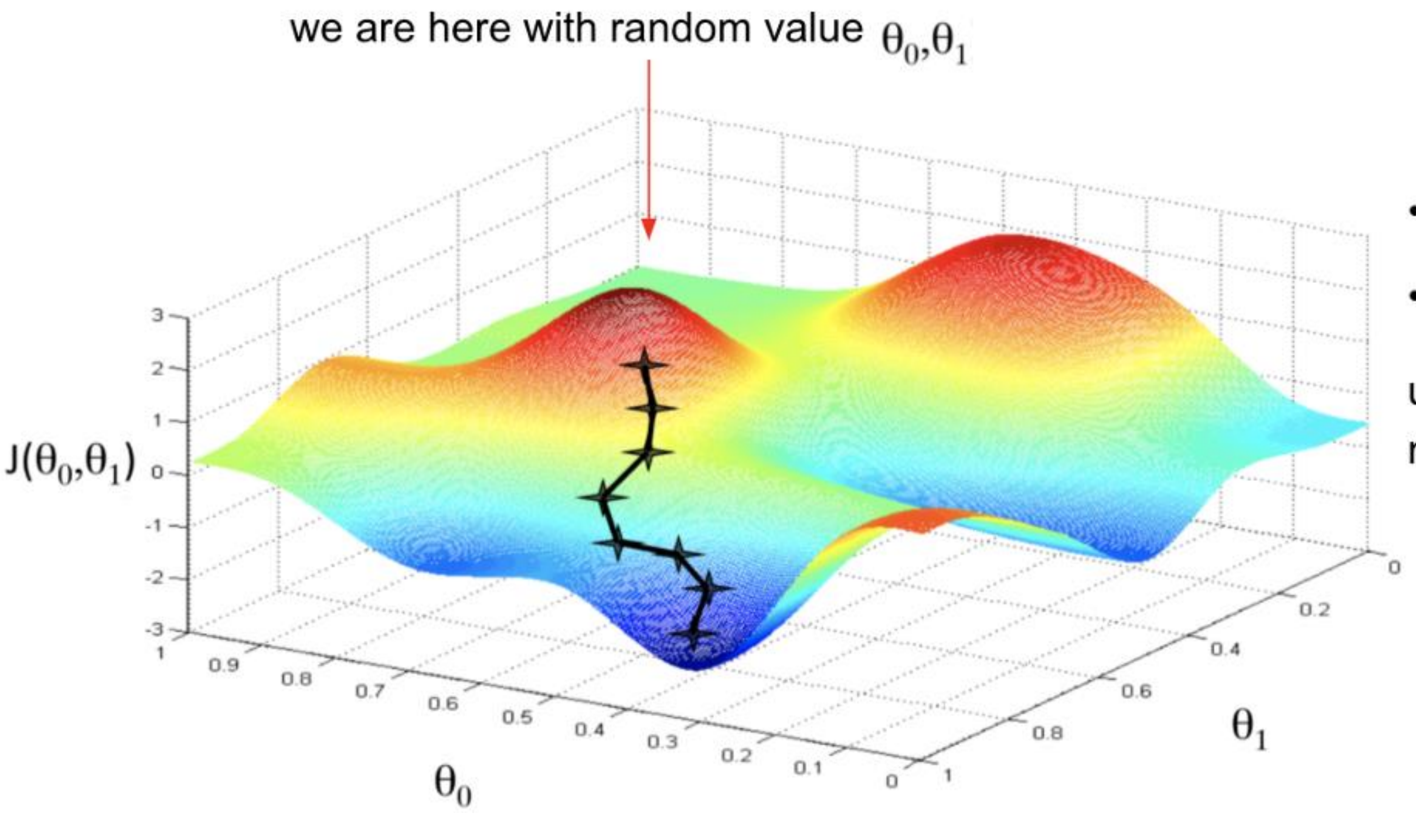
Why Deep Learning (DL) now?



Source: https://medium.com/@lmpo/a-brief-history-of-ai-with-deep-learning-26f7948bc87b

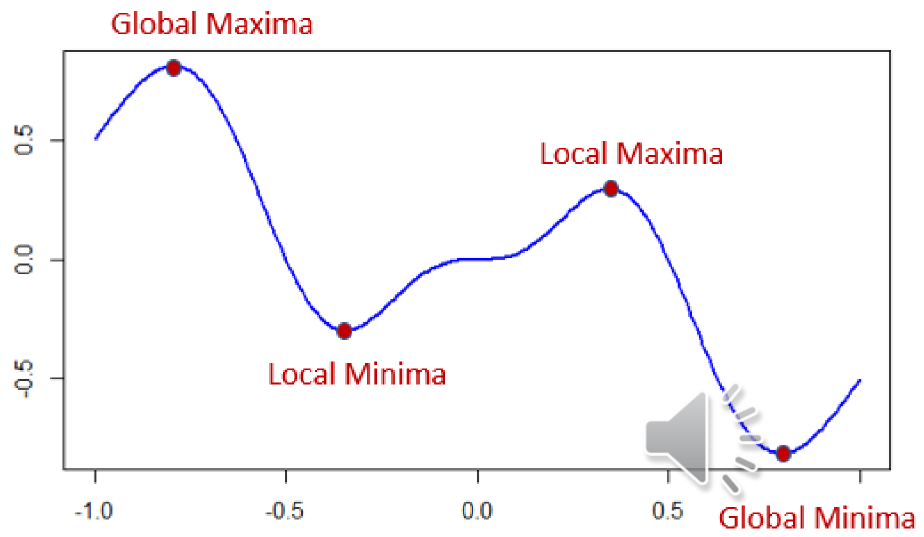
Technology development both in hardware & software !

Global vs. Local Minimum during gradient descent learning alg.



- Start with some θ_0,θ_1
- Keep changing θ_0,θ_1 to reduce $J(\theta_0,\theta_1)$

until we hopefully end up at a minimum



The goal of the learning phase is to find the global minimum; however, the algorithm can get stuck in a local minimum as well.
To avoid this, it is recommended to repeat the learning process several times with random initial data.

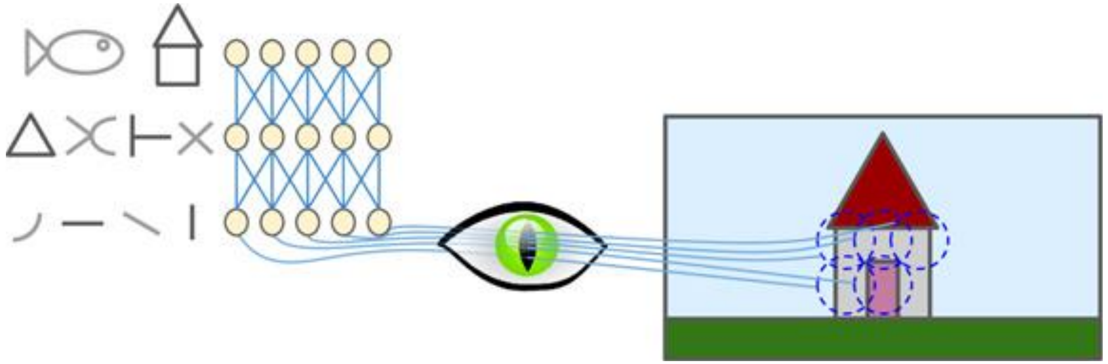
Source: https://medium.com/@sean.gahagan/building-intuition-around-high-dimensional-space-in-deep-learning-44dda9e43595

CNNS: *It all started with a study of the visual cortex of cats and monkeys - how our vision acquires knowledge about an object*

