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

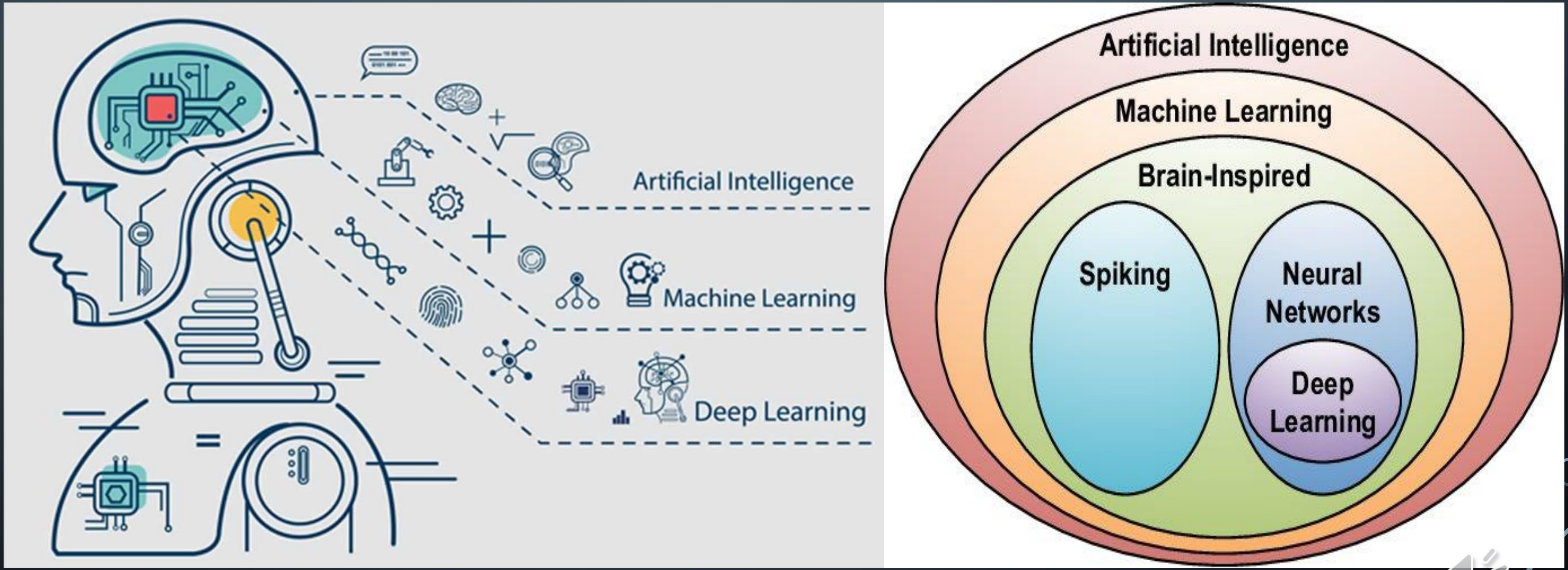
VIBE PROJECT

PATTERN RECOGNITION IN BIOMEDICAL ENGINEERING

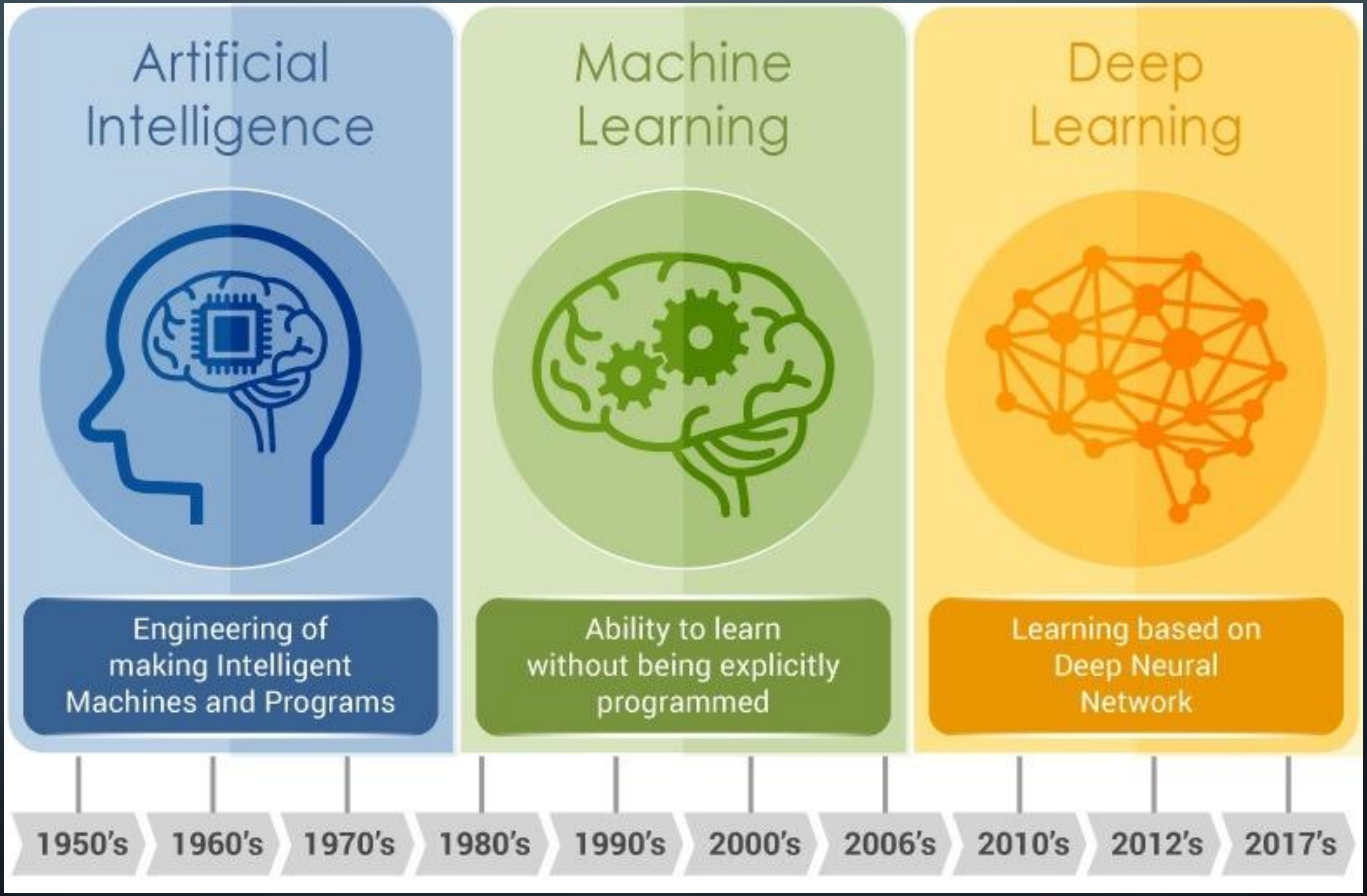
INTRODUCTION TO NEURAL NETWORKS - ALGORITHMS AND METHODS INSPIRED BY BIOLOGICAL PROCESSES

WHERE NN & OTHER BIOLOGICALLY INSPIRED ALGORITHMS ARE PLACED IN?

DATA SCIENCE, MACHINE LEARNING, AI (ARTIFICIAL INTELLIGENCE)



Source: https://www.researchgate.net/publication/359285491_Machine-Learning-Based_Disease_Diagnosis_A_Comprehensive_Review



Source: https://www.researchgate.net/publication/359285491_Machine-Learning-Based_Disease_Diagnosis_A_Comprehensive_Review

DATA SCIENCE (DATA EXPLORATION & DIGGING)

IS A „NEW OIL" OF XXI CENTUARY

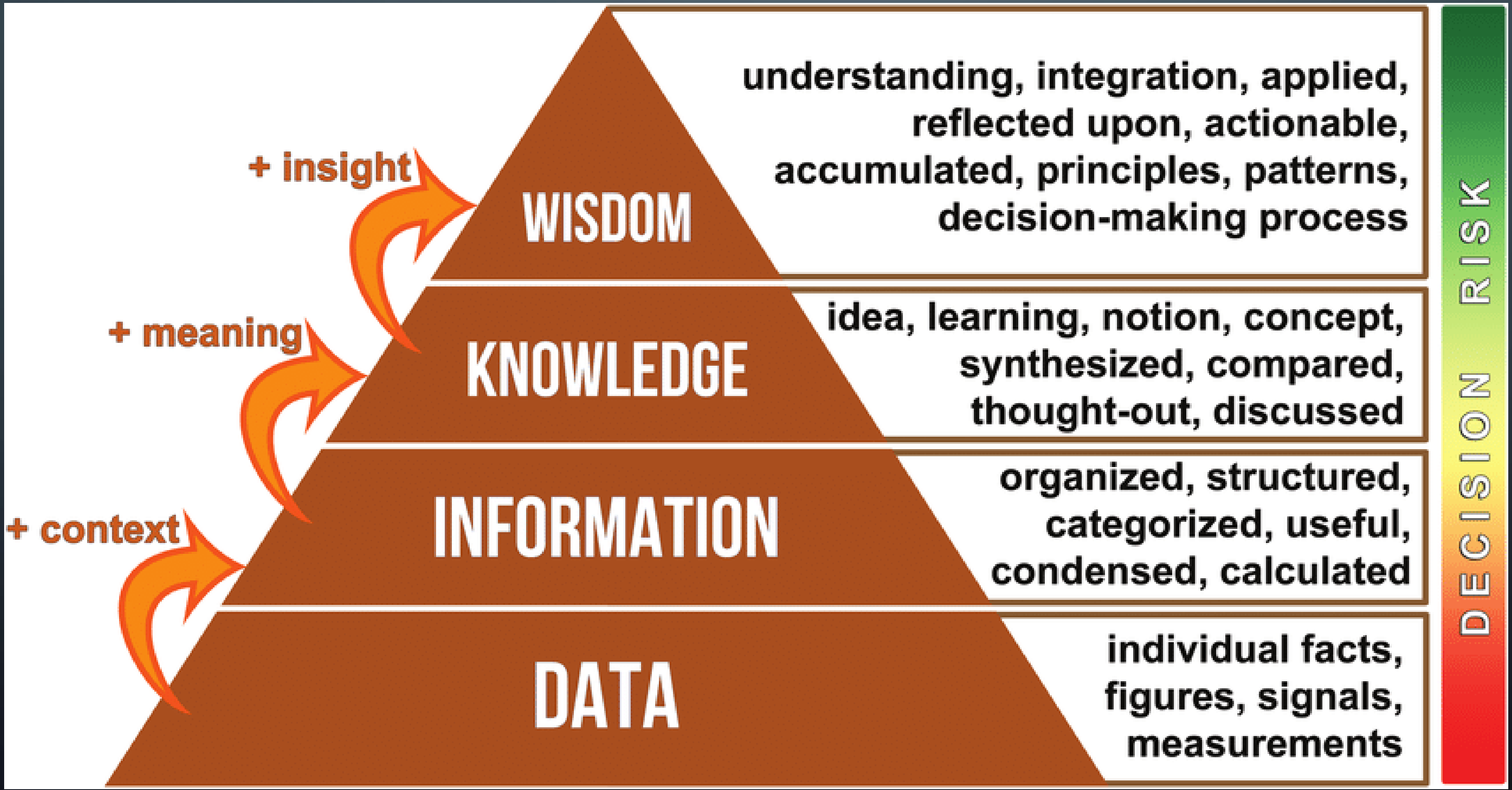
GOAL:

CHANGE RAW INPUT DATA INTO KNOWLEDGE AND WISDOM

HOW:

To develope ALGORITHMS (SET OF RULES) based on different type of methods: *mathematical, statistical, biologically inspired* by means of COMPUTER SCIENCE, to find crucial, significant dependencies into data groups.

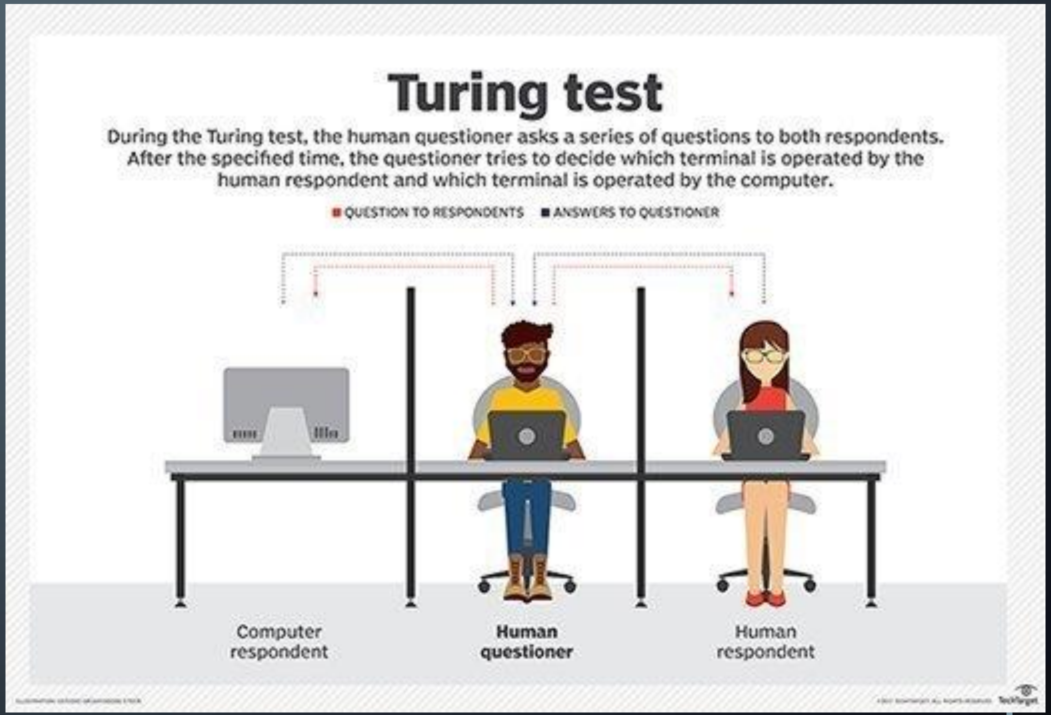
Role of general machine learning systems, including Neural Networks is to extract the information (parameters, measures) and then knowledge from raw data.