Architecture of the visual cortex

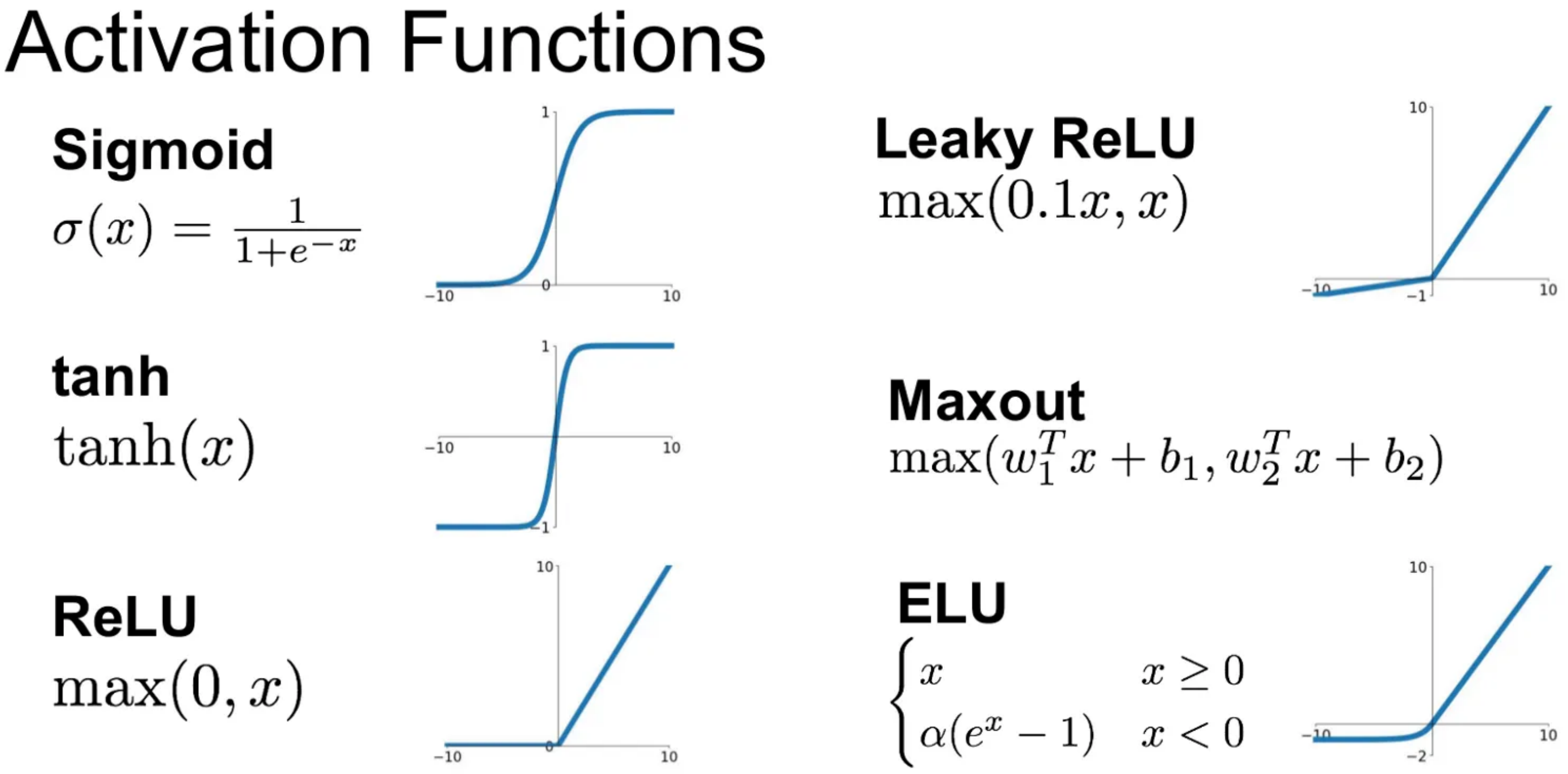
- David H. Hubel and Torsten Wiesel conducted a series of experiments on cats in 1958-59, also on monkeys, thanks to which we learned the structure of the visual cortex (the authors received the Nobel Prize in Physiology or Medicine in 1981 for their contribution to science).
- In particular, they have shown that many of the neurons that make up the visual cortex form local receptive fields, i.e., that they respond only to visual stimuli that fall within a specific region of the visual field

Local receptive fields in the visual cortex



Source: Kunihiko Fukushima, "Neocognitron: A Self-Organizing Neural Network Model for a Mechanism of Pattern Recognition Unaffected by Shift in Position," Biological Cybernetics 36 (1980): 193–202.

Simple percepron with forward data propagation:
nonlinear activation functions (AF) and their derivatives (important in learning proces)

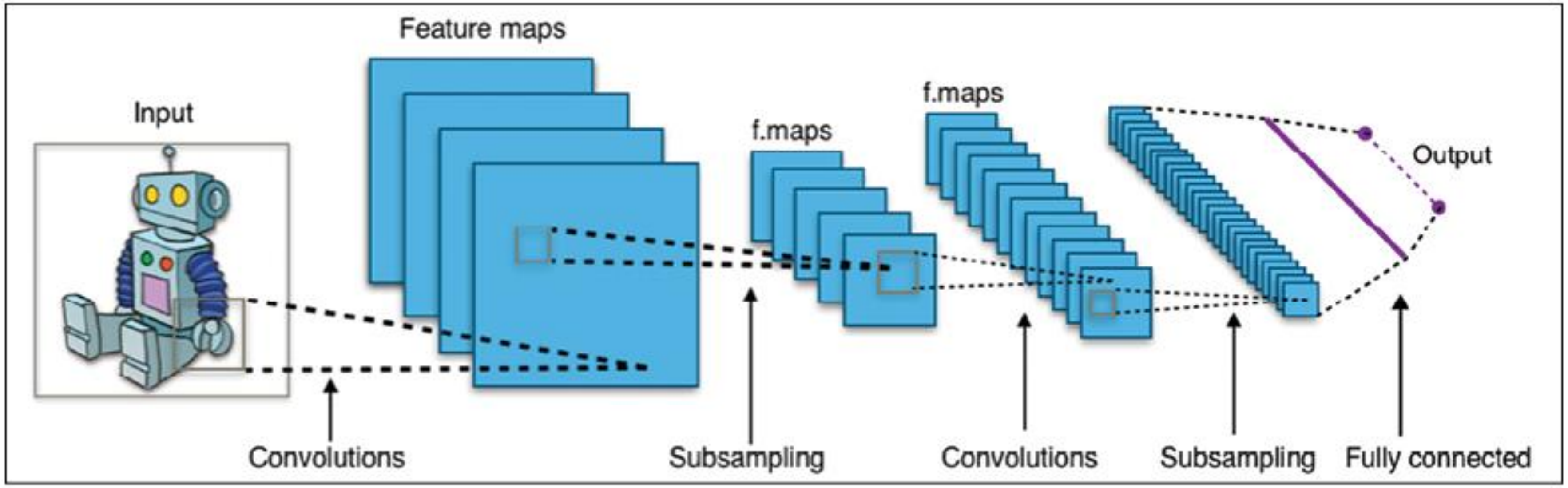


Output values of AF: g(z) are <0;1> or <-1; 1> or <0; +∞)

Source: https://blog.devops.dev/exploring-activation-functions-in-deep-learning-properties-derivatives-and-impact-on-model-7585aad8a757

It does it by means of Deep Convolution Neural Networks (DCNNs)

(math. convolution operator, which detects, try to find similarities ***between fragment of an image & prepared/designed filter)***

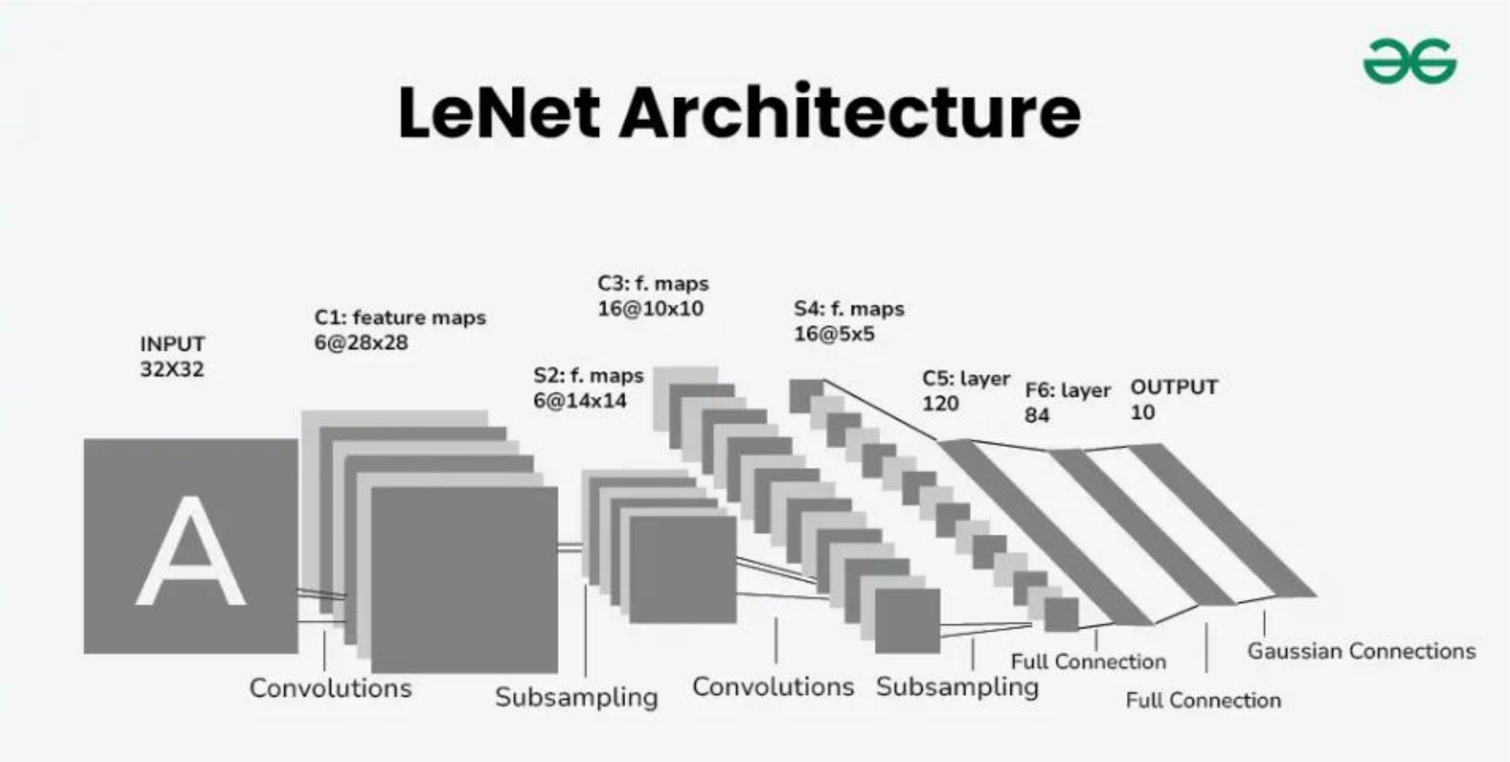


DCNN consists of two main parts: Convolution layers as Feature Extractors & Fully connected Classifier.

Source: Amita Kapoor, Antonio Gulli, Sujit Pal, Deep Learning with TensorFlow and Keras: Build and deploy supervised, unsupervised, deep, and reinforcement learning models, 3rd Edition, Packt Publishing 2022.

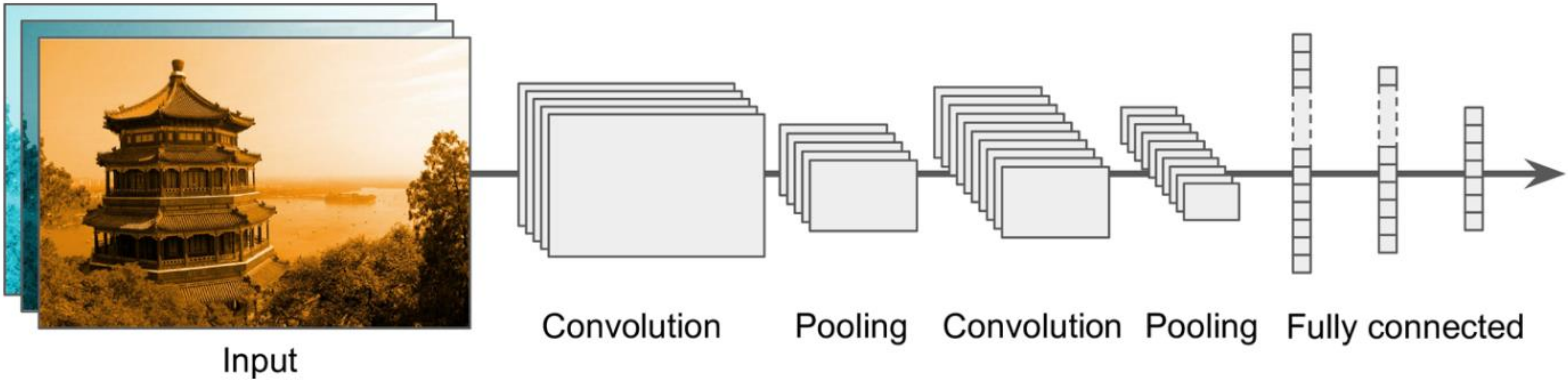
CNN structure example with several feature extraction convolution maps + classifier NN:

Visualization of LeNet structure



Source: https://www.geeksforgeeks.org/lenet-5-architecture/

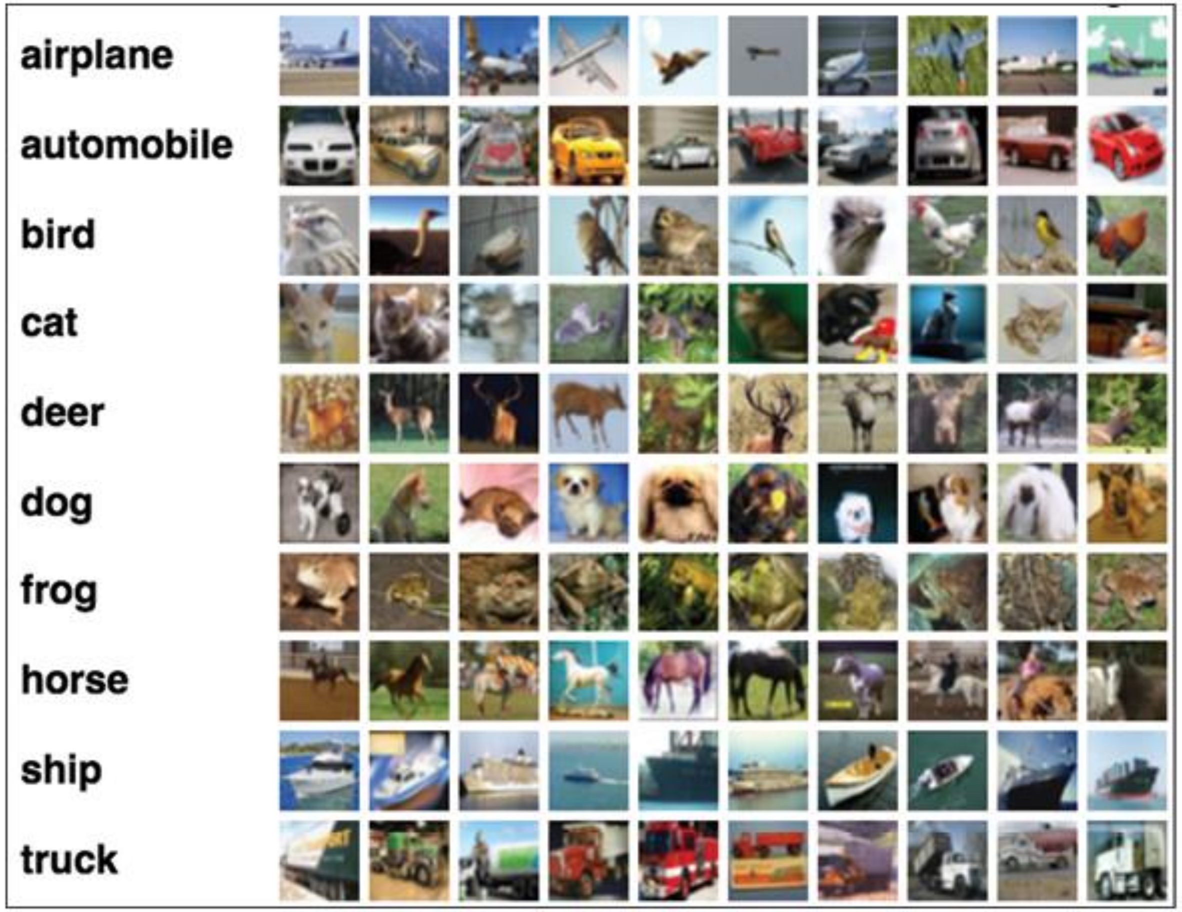
How Deep Learning (DL) recognizes the object in an image?



Source: https://opendatascience.com/a-beginners-guide-to-understanding-convolutional-neural-networks/

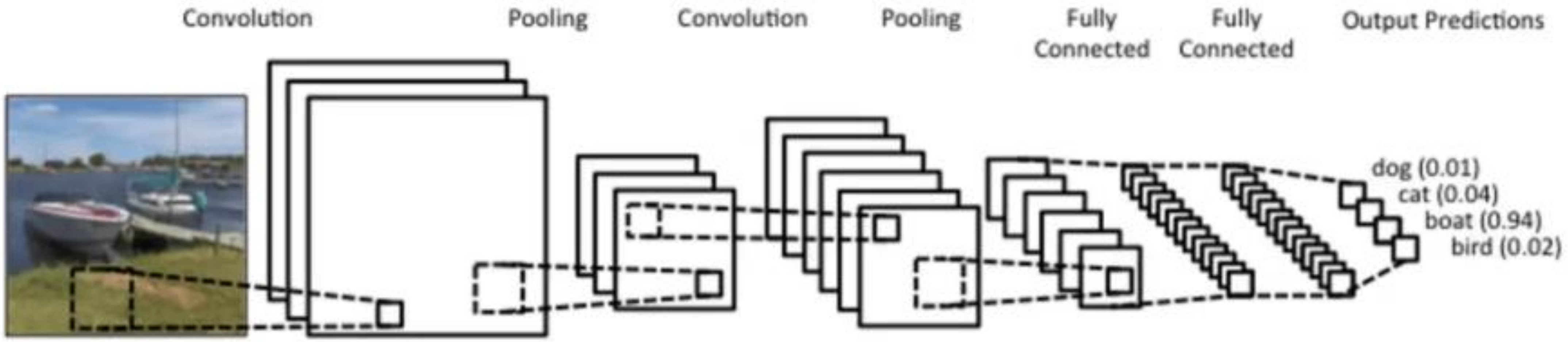
Big Data Sets are crucial to learn the CNN. Examples of free data sets:

An example of CIFAR-10 images



Sources: *https://www.cs.toronto.edu/~kriz/cifar.html*
https://www.kaggle.com/datasets