Source:https://www.researchgate.net/publication/332400827_How_can_nutrition_models_increase_the_production_efficiency_of_sheep_and_goat_operations/

ARTIFICIAL INTELLIGENCE (AI)

- Alan Turing proposed that a computer can be said to possess artificial intelligence if it can mimic human responses under specific conditions.
- The original Turing Test requires three terminals, each of which is physically separated from the other two.



Source: https://www.techtarget.com/searchenterpriseai/definition/Turing-test

Systems that can learn, reason, and act in a manner similar to humans.

WHAT IS MACHINE LEARNING?

Machine Learning is the science (and art) of programming computers so they can learn from data.

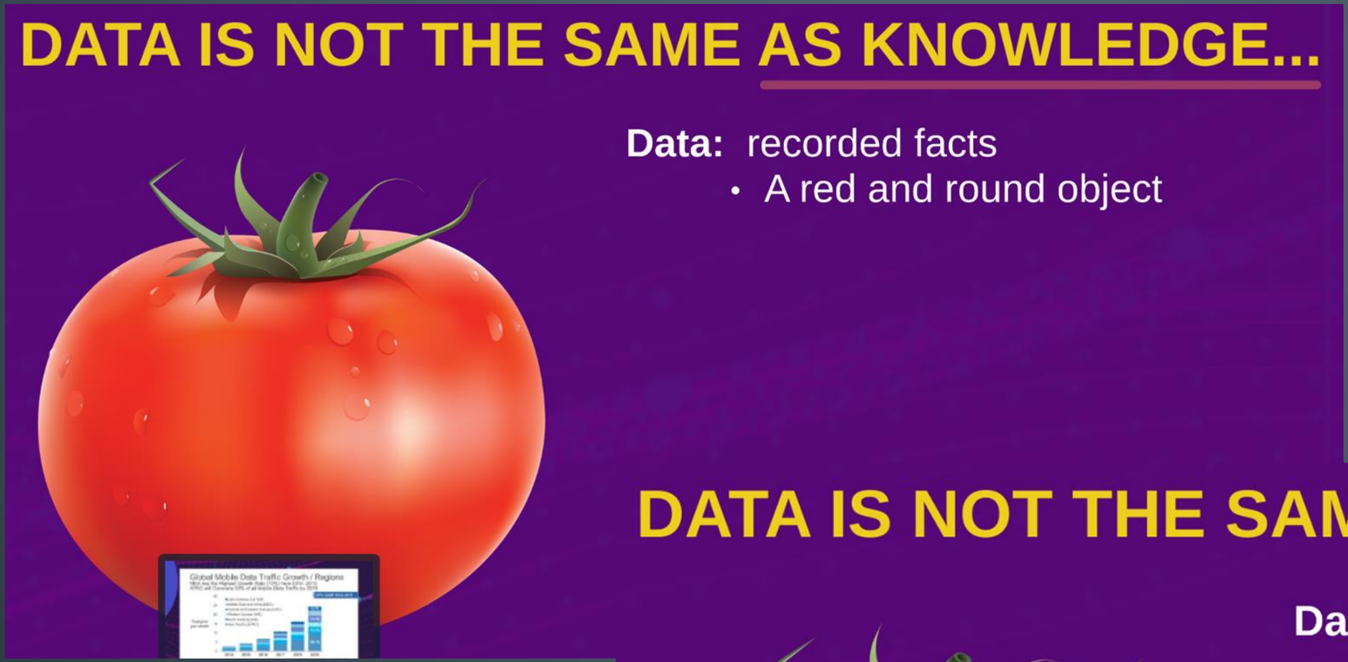
Here is a slightly more general definition:

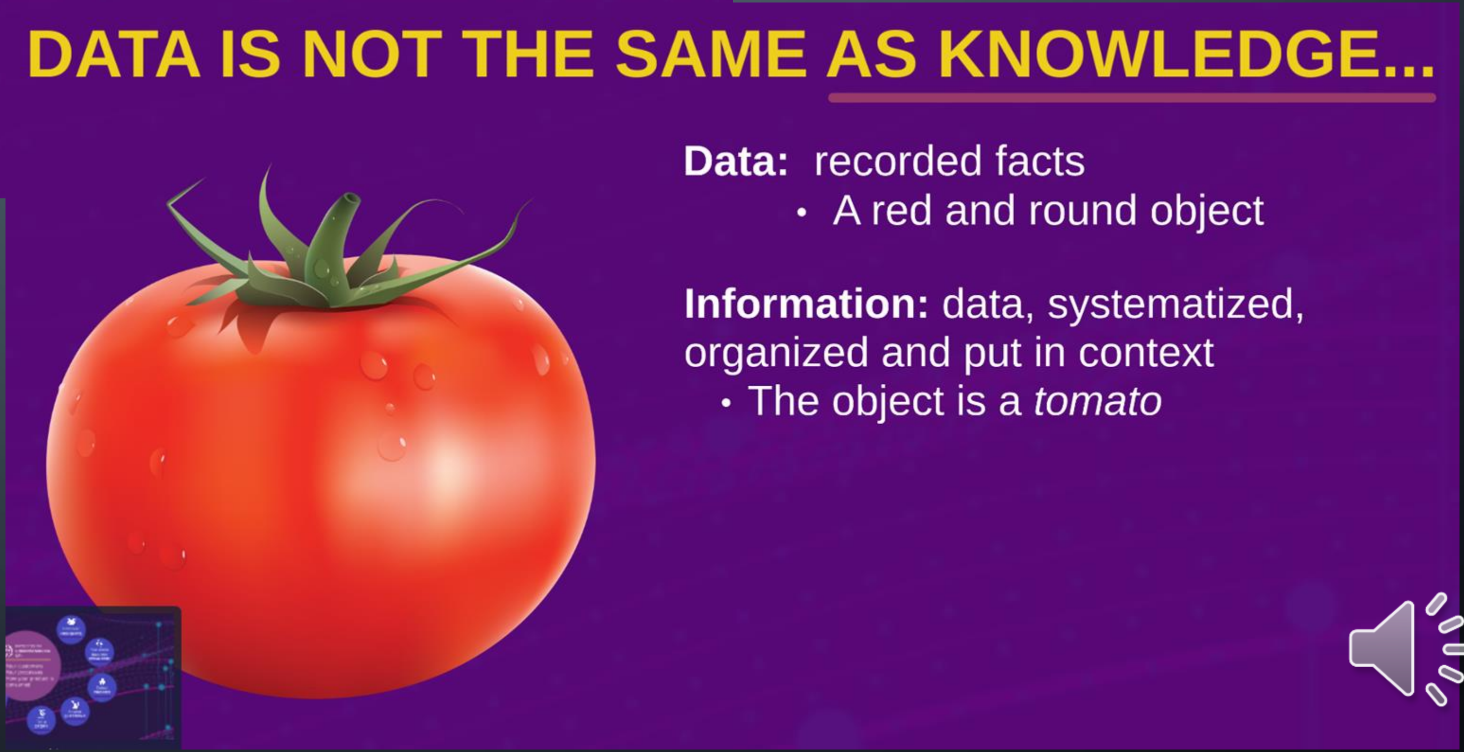
- [Machine Learning is the] field of study that gives computers the ability to learn without being explicitly programmed.

Arthur Samuel, 1959

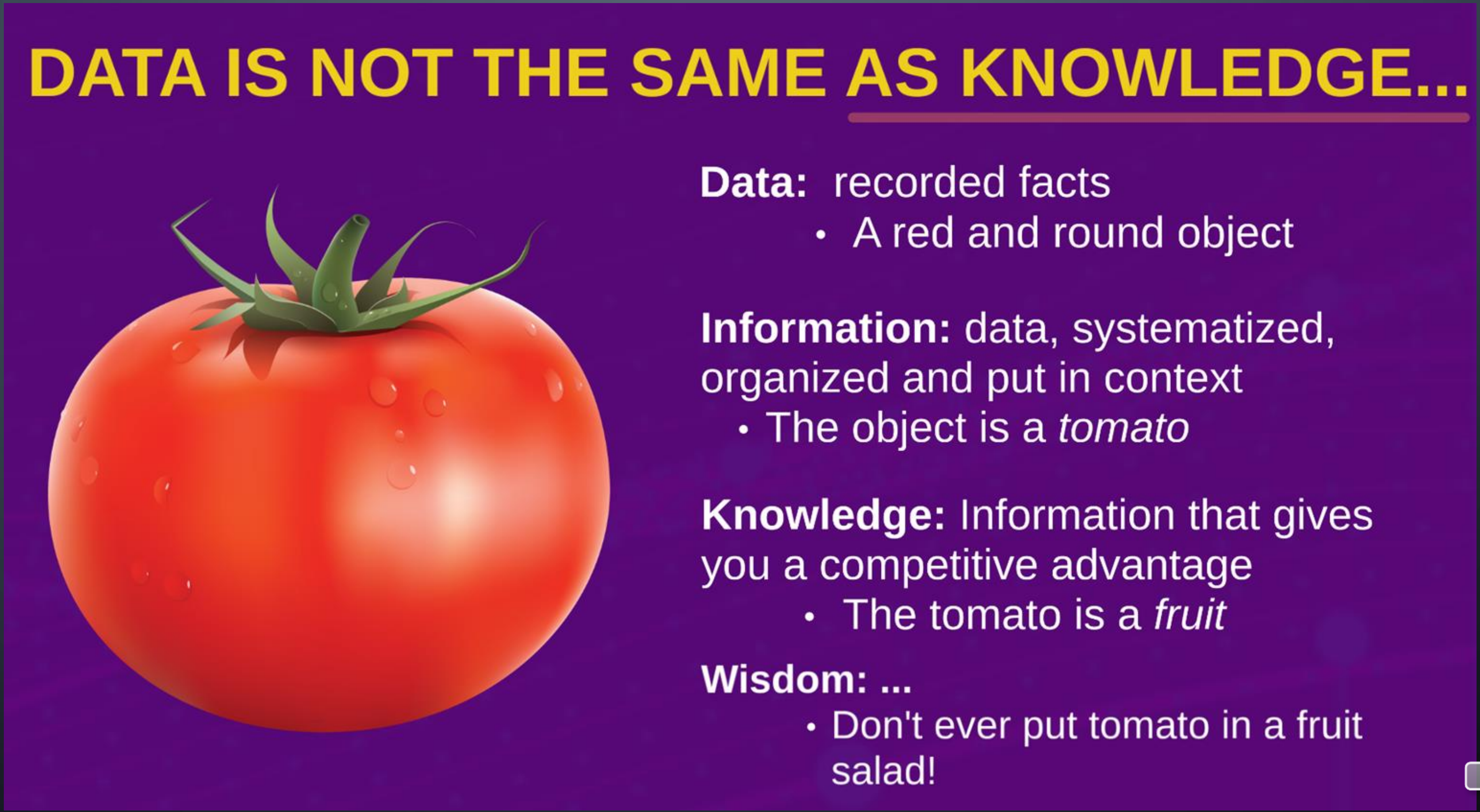
And a more engineering-oriented one:

- A computer program is said to learn from experience E with respect to some task T and some performance measure P, if its performance on T, as measured by P, improves with experience E.
- Tom Mitchell, 1997