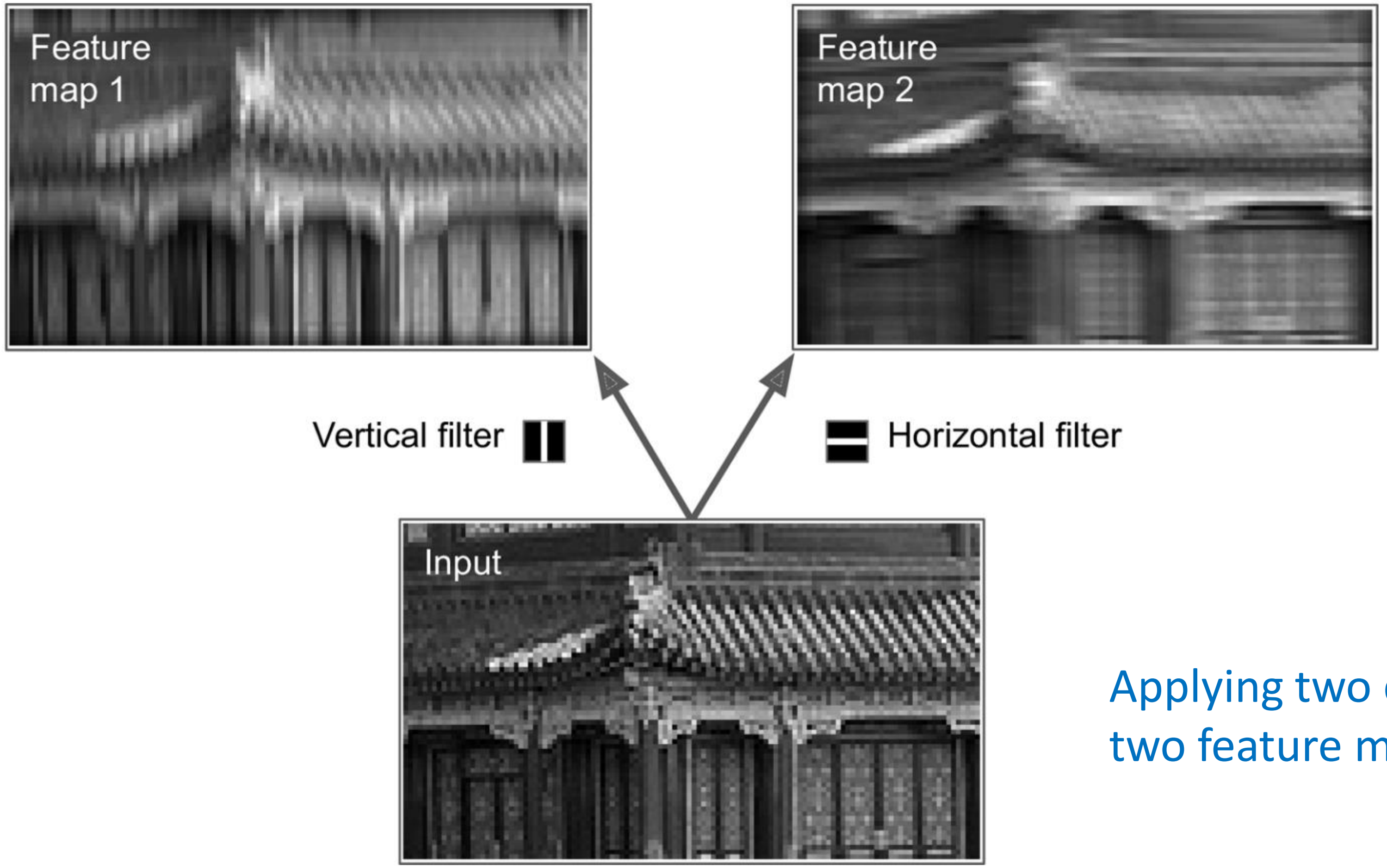
CNNs : *Input layer of neurons*



Source: https://medium.com/@rohithramesh1991/convolutional-neural-network-3818bb487ce8
https://www.ksolves.com/blog/artificial-intelligence/understanding-convolution-neural-network-architecture
https://medium.com/@Aj.Cheng/convolutional-neural-network-d9f69e473feb

Idea and example of convolution layer with filter diagonal/horiz.

(math. convolution operator, which detects, try to find similarities ***between fragment of an image & prepared/designed filter)***



Applying two different filters to get two feature maps

Source:Aurel ☺

Mathematical example – how to conduct convolution between image Region of Interest (ROI) (J matrix) and filter mask (K matrix).

One simple way to understand convolution is to think about a sliding window function applied to a matrix. In the following example, given the input matrix I and the kernel K, we get the convolved output. The 3 x 3 kernel **K** (*sometimes called the filter or feature detector*) is multiplied elementwise with the input matrix to get one cell in the output matrix.
All the other cells are obtained by sliding the window over I

J

1	1	1	0	0
0	1	1	1	0
0	0	1	1	1
0	0	1	1	0
0	1	1	0	0

K

1	0	1
0	1	0
1	0	1

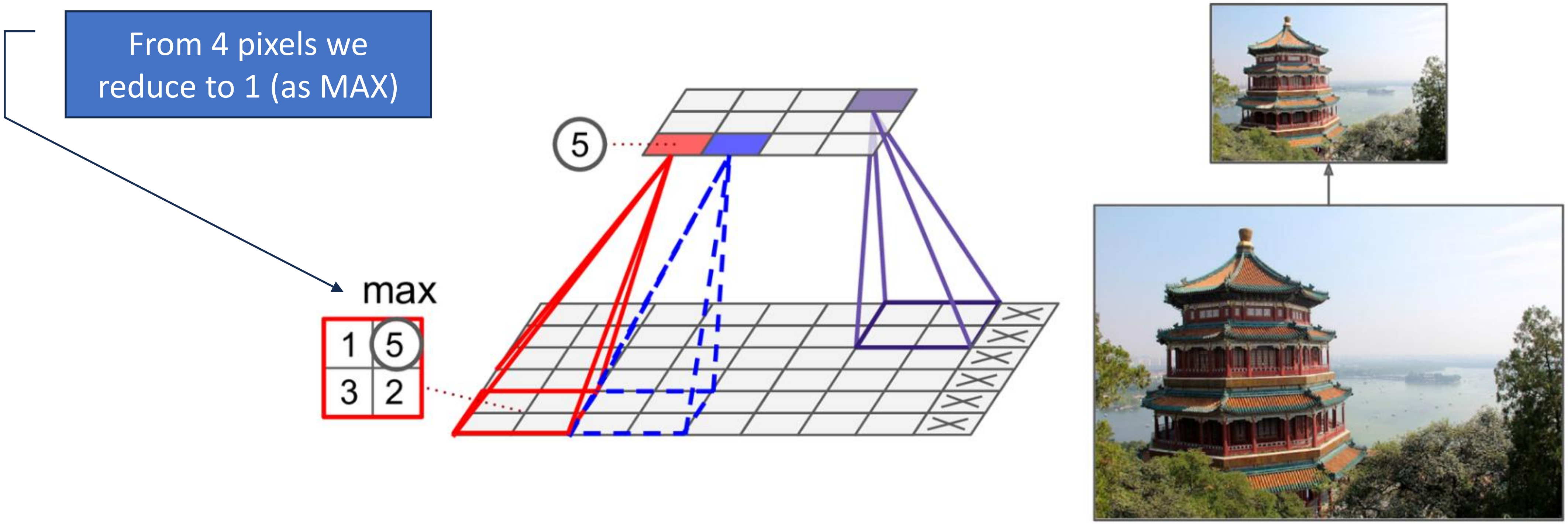
Convolved

4	3	4
2	4	3
2	3	4

Source: Amita Kapoor, Antonio Gulli, Sujit Pal, Deep Learning with TensorFlow and Keras: Build and deploy supervised, unsupervised, deep, and reinforcement learning models, 3rd Edition, Packt Publishing 2022.

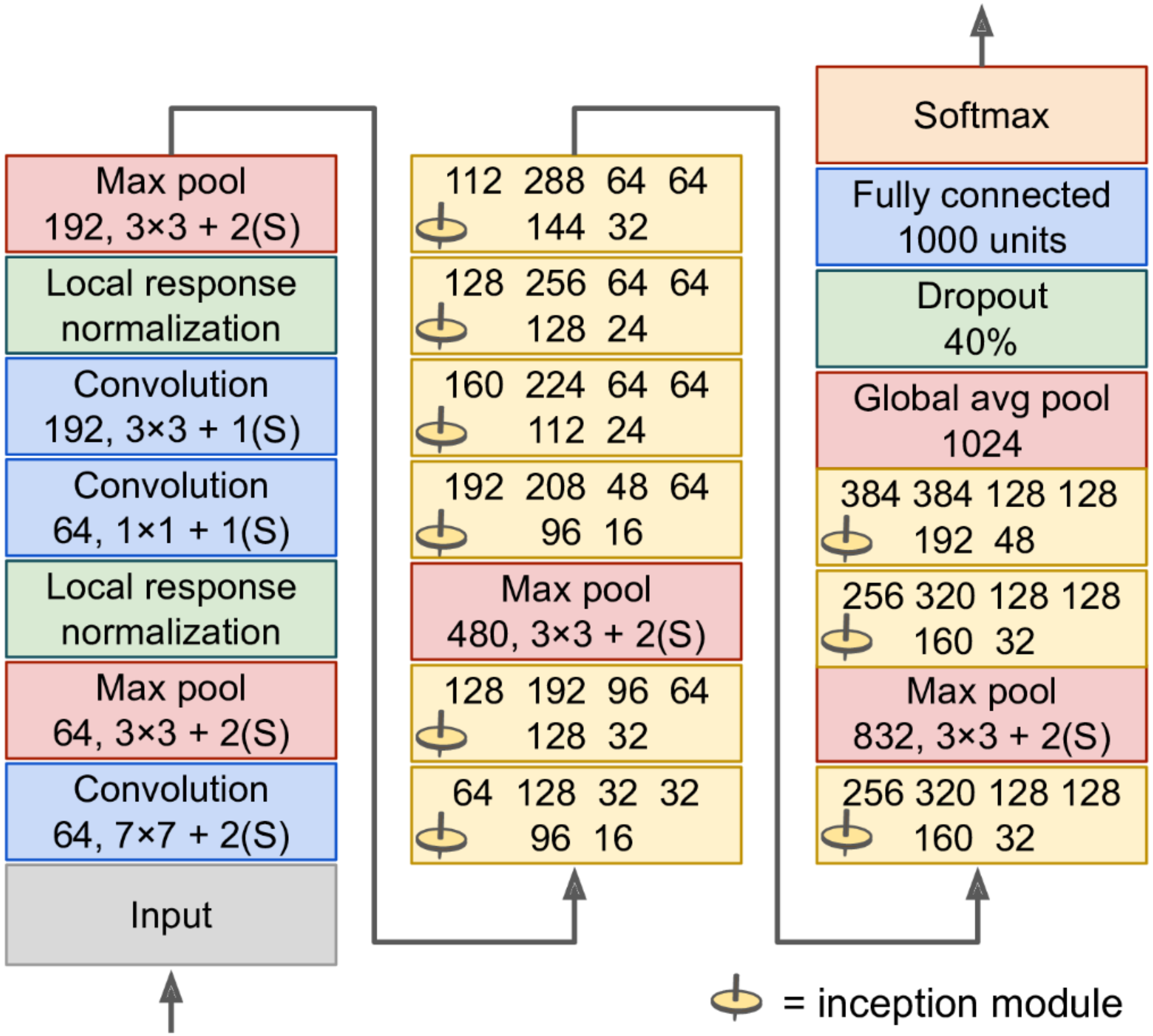
Next stage: Pooling layers.