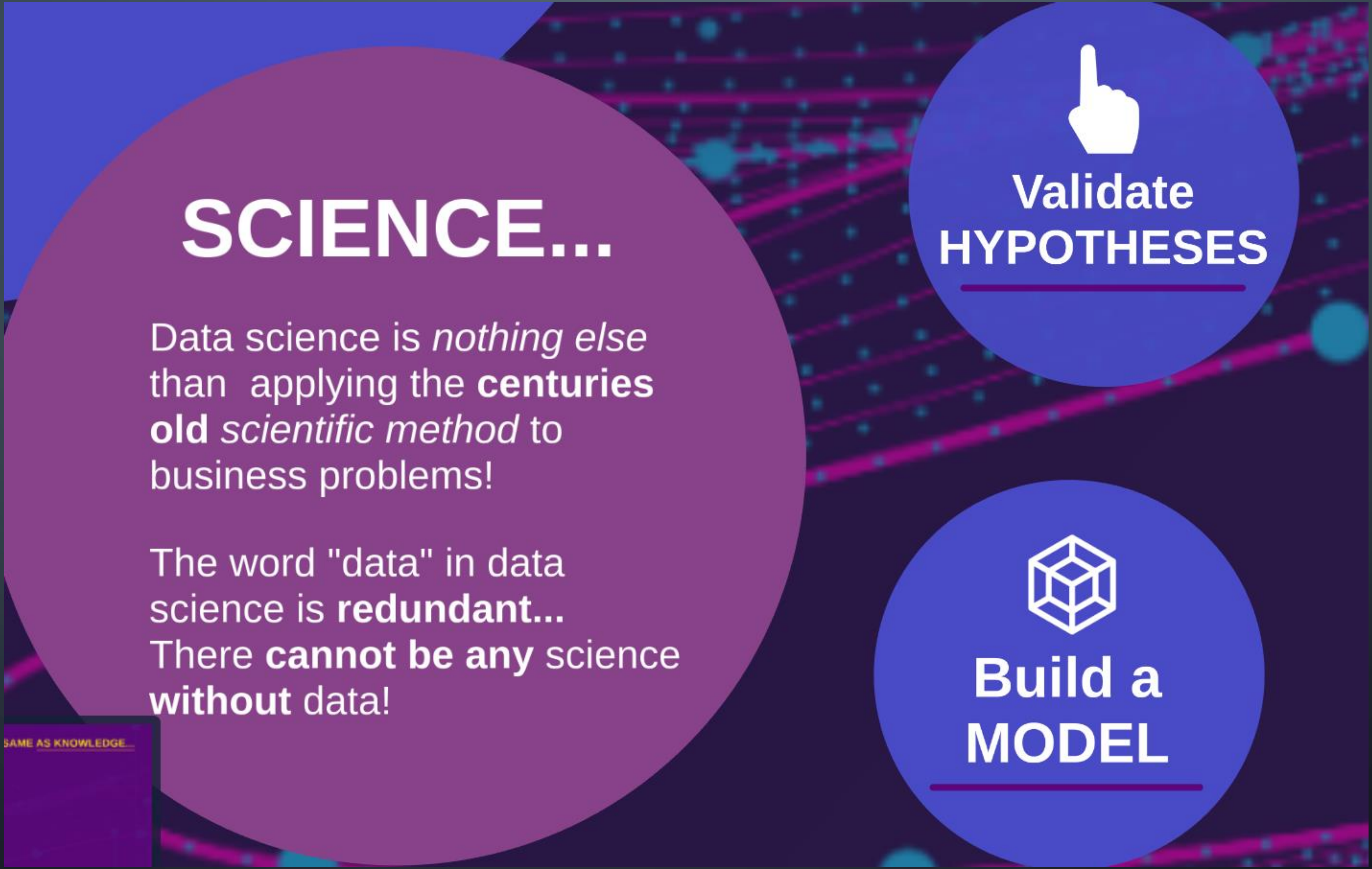




Source: https://www.datascience-pm.com/data-analytics-vs-data-science/



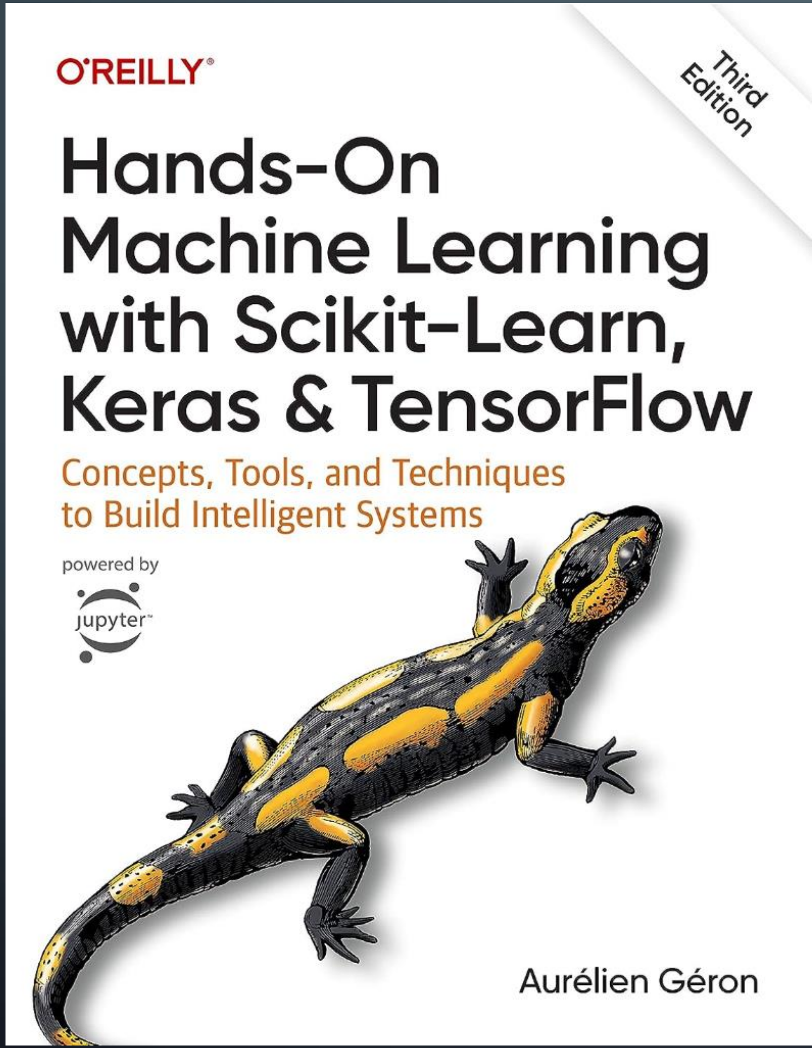
Source: https://www.datascience-pm.com/data-analytics-vs-data-science/



Source: https://www.reddit.com/r/PowerBI/comments/14aw4sh/data_analyst_brain/

Source: https://www.reddit.com/r/PowerBI/comments/14aw4sh/data_analyst_brain/

For you to recommend as a basic, essential 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

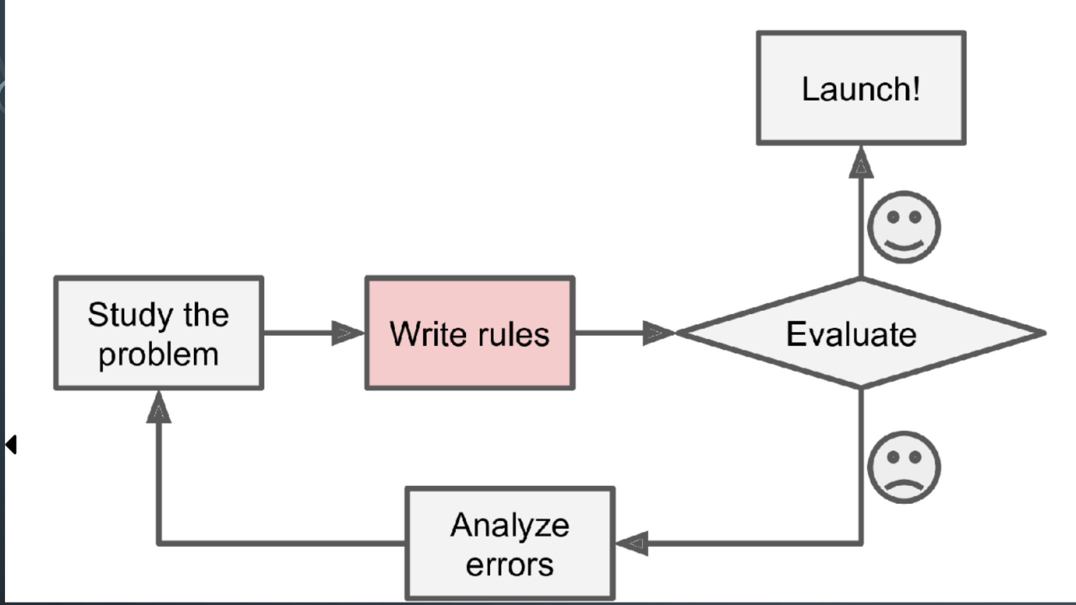
Lecturers and bloggers of specialized websites draw material from this book and Github repository. What is beautiful and builds the development of this discipline is a „Community”, that shares its experiences and projects even GitHub (like this above) with code examples for free.

Examples of Data Science community sites with projects & data sets:

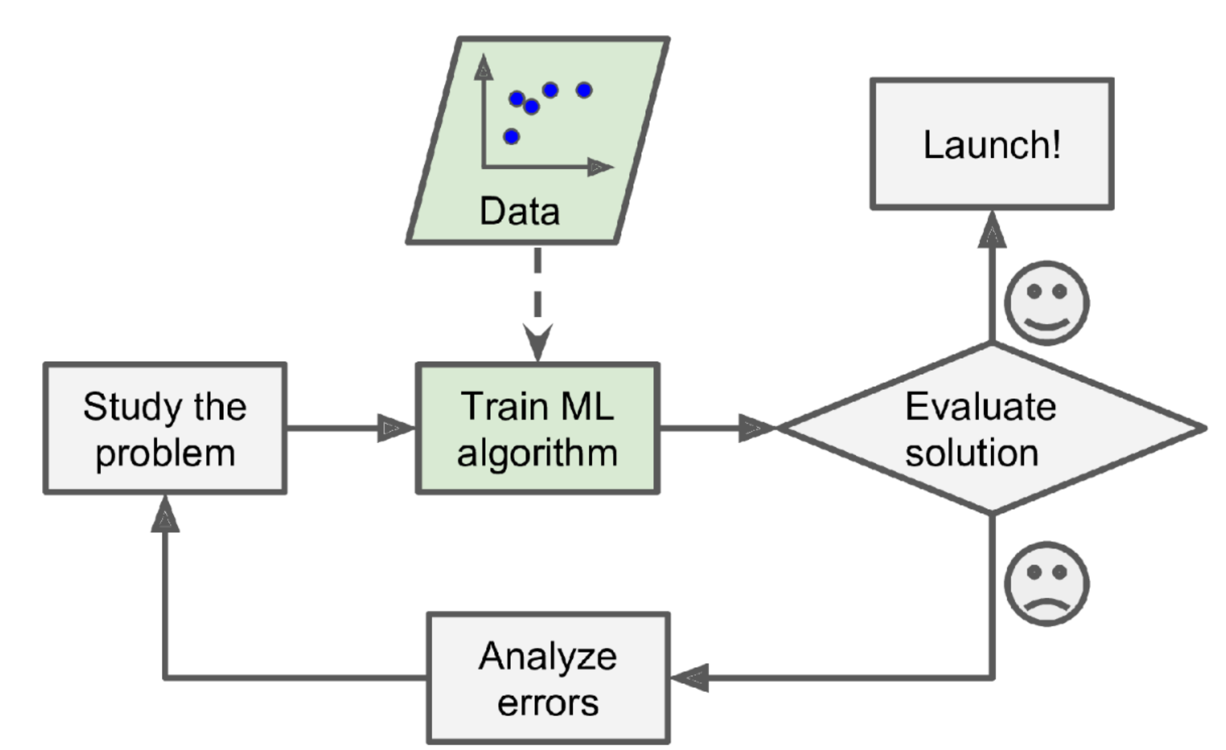
- https://keras.io/examples/
- https://www.kaggle.com/datasets

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

A Comparison of Traditional and AI Approaches in Optimization and Classification Problems.



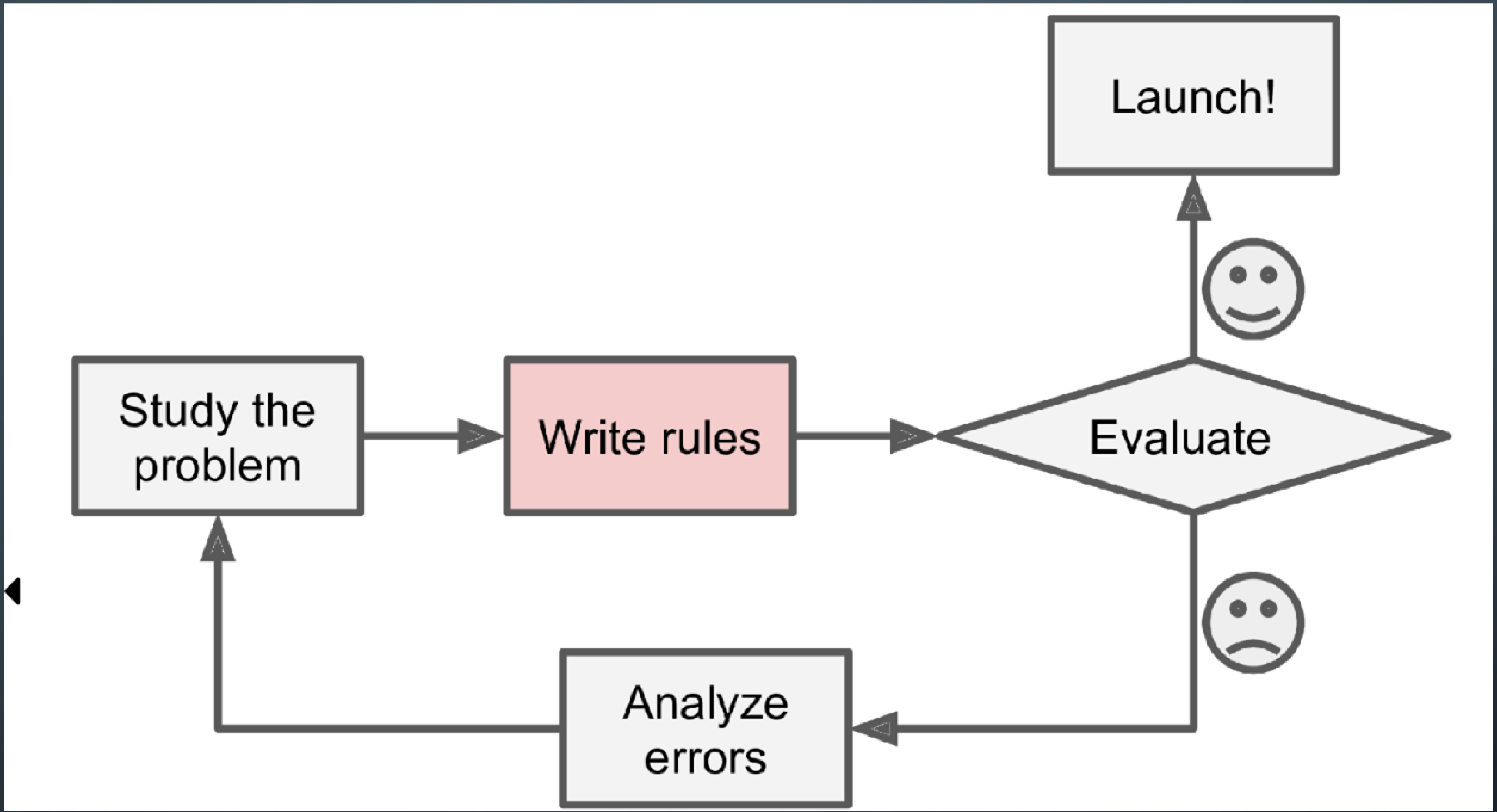
Traditional optimization approach



Machine Learning & AI optimization approach

The main difference lies in the "learning from data" in ML algorithms compared to the classic rule set: IF ... THEN in the classical approach.

Source: Aurélien Géron, „Hands-On Machine Learning with Scikit-Learn, Keras, and TensorFlow"



Source: Aurélien Géron, „Hands-On Machine Learning with Scikit-Learn, Keras, and TensorFlow”

Traditional optimization approach

e.g. Spam detector/classifier – classical approach:
You would write a detection algorithm for each of the patterns that you noticed, and your program would flag emails as spam if a number of these patterns were detected.

ML IS CLASSIFIED INTO THREE BROAD MAIN DOMAINS:

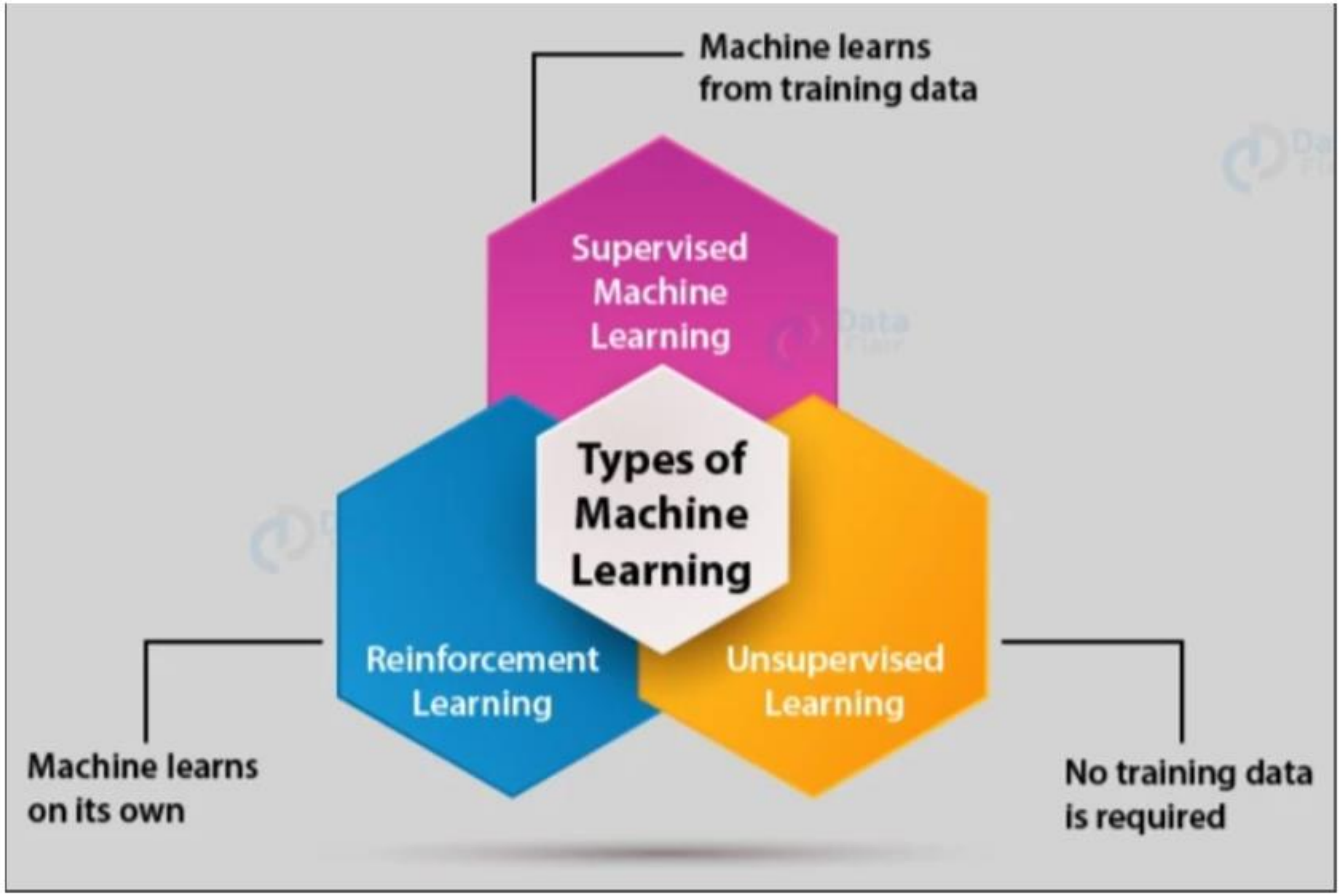
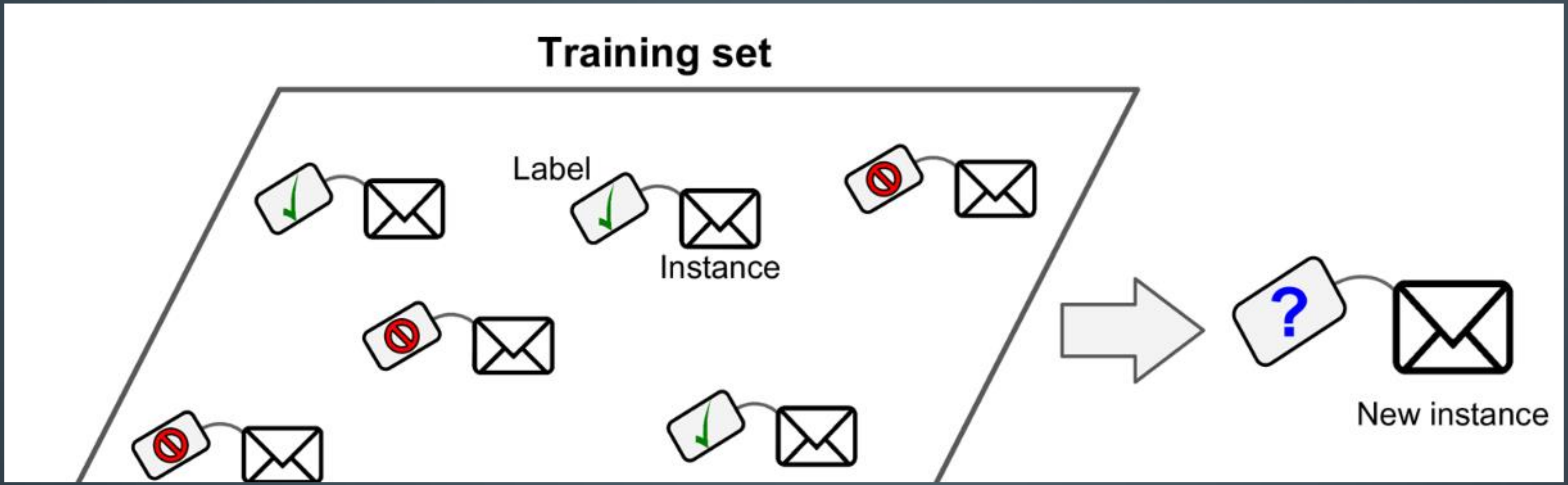
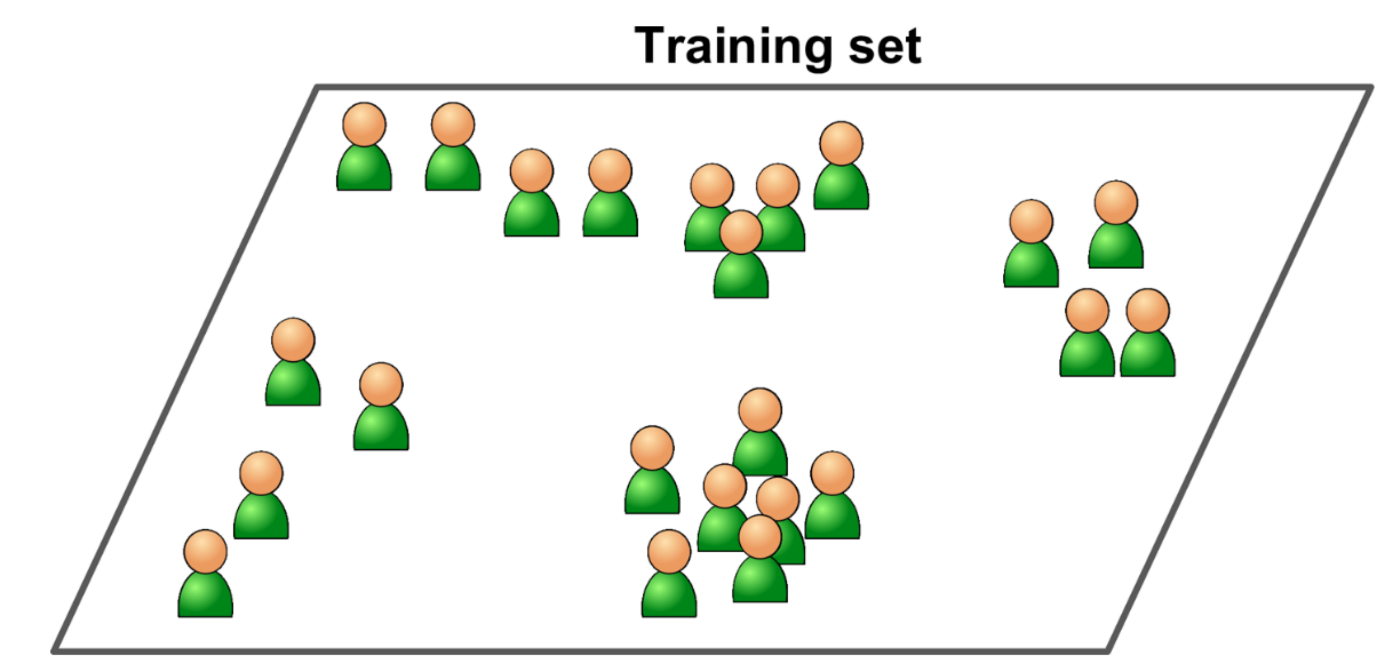


Image Source: www.dataflair.com

„Machine Learning is the field of study that gives computers the ability to learn without being explicitly programmed." - *Arthur Samuel, 1959*



Supervised learning

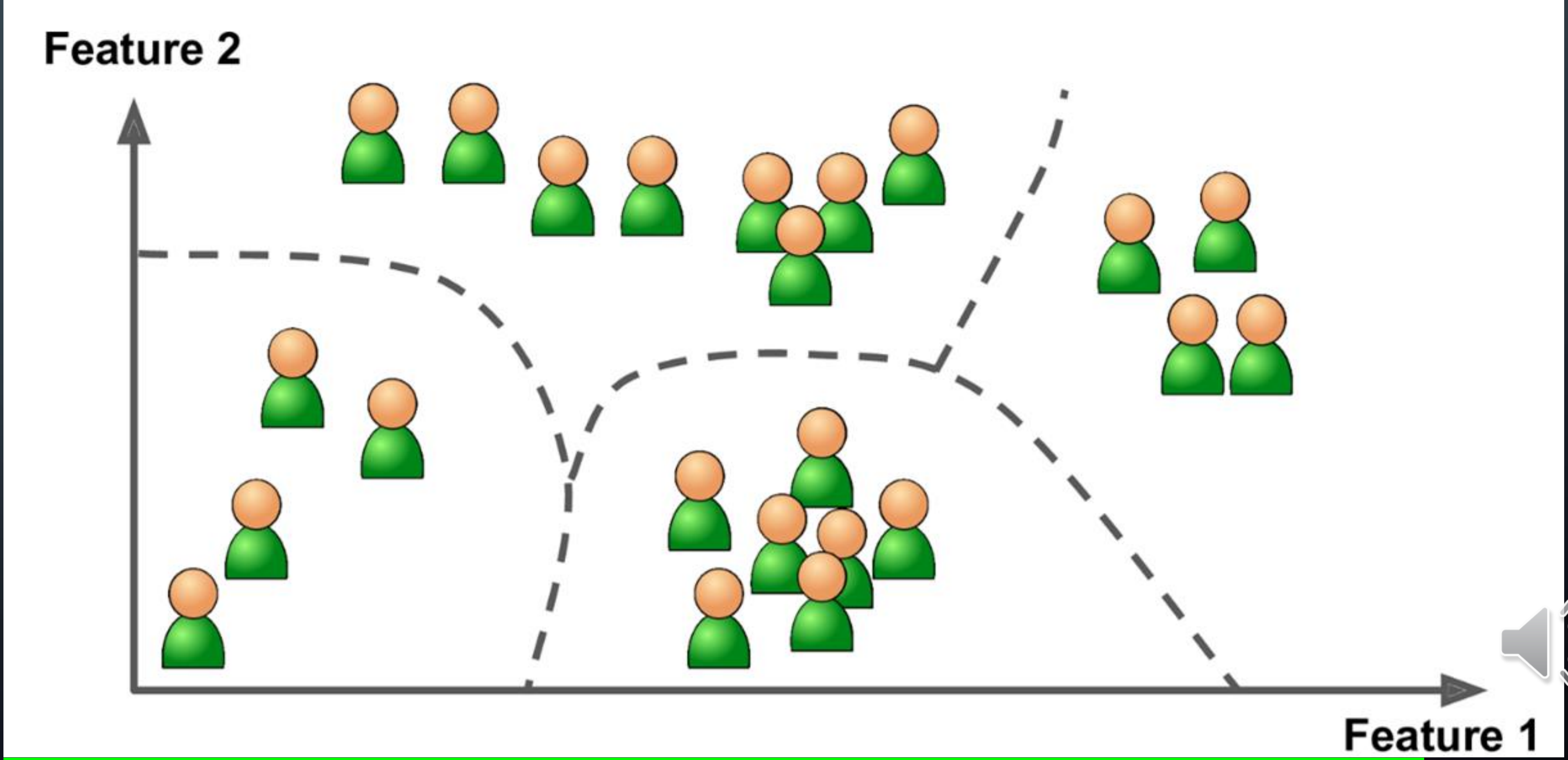


Unsupervised learning

Source: Aurélien Géron, „Hands-On Machine Learning with Scikit-Learn, Keras, and TensorFlow”

Clustering as an Unsupervised learning approach

When we don't have known output labels for the data, the machine learning system tries to find the groups itself by analyzing the clusters - this is the *clustering process*.