Once you understand how convolutional layers work, the pooling layers are quite easy to grasp. Their goal is to subsample (i.e., shrink) the input image in order to reduce the computational load, the memory usage, and the number of parameters (thereby limiting the risk of overfitting) – using e.g. the MAX operator (see picture below).



Source:Aurel ☺

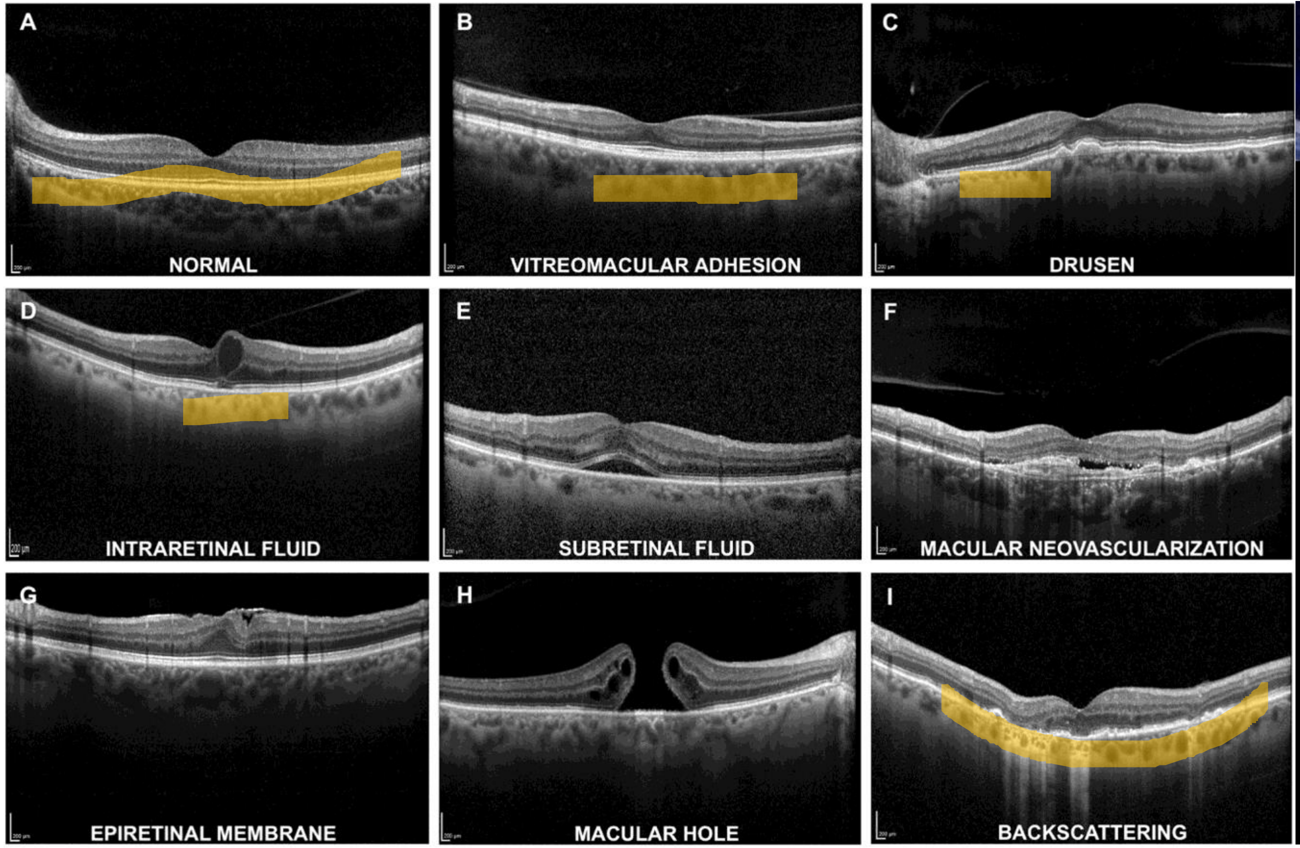
Already created and learned CNNs available on the ‘market’.
Google LeNet architecture example.

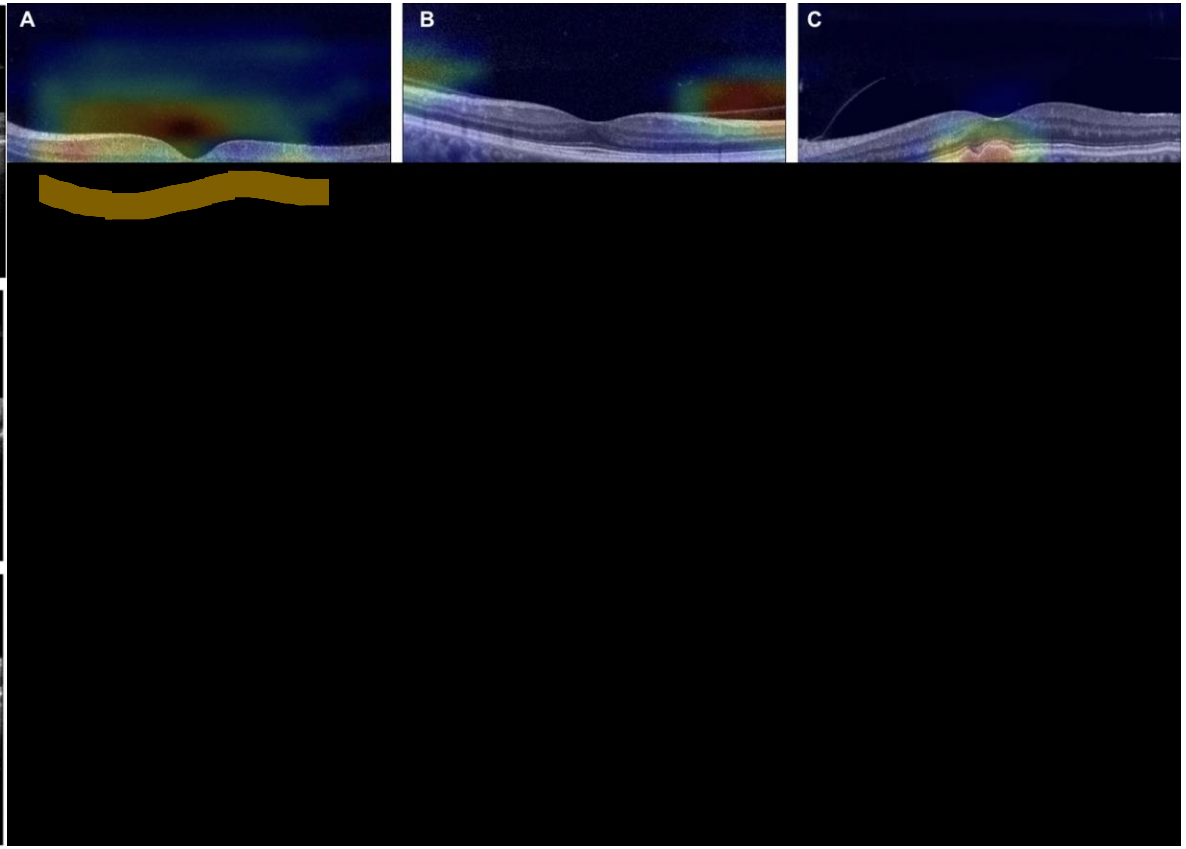


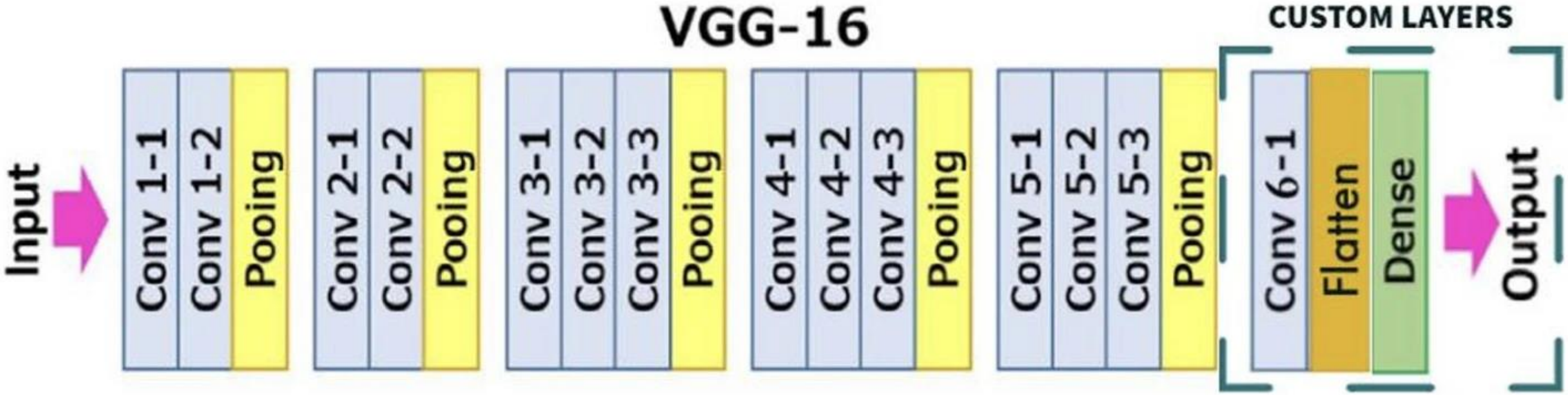
Source: https://www.cv-foundation.org/openaccess/content_cvpr_2015/html/Szegedy_Going_Deeper_With_2015_CVPR_paper.html
https://www.geeksforgeeks.org/understanding-googlenet-model-cnn-architecture/
https://arxiv.org/pdf/1409.4842

Real example: Retina OCT scans classification

Retina key signs visualisation







source: https://www.nature.com/articles/s41598-023-41362-4

Real example: Retina OCT scans classification - Results

	Healthy	Pathological
Healthy	560	2
Pathological	8	553

	ERM	O.S.
ERM	441	11
O.S.	16	445

	IF	O.S.
IF	350	7
O.S.	3	353

	SF	O.S.
SF	118	8
O.S.	1	118

	D	O.S.
D	281	12
O.S.	11	281

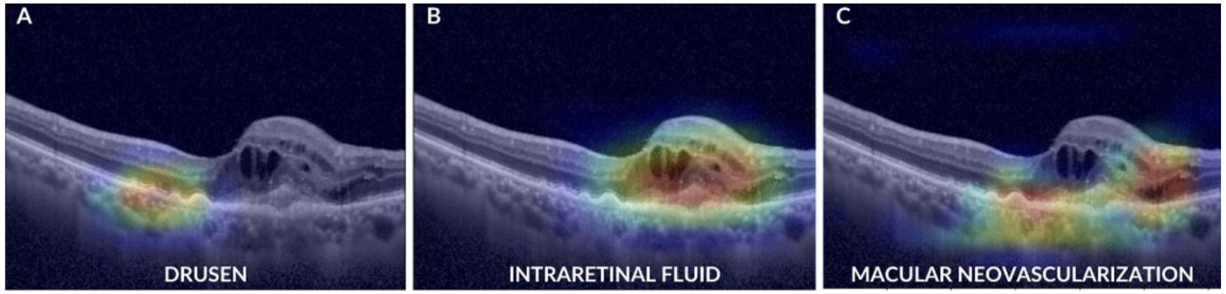
	MNV	O.S.
MNV	107	9
O.S.	3	107

	VMA	O.S.
VMA	359	1
O.S.	6	354

	MH	O.S.
MH	85	3
O.S.	1	87

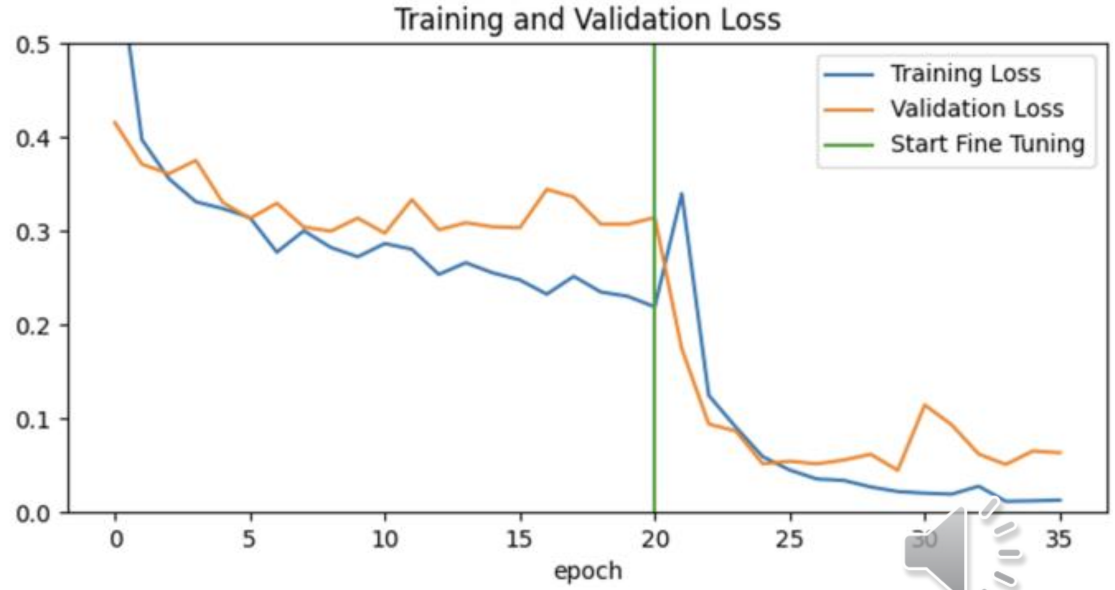
	BS	O.S.
BS	142	8
O.S.	14	148

Confusion matrices obtained on the validation set for each model: Healthy vs Pathological, One sign (ERM, IF, SF, D, MNV, VMA, MH or BS) vs all Other Signs (O.S.).



Grad-CAM images demonstrate the capacity of our CNNs to recognize multiple signs in the same OCT image.

source: https://www.nature.com/articles/s41598-023-41362-4



A total of 21,500 completely anonymized OCT scans of 11,245 patients (5258 Male and 5987 Female) with a mean age of 71.2 ± 16.5 were screened.

After textbook introduction to Convolutional NN and Deep Learning (DL) algorithms, from well-known sources, some original examples of projects using CNN with DL, in the area of Biomedical Engineering from our team, as motivation for PhD students. A pipeline of AI methods is created to analyse Biomedical Data.

Heart Rate Variability Analysis on CEBS Database Signals

Szymon Siecinski[1], Pawel S Kostka[2] and Ewaryst J Tkacz[3]

TABLE III

COEFFICIENTS OF DETERMINATION (R^2) OF NON-ROBUST LINEAR REGRESSION FIT OF HRV INDICES AND THE R^2 VALUES CALCULATED ON HRV INDICES FOR ROBUST LINEAR REGRESSION. LAR STANDS FOR LEAST ABSOLUTE RESIDUAL METHOD AND BISQUARE STANDS FOR LEAST SQUARES METHOD.

HRV index	R^2 (non-robust fit)	R^2 (robust fit)	Robust fit method
Mean NN	0.9500	0.9917	LAR
SDNN	0.0591	0.8401	LAR
RMSSD	0.0966	0.8427	LAR
PNN50	0.0523	0.8420	LAR
PLF	0.9305	0.9864	Bisquare
PVLF	0.9305	0.9885	LAR
PHF	0.9333	0.9885	LAR
LF/HF	0.0966	0.8494	LAR

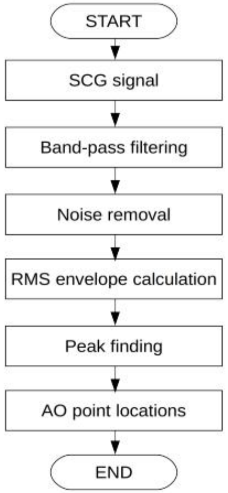
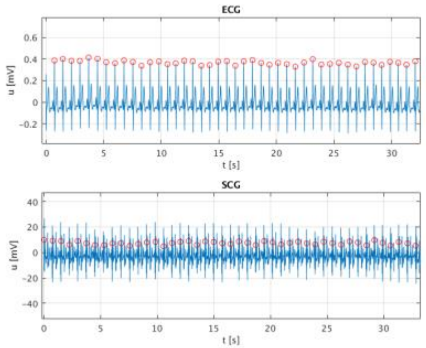


Fig. 1. SCG beat detection algorithm flowchart.



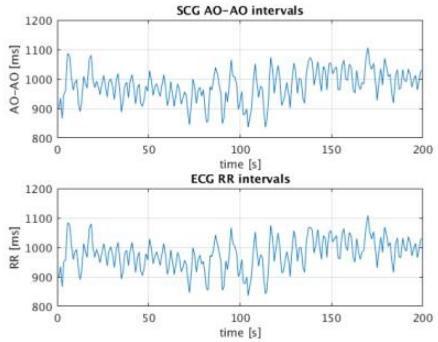


Fig. 3. AO-AO intervals graph (above) and RR intervals graph (below) for signal b002.