Source: Aurélien Géron, „Hands-On Machine Learning with Scikit-Learn, Keras, and TensorFlow"

FEATURE SET REDUCTION/EXTRACTION

- A related task is dimensionality reduction, in which the goal is to simplify the data without losing too much information.

- One way to do this is to merge several correlated features into one. For example, a car's mileage may be strongly correlated with its age, so the dimensionality reduction algorithm will merge them into one feature that represents the car's wear and tear. This is called feature extraction.

Source: Aurélien Géron, „Hands-On Machine Learning with Scikit-Learn, Keras, and TensorFlow"

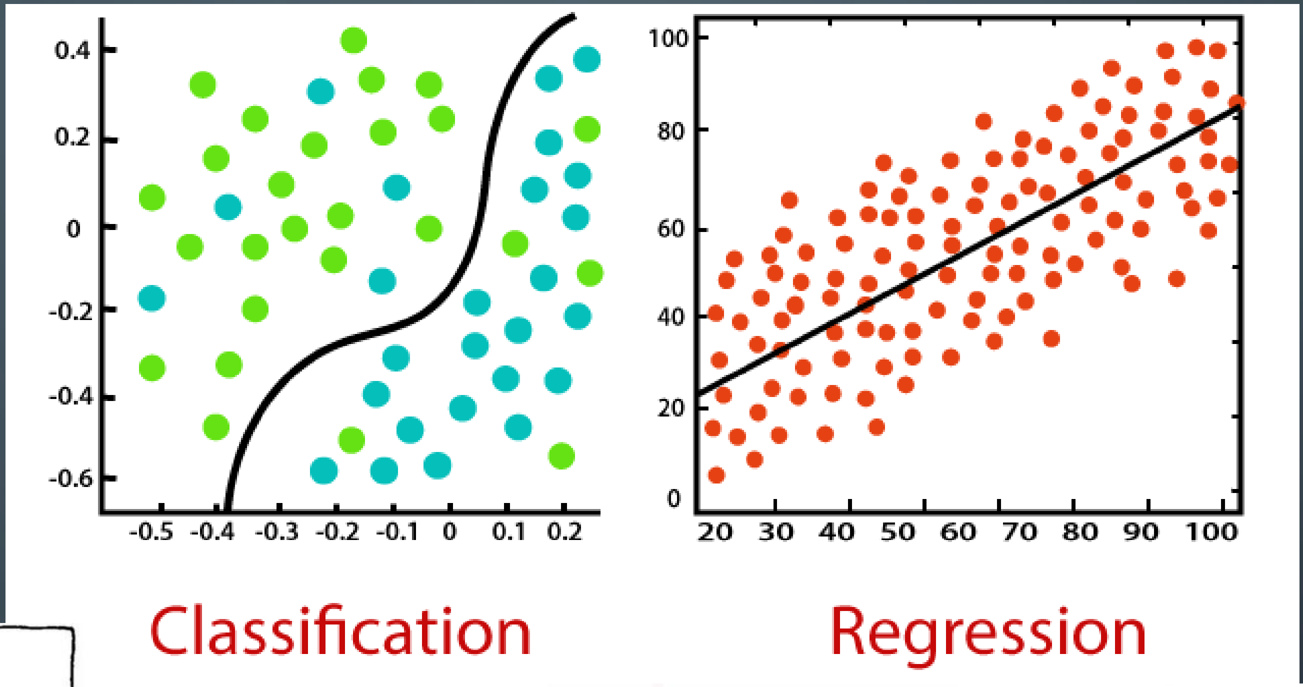
Yet another important unsupervised task is anomaly detection—for example, detecting unusual credit card transactions to prevent fraud, catching manufacturing defects, or automatically removing outliers from a dataset before feeding it to another learning algorithm.

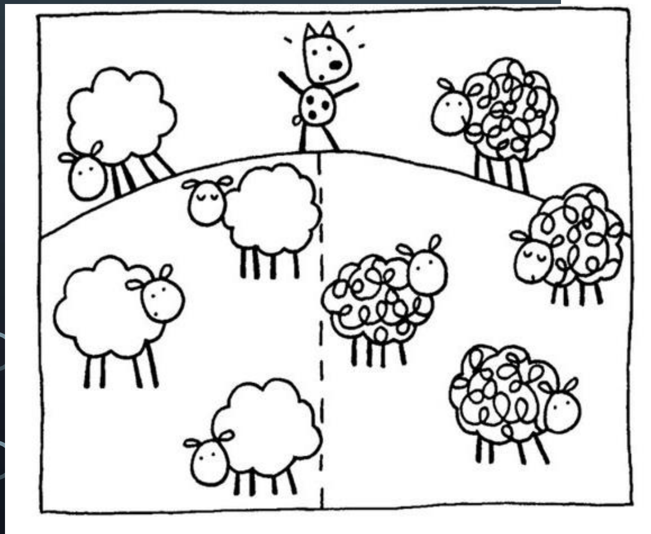
The system is shown mostly normal instances during training, so it learns to recognize them; then, when it sees a new instance, it can tell whether it looks like a normal one or whether it is likely an anomaly.

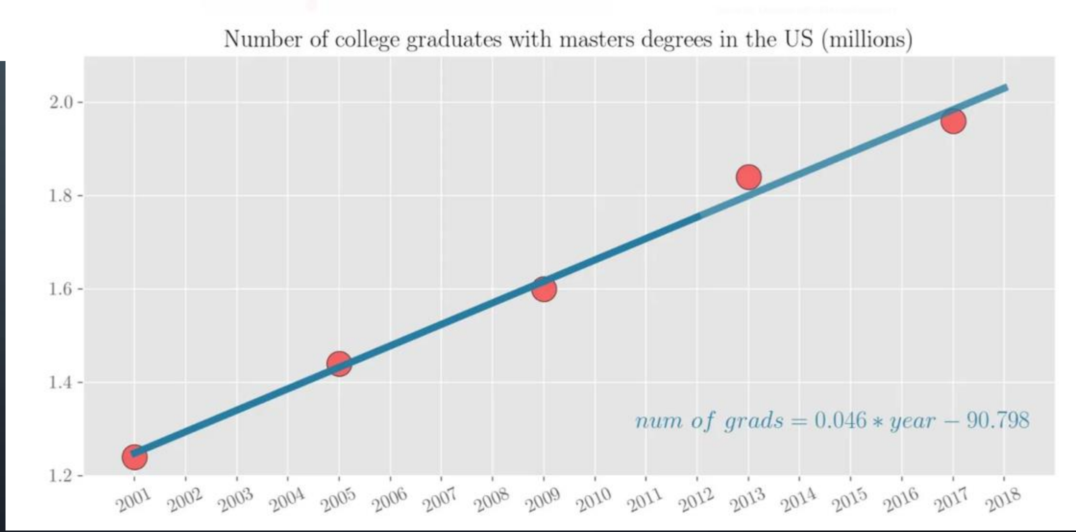
A very similar task is novelty detection: it aims to detect new instances that look different from all instances in the training set. This requires having a very "clean" training set, devoid of any instance that you would like the algorithm to detect. For example, if you have thousands of pictures of dogs, and 1% of these pictures represent Chihuahuas, then a novelty detection algorithm should not treat new pictures of Chihuahuas as novelties. On the other hand, anomaly detection algorithms may consider these dogs as so rare and so different from other dogs that they would likely classify them as anomalies (no offense to Chihuahuas).

Source: Aurélien Géron, „Hands-On Machine Learning with Scikit-Learn, Keras, and TensorFlow"

TWO BASIC PROBLEM TYPES TO SOLVE:

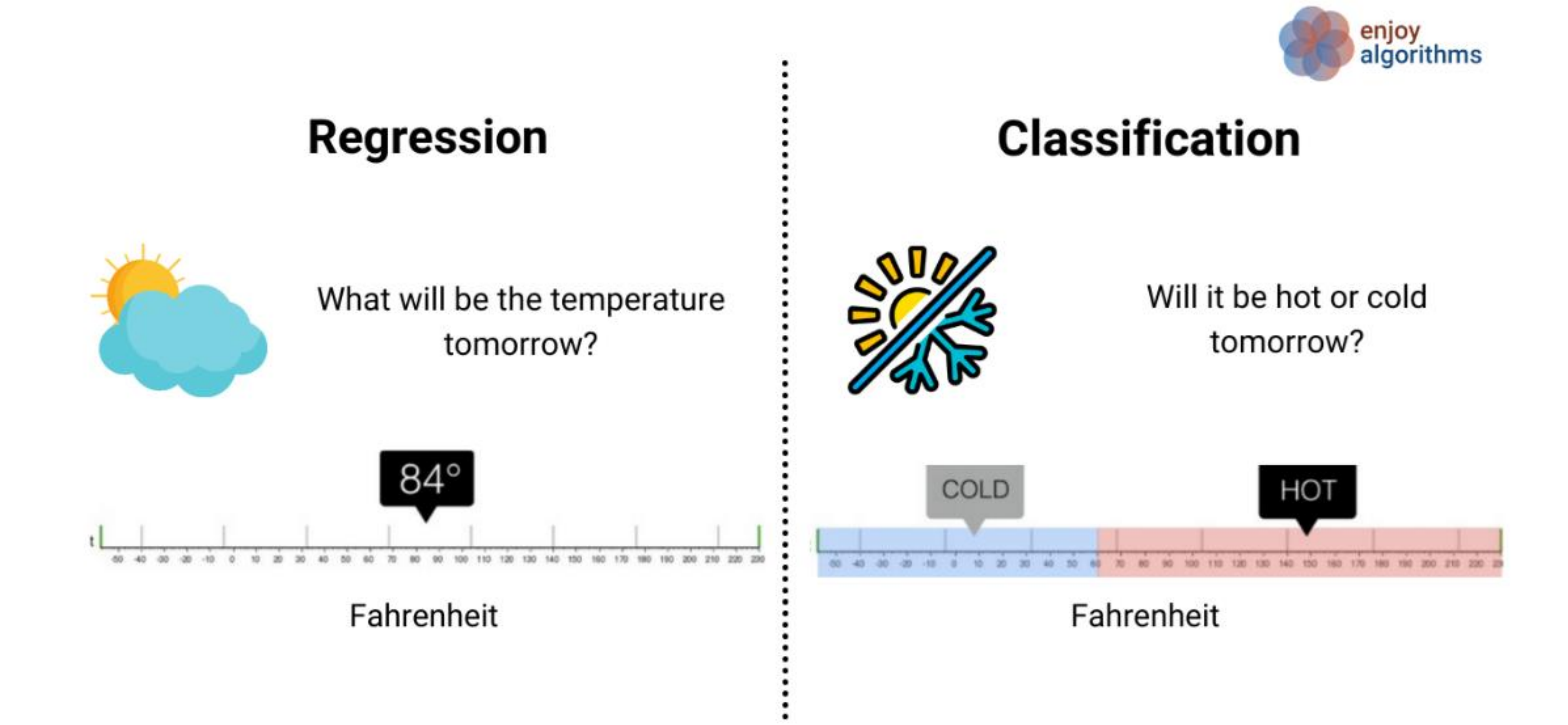






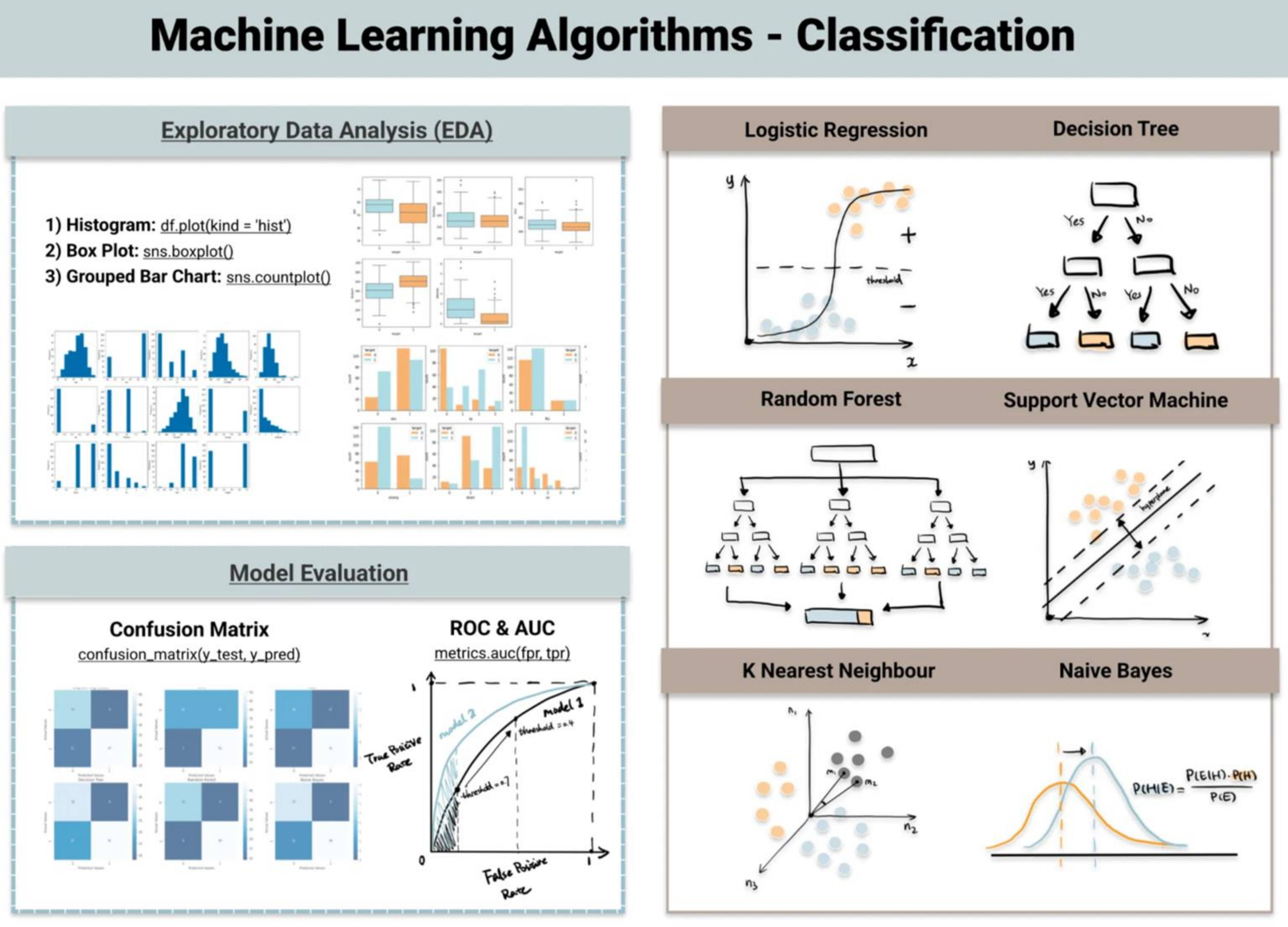
Source: www.javapoint.com

TWO BASIC PROBLEM TYPES TO SOLVE:



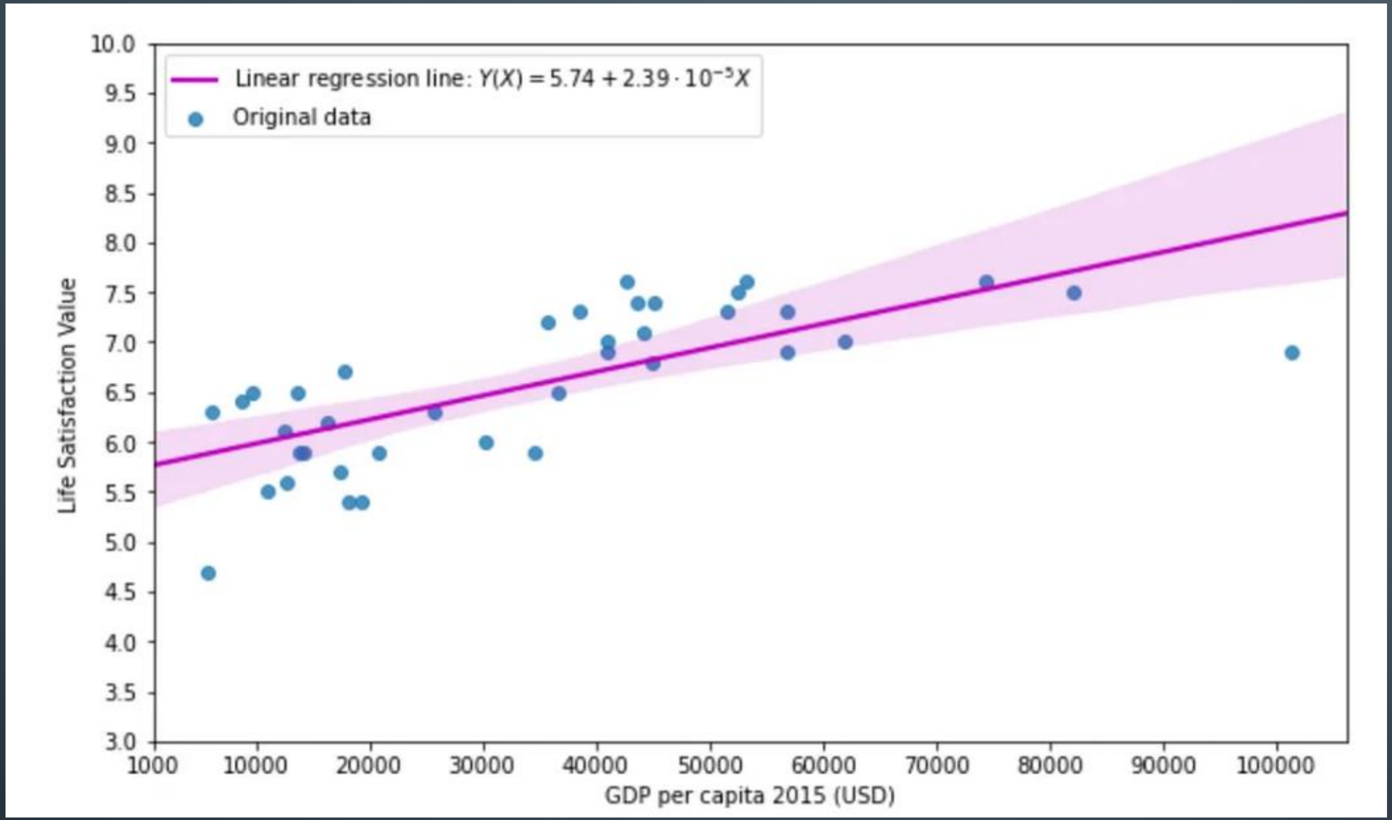
https://www.enjoyalgorithms.com/blogs/classification-and-regression-in-machine-learning
https://machinelearningmastery.com/classification-versus-regression-in-machine-learning/
https://www.simplilearn.com/regression-vs-classification-in-machine-learning-article

CLASSIFICATION



https://towardsdatascience.com/top-machine-learning-algorithms-for-classification-2197870ff501

REGRESSION



- https://towardsdatascience.com/five-regression-python-modules-that-every-data-scientist-must-know-a4e03a886853
- https://www.analyticsvidhya.com/blog/2021/05/5-regression-algorithms-you-should-know-introductory-guide/
- https://towardsdatascience.com/ml-101-linear-regression-bea0f489cf54
- https://towardsdatascience.com/a-beginners-guide-to-regression-analysis-in-machine-learning-8a828b491bbf

DATA SCIENCE, MACHINE LEARNING, AI (ARTIFICIAL INTELLIGENCE)

- ‚TRADITIONAL’ STATISTICAL METHODS OF DATA PROCESSING: *STILL STRONG*!
- BIOLOGICALLY INSPIRED ALGORITHMS (*SOFT COMPUTING, METODY INTELIGENCJI OBLICZENIOWEJ*):
  - NEURAL NETWORKS, incl. DEEP LEARNING ALGORITHMS
  - GENETICS ALGORITHMS -> GENETICS PROGRAMMING
  - *FUZZY SETS vs. CLASSICAL SETS*
  - *+ OTHER e.g. ANT or BEE COLONY/SWARM ALGORITHMS*

FROM BIOLOGICAL TO ARTIFICIAL „MATH" NEURONS ☺

The presented mathematical model of the neuron, developed by Rosenblatt in the 1950s, as seen, sums the previous inputs (dendrites) with weights and its output (axon) is the value of the activation function.

https://www.geeksforgeeks.org/what-is-perceptron-the-simplest-artificial-neural-network/

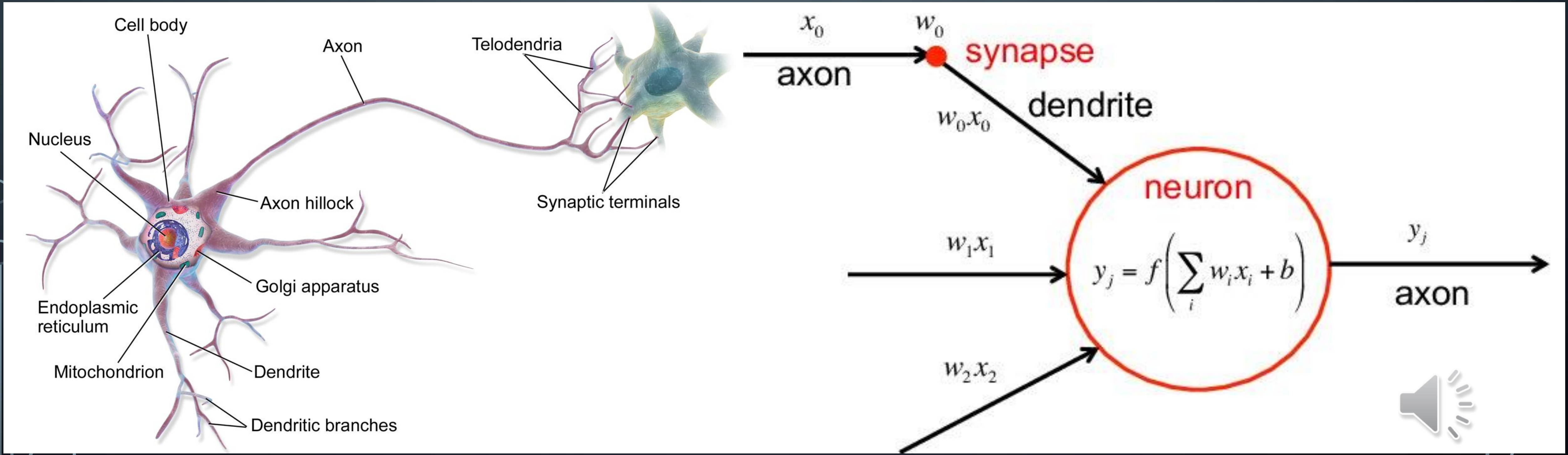
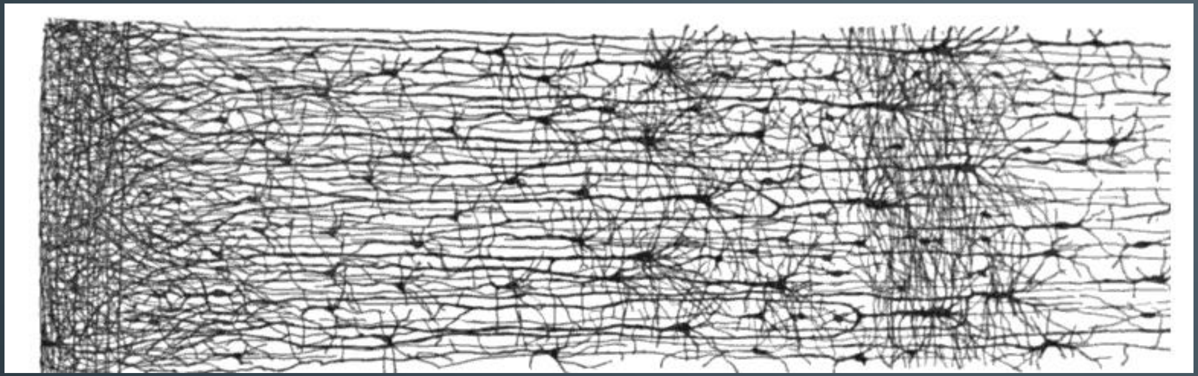


Image by Bruce Blaus (Creative Commons 3.0). Reproduced from https://en.wikipedia.org/wiki/Neuron

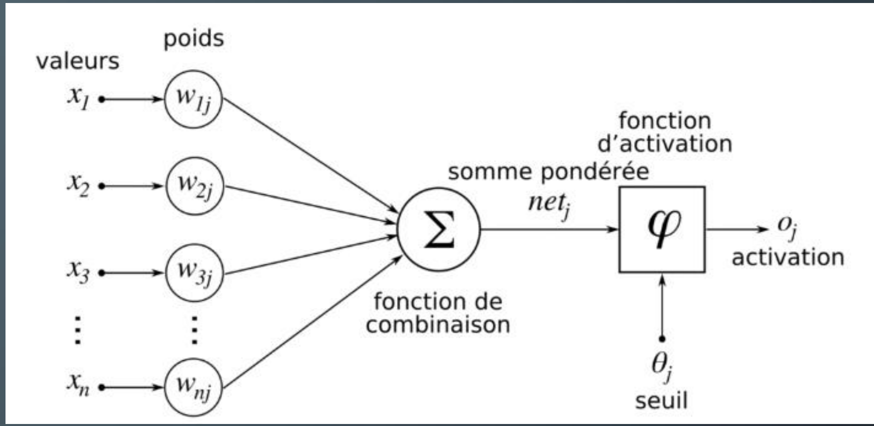
BIOLOGICAL VS. ARTIFICIAL NEURON AS DATA PROCESSING UNIT

Drawing of a cortical lamination by S. Ramon y Cajal (public domain).