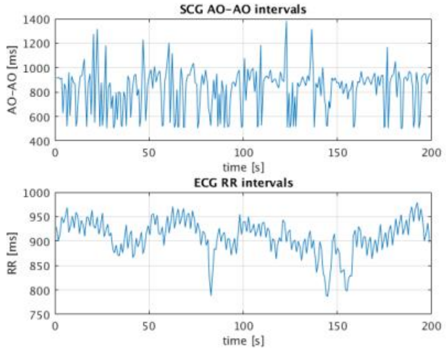


Fig. 4. AO-AO intervals graph (above) and RR intervals graph (below) for signal b001.

Source: Heart Rate Variability Analysis on CEBS Database Signals | IEEE Conference Publication | IEEE Xplore

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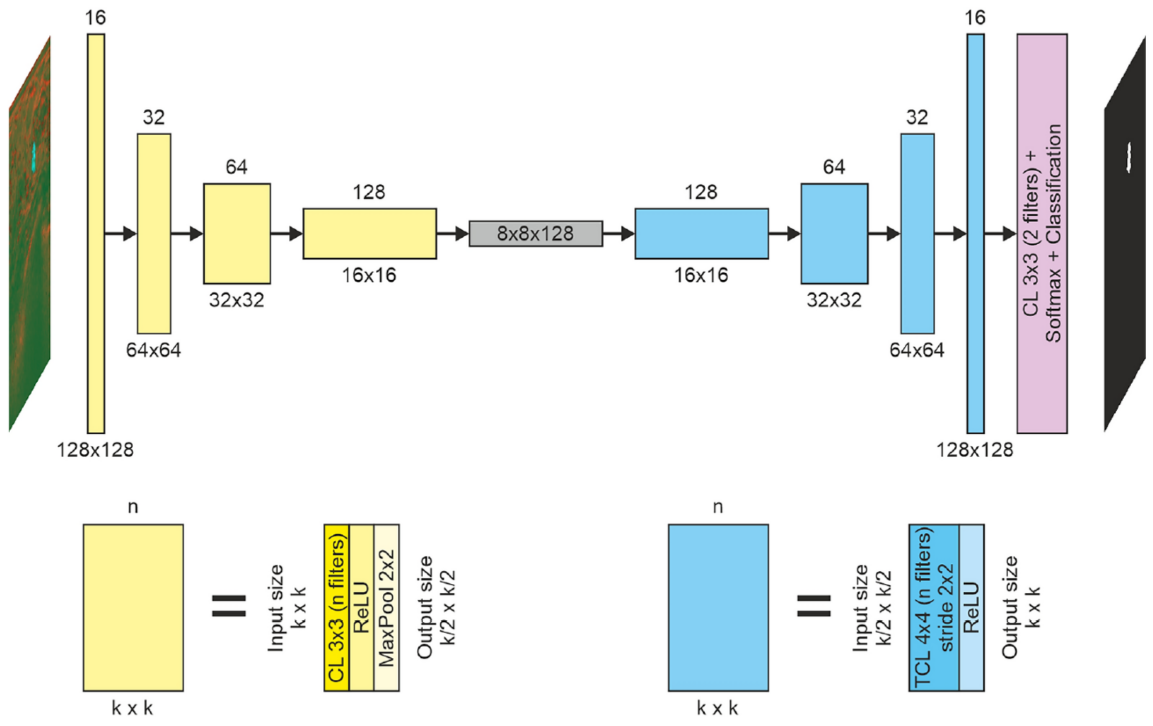
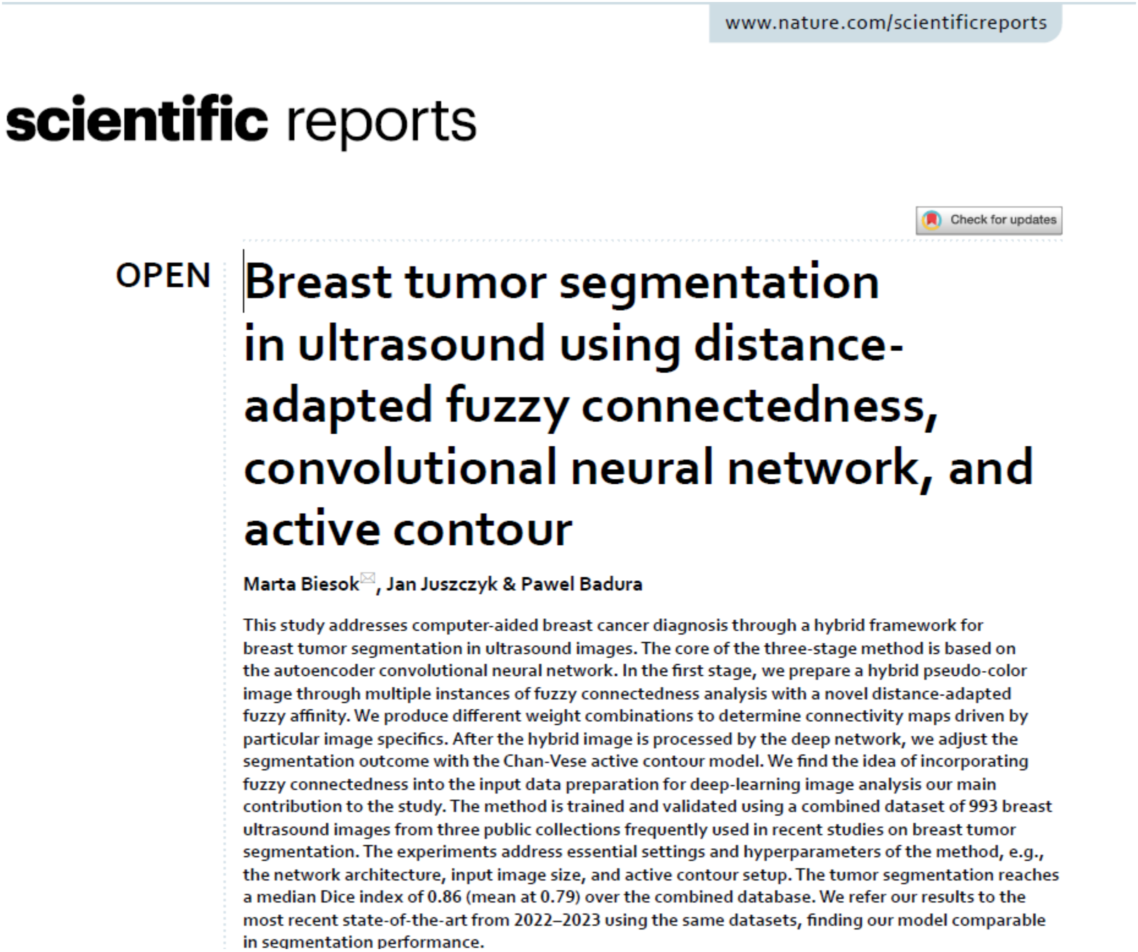


Autoencoder CNN architecture for breast tumor segmentation.
CL – convolutional layer, TCL – transposed CL


www.nature.com/scientificreports

scientific reports

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OPEN

Breast tumor segmentation in ultrasound using distance-adapted fuzzy connectedness, convolutional neural network, and active contour

Marta Biesok, Jan Juszczyk & Pawel Badura

This study addresses computer-aided breast cancer diagnosis through a hybrid framework for breast tumor segmentation in ultrasound images. The core of the three-stage method is based on the autoencoder convolutional neural network. In the first stage, we prepare a hybrid pseudo-color image through multiple instances of fuzzy connectedness analysis with a novel distance-adapted fuzzy affinity. We produce different weight combinations to determine connectivity maps driven by particular image specifics. After the hybrid image is processed by the deep network, we adjust the segmentation outcome with the Chan-Vese active contour model. We find the idea of incorporating fuzzy connectedness into the input data preparation for deep-learning image analysis our main contribution to the study. The method is trained and validated using a combined dataset of 993 breast ultrasound images from three public collections frequently used in recent studies on breast tumor segmentation. The experiments address essential settings and hyperparameters of the method, e.g., the network architecture, input image size, and active contour setup. The tumor segmentation reaches a median Dice index of 0.86 (mean at 0.79) over the combined database. We refer our results to the most recent state-of-the-art from 2022–2023 using the same datasets, finding our model comparable in segmentation performance.

Source: https://www.nature.com/articles/s41598-024-76308-x

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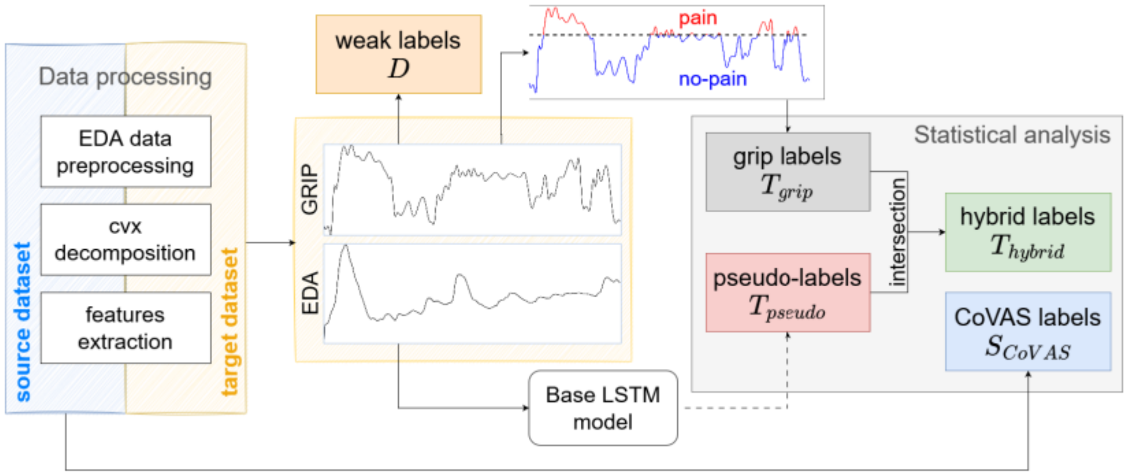
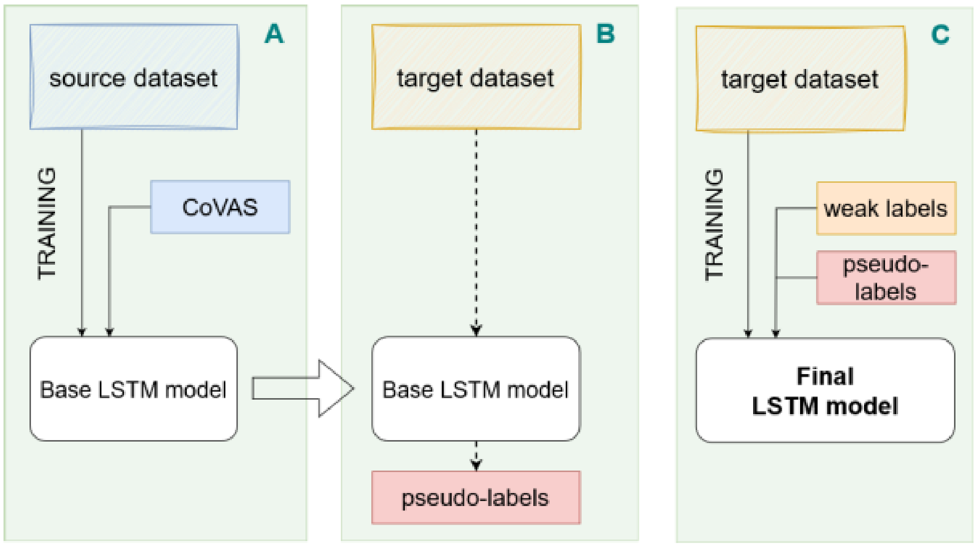


Development of the classification model: A. base model training, B. target data labeling, C. final model training. Solid lines reflect training, whereas dashed lines stand for classification.

IEEE EMBS IEEE TRANSACTIONS ON NEURAL SYSTEMS AND REHABILITATION ENGINEERING, VOL. 32, 2024 3565

Continuous Short-Term Pain Assessment in Temporomandibular Joint Therapy Using LSTM Models Supported by Heat-Induced Pain Data Patterns

Aleksandra Badura, Maria Bienkowska, Andrzej Mysliwiec, and Ewa Pietka



Source: https://ieeexplore.ieee.org/document/10680582

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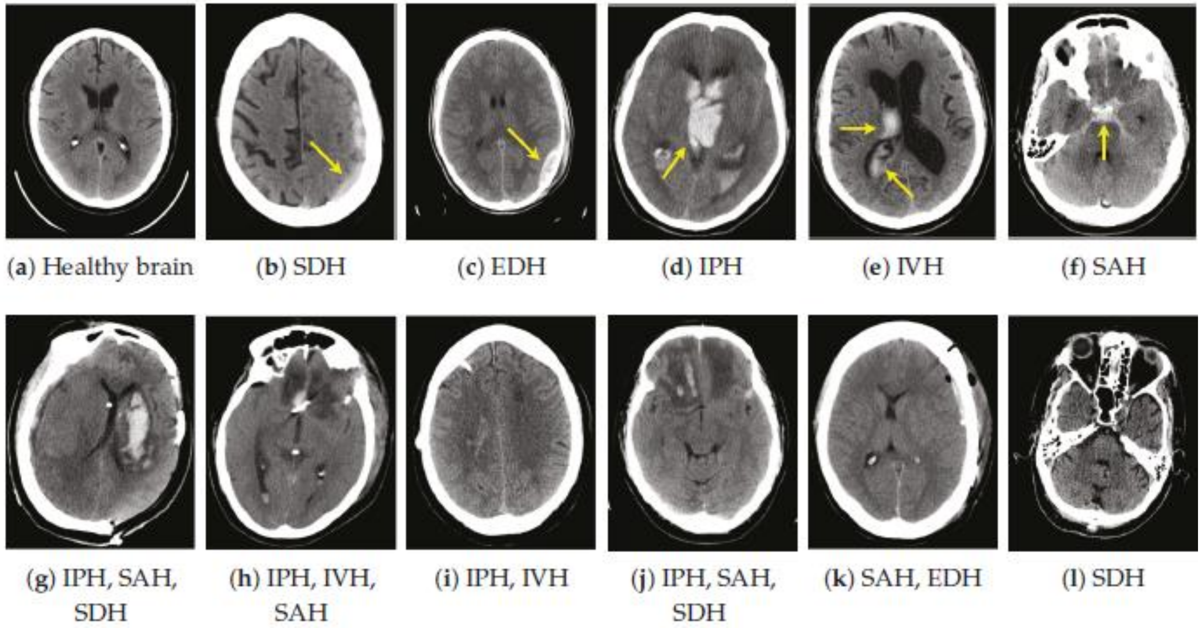


applied sciences

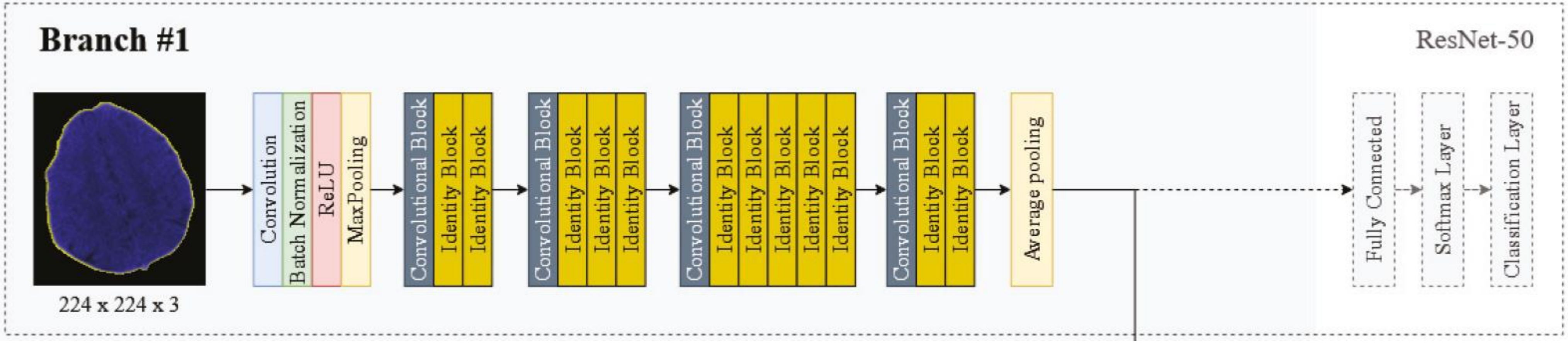
MDPI

Article

Intracranial Hemorrhage Detection in Head CT Using Double-Branch Convolutional Neural Network, Support Vector Machine, and Random Forest

Agata Sage * and Pawel Badura

Sample non-contrast computed tomography (CT) slices with various intracranial hemorrhage (ICH) subtypes



Source: https://www.mdpi.com/books/reprint/5130-machine-learning-for-biomedical-application

Chosen resources for CNNs & DL structures:

Key textbooks:

1) Amita Kapoor, Antonio Gulli, Sujit Pal, Deep Learning with TensorFlow and Keras: Build and deploy supervised, unsupervised, deep, and reinforcement learning models, 3rd Edition. https://www.amazon.com/Deep-Learning-TensorFlow-Keras-reinforcement/dp/1803232919
2) Aurélien Géron, Hands-On Machine Learning with Scikit-Learn, Keras, and TensorFlow, 3rd Edition. https://www.oreilly.com/library/view/hands-on-machine-learning/9781098125967/

Free development tools and projects from the Data Science and NN “Communities”:

- https://keras.io/getting_started/
- https://towardsdatascience.com/a-comprehensive-guide-to-convolutional-neural-networks-the-eli5-way-3bd2b1164a53
- https://www.analyticsvidhya.com/blog/2021/05/convolutional-neural-networks-cnn/
- https://www.geeksforgeeks.org/convolutional-neural-network-cnn-in-machine-learning/
- https://www.tensorflow.org/tutorials
- https://www.interviewbit.com/blog/deep-learning-projects/
- https://www.intel.com/content/www/us/en/internet-of-things/computer-vision/convolutional-neural-networks.html
- https://keras.io/examples/vision/mnist_convnet/
- https://www.kaggle.com/code/elcaiseri/mnist-simple-cnn-keras-accuracy-0-99-top-1
- https://machinelearningmastery.com/how-to-develop-a-convolutional-neural-network-from-scratch-for-mnist-handwritten-digit-classification/
- https://www.mdpi.com/books/reprint/5130-machine-learning-for-biomedical-application