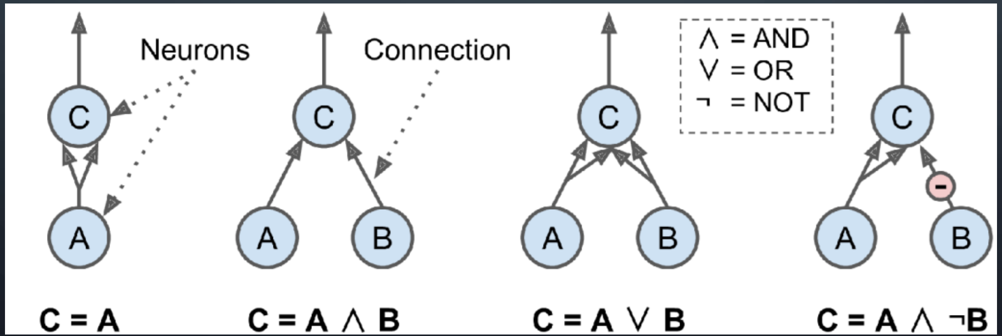
Source: Reproduced from https://en.wikipedia.org/wiki/Cerebral_cortex

Mathematical operation of the artificial neuron



Source: https://ikramchraibik.com/2021/04/28/reprenons-les-bases-neurone-artificiel-neurone-biologique/

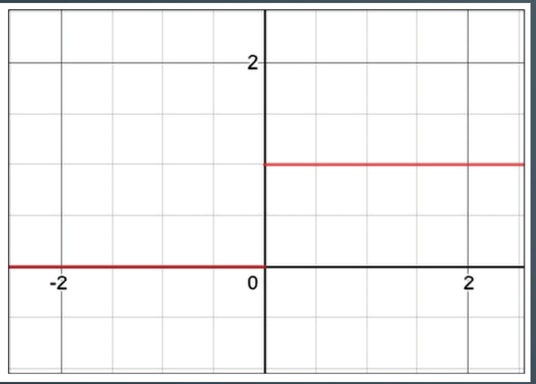
Logical Computations with Neurons



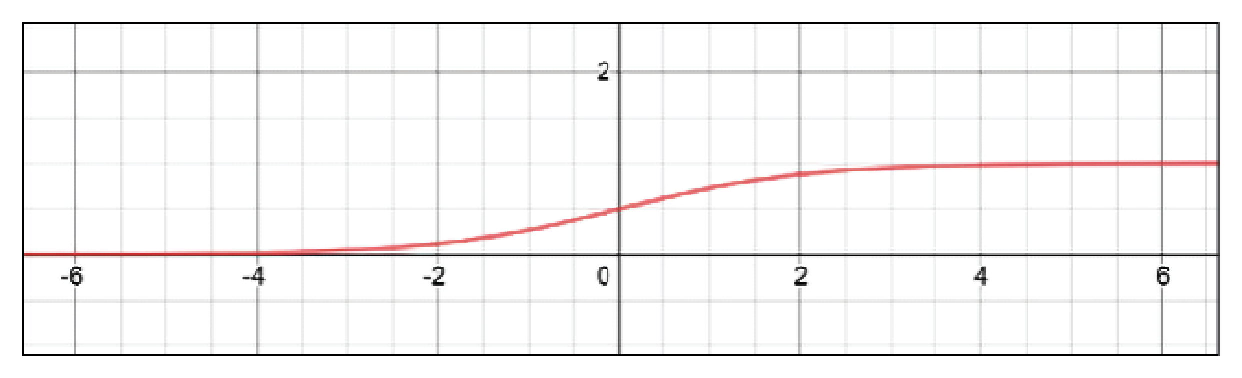
Source: Aurélien Géron, „Hands-On Machine Learning with Scikit-Learn, Keras, and TensorFlow"

DIFFERENT KIND ACTIVATION FUNCTIONS (LINEAR OR NONLINEAR): *TO GENERATE THE NEURON ANSWER*

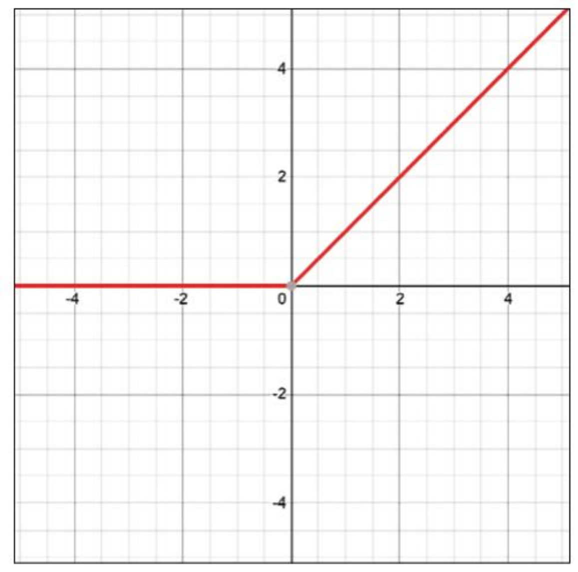
Hard Lim: either a 0 or 1



Sigmoid function with output in the range (0,1)



RelU activation function



Source: Original work by the author.

AI, NEURAL NETWORK-BASED COMPUTER VISION EXAMPLE.

Source: https://www.automate.org/vision/blogs/embedded-vision-explained-how-do-autonomous-cars-see

AUTONOMOUS VEHICLES

Self-driving cars.

- Autonomous vehicles are probably the pinnacle of AI nowadays. If you think about it, aself-driving car is actually a **robot**, although it might not look like one. It perceives (gathers data about) its environment through a rich set of *sensors* (cameras, radars, lidars, GPS) and it is also endowed with *actuators* that allow it to perform actions (steering, accelerating) to change its own situation in — or otherwise affect — the environment. Self-driving cars constitute a prime example of the general concept of “**autonomous agents”,** which will be key in properly defining AI later on.

- Beyond sensors and actuators, which roughly correspond to the input and output layers, there is an *intermediate processing layer* that interprets the raw data coming from the sensors and turns it into information/knowledge that is ultimately used to solve the problem of driving safely and taking you from A to B. This layer is of course what gives a self-driving car its smarts and combines quite a few key AI techniques. To list just three, we have:
- **Computer vision:** This refers to a set of relatively low level techniques used to turn raw pixels captured by an optical or infrared camera into actual detection of lane lines, obstacles, pedestrians, deer, traffic signs, etc. This is really a pure ML problem, currently solved with Deep Learning techniques and specialized hardware (GPUs).
- **Search and planning:** These are employed, among other things to find the most convenient route from A to B, subject to constraints given by obstacles, traffic, road closings, speed limits, weather, etc… Incidentally, *this is one of the problems solved by AI that cannot be solved through pure ML techniques,* proving that there is more to AI than just ML.
- **Decision making under uncertainty:** as sensor measurements are not absolutely exact and the available information about the surrounding environment is necessarily incomplete, any autonomous engine is forced to make decisions under uncertainty almost all the time. This is not a common feature of computer systems pre-AI, or even something that most people would think computers can do. Luckily, during the last half of the 20th century there was a big deal of progress in the field of computational Bayesian statistics to enable inherently deterministic computers to deal with uncertainty.

Personalized Content Recommendation

- Although sometimes invisible, recommendation systems are virtually everywhere, starting from e-commerce sites — think Amazon — and going all the way to digital content distribution platforms such as Netflix and Spotify, as well as social networks. Whenever you see messages of the sort 'based on your recent viewing / purchasing history, we think you would also like Y' you can be sure there is a recommendation system in action.

- The use of this kind of system has permeated even traditional content providers, recently turned digital. Most people don't realize it but the front page of the online version of the New York Times is different for each reader. Recommendation algorithms determine the content each user sees in a personalized way.

3. MACHINE VISION

Source: https://markus-enzweiler.de/datasets/

*Luckily, there's still something else to do. AI, NN based **binary** (class/rest) classifier example:*
https://www.youtube.com/watch?v=vIci3C4JkL0

- **Object detection**: This refers to locating, that is, drawing bounding boxes, around all instances of a particular class of object, e.g. pedestrian, in a given image. Variants of this can be used to find defects in images of manufactured pieces, for instance.
- **Object classification**: Given an image of a single isolated object, identify which class of object it is. In other words, is this a picture of a fruit, a person, a table, another car… ?
- **Face recognition**: Given a picture of a face, tell me who it is.
- **Image segmentation**: Given a picture of a complex scene, separate the different components (sets of pixels) corresponding to each individual

CLASSIFIER'S PERFORMANCE MEASURES

Performance Measures

Evaluating a classifier is often significantly trickier than evaluating a regressor.

There are many performance measures available, so grab another coffee and get ready to learn many new concepts and acronyms!

$$\text{precision} = \frac{TP}{TP + FP}$$

TP is the number of true positives, and *FP* is the number of false positives.

A trivial way to have perfect precision is to make one single positive prediction and ensure it is correct (precision = 1/1 = 100%). But this would not be very useful, since the classifier would ignore all but one positive instance. So precision is typically used along with another metric named *recall*, also called *sensitivity* or the *true positive rate* (TPR): this is the ratio of positive instances that are correctly detected by the classifier (Equation 3-2).

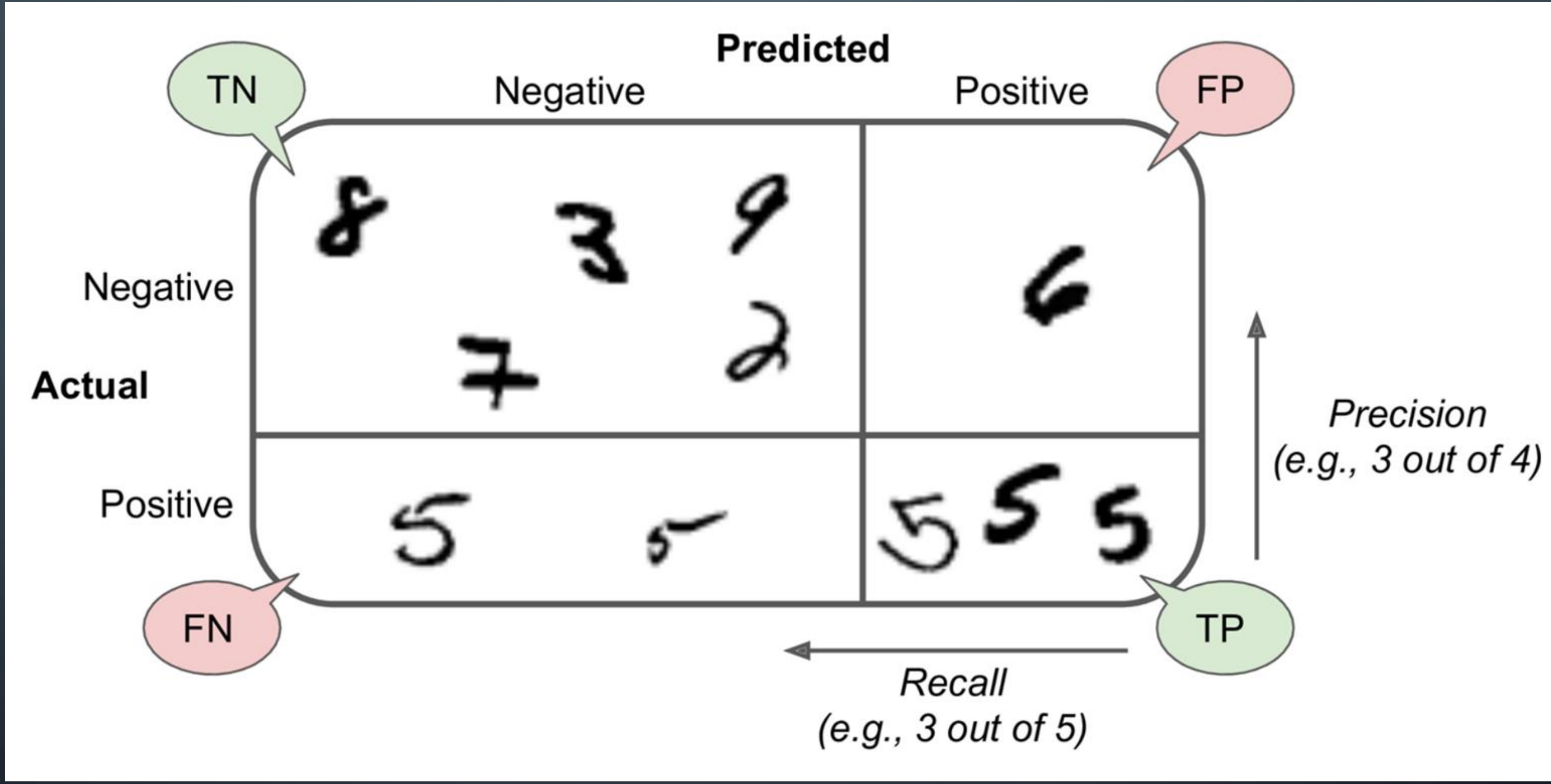
Equation 3-2. Recall

$$\text{recall} = \frac{TP}{TP + FN}$$

FN is, of course, the number of false negatives.

If you are confused about the confusion matrix, Figure 3-2 may help.

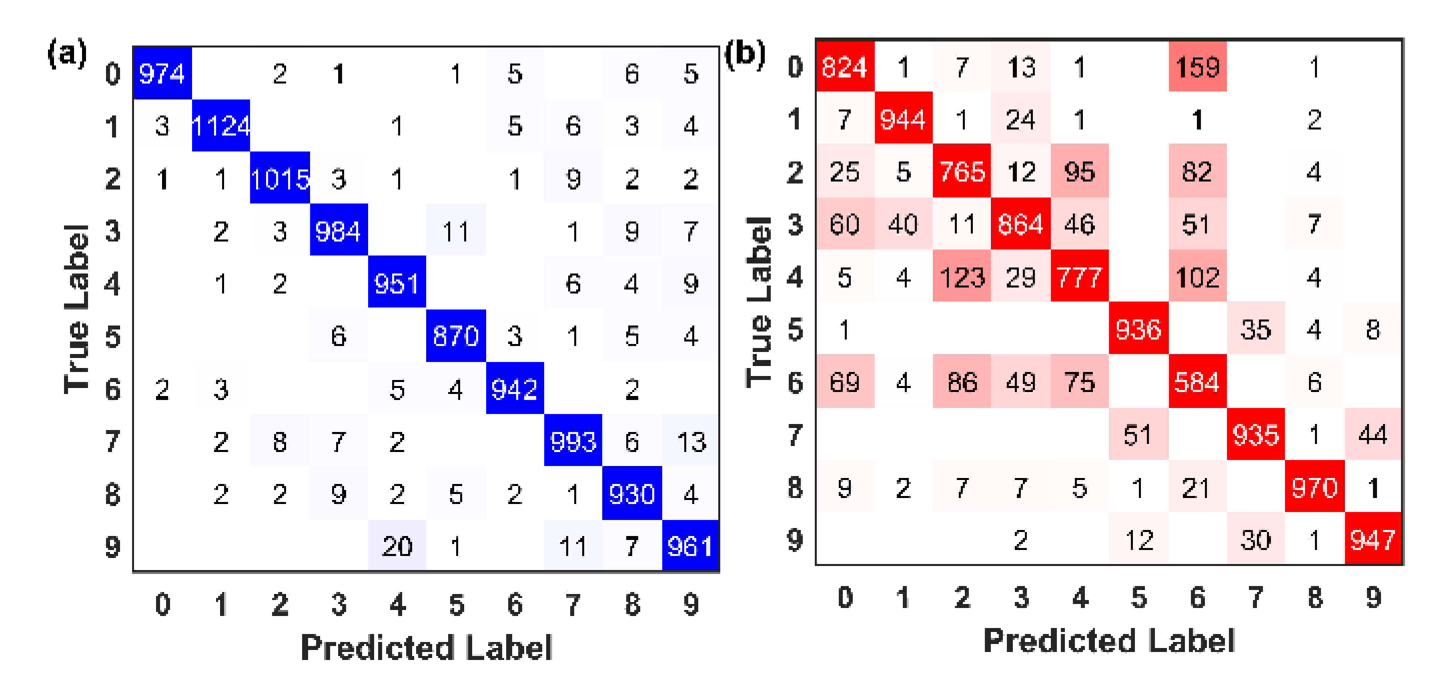
CLASSIFIER'S PERFORMANCE MEASURES
CONFUSION MATRIX



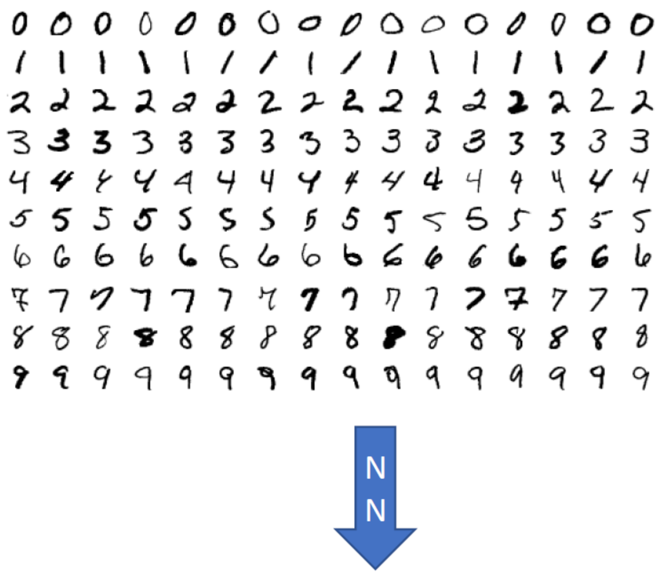
Source: Original work by the author.

An illustrated confusion matrix shows examples of true negatives (top left), false positives (top right), false negatives (lower left), and true positives (lower right)

CLASSIFIER'S PERFORMANCE MEASURES
CONFUSION MATRIX



Goal of the exercise:



classifier to 1/10 target classes

An example of a confusion matrix for the classification of handwritten digits from the benchmark MNIST database.

Source: https://www.researchgate.net/publication/354885511_Time-Delayed_Reservoir_Computing_Based_on_a_Two-Element_Phased_Laser_Array_for_Image_Identification

CONFUSION MATRIX:
EXCELLENT TOOL TO SHOW CLASSIFIER PERFORMANCE QUALITY ☺

		Predicted condition	
	Total population = P + N	Positive (PP)	Negative (PN)
Actual condition	Positive (P)	True positive (TP)	False negative (FN)
	Negative (N)	False positive (FP)	True negative (TN)

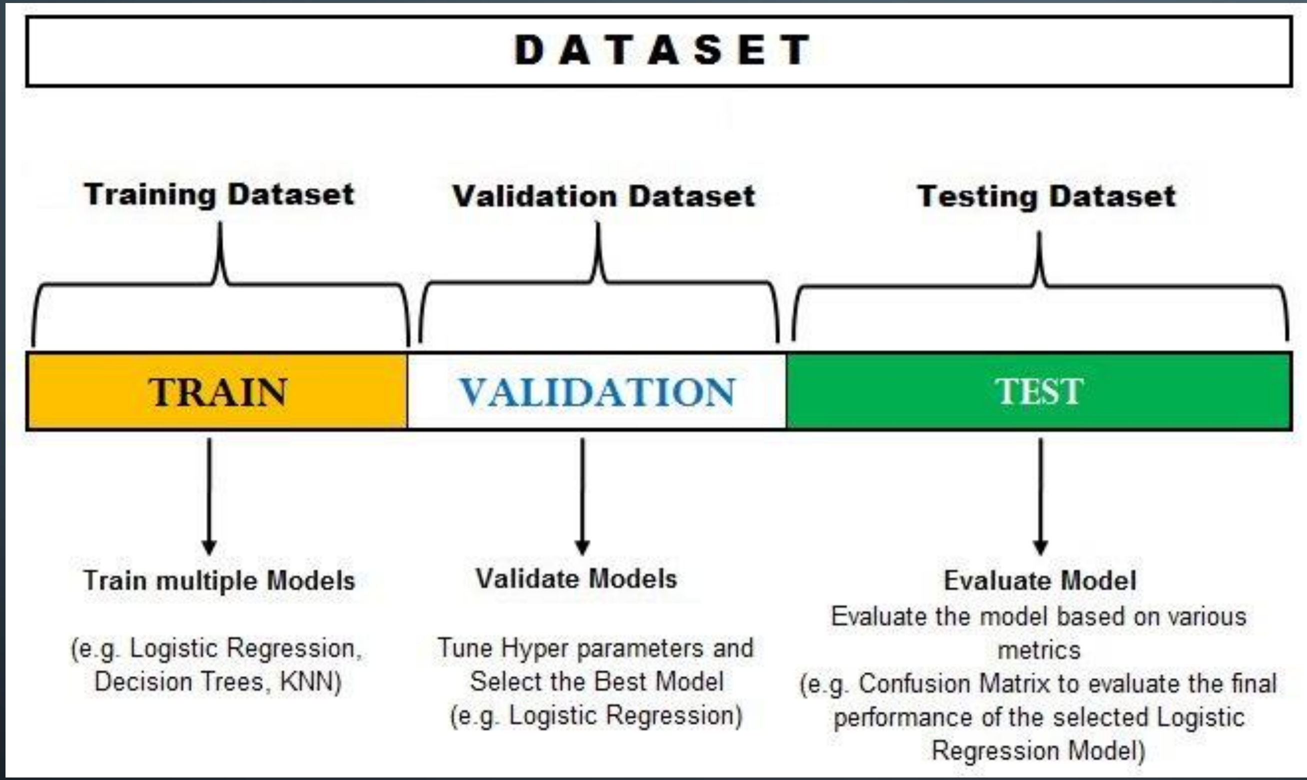
Source: https://en.wikipedia.org/wiki/Confusion_matrix

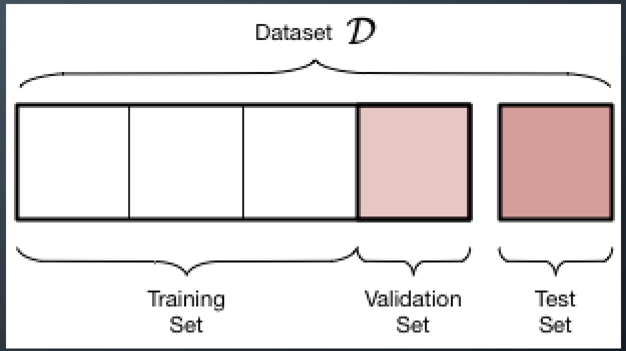
CONFUSION MATRIX + MEASURES, INDICATORS

	Total population $= P + N$	**Predicted positive**	**Predicted negative**	Informedness, bookmaker informedness (BM) $= TPR + TNR - 1$	Prevalence threshold (PT) $= \frac{\sqrt{TPR \times FPR} - FPR}{TPR - FPR}$
Actual condition	**Positive (P)** [a]	**True positive** (TP), hit[b]	**False negative** (FN), miss, underestimation	True positive rate (TPR), recall, sensitivity (SEN), probability of detection, hit rate, power $= \frac{TP}{P} = 1 - FNR$	False negative rate (FNR), miss rate type II error [c] $= \frac{FN}{P} = 1 - TPR$
Actual condition	**Negative (N)**[d]	**False positive** (FP), false alarm, overestimation	**True negative** (TN), correct rejection[e]	False positive rate (FPR), probability of false alarm, fall-out type I error [f] $= \frac{FP}{N} = 1 - TNR$	True negative rate (TNR), specificity (SPC), selectivity $= \frac{TN}{N} = 1 - FPR$
	Prevalence $= \frac{P}{P + N}$	Positive predictive value (PPV), precision $= \frac{TP}{TP + FP} = 1 - FDR$	False omission rate (FOR) $= \frac{FN}{TN + FN} = 1 - NPV$	Positive likelihood ratio (LR+) $= \frac{TPR}{FPR}$	Negative likelihood ratio (LR−) $= \frac{FNR}{TNR}$
	Accuracy (ACC) $= \frac{TP + TN}{P + N}$	False discovery rate (FDR) $= \frac{FP}{TP + FP} = 1 - PPV$	Negative predictive value (NPV) $= \frac{TN}{TN + FN} = 1 - FOR$	Markedness (MK), deltaP (Δp) $= PPV + NPV - 1$	Diagnostic odds ratio (DOR) $= \frac{LR+}{LR-}$
	Balanced accuracy (BA) $= \frac{TPR + TNR}{2}$	F_1 score $= \frac{2\,PPV \times TPR}{PPV + TPR} = \frac{2\,TP}{2\,TP + FP + FN}$	Fowlkes–Mallows index (FM) $= \sqrt{PPV \times TPR}$	Matthews correlation coefficient (MCC) $= \sqrt{TPR \times TNR \times PPV \times NPV} - \sqrt{FNR \times FPR \times FOR \times FDR}$	Threat score (TS), critical success index (CSI), Jaccard index $= \frac{TP}{TP + FN + FP}$

Source: https://en.wikipedia.org/wiki/Confusion_matrix

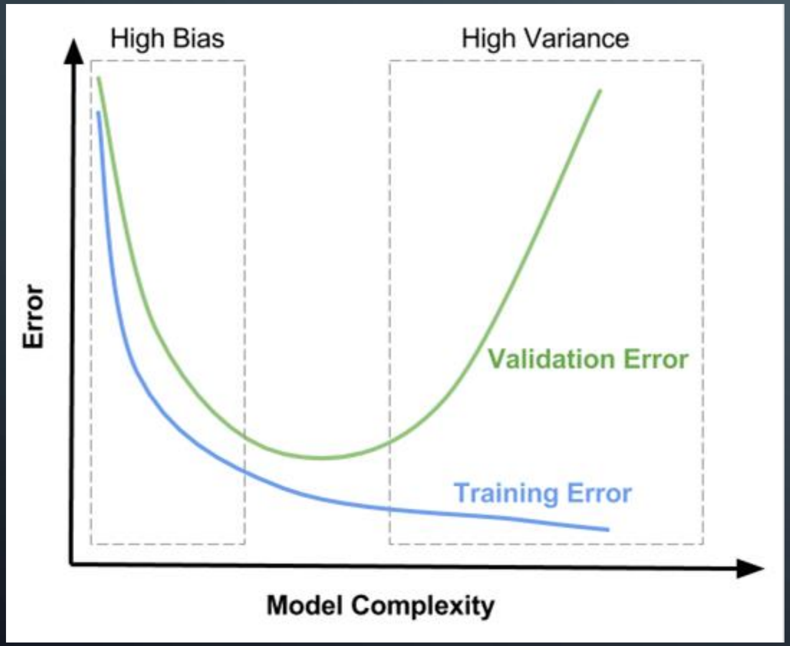
TRAIN -> VALIDATE -> TEST !!! (GENERALIZATION VERICATION)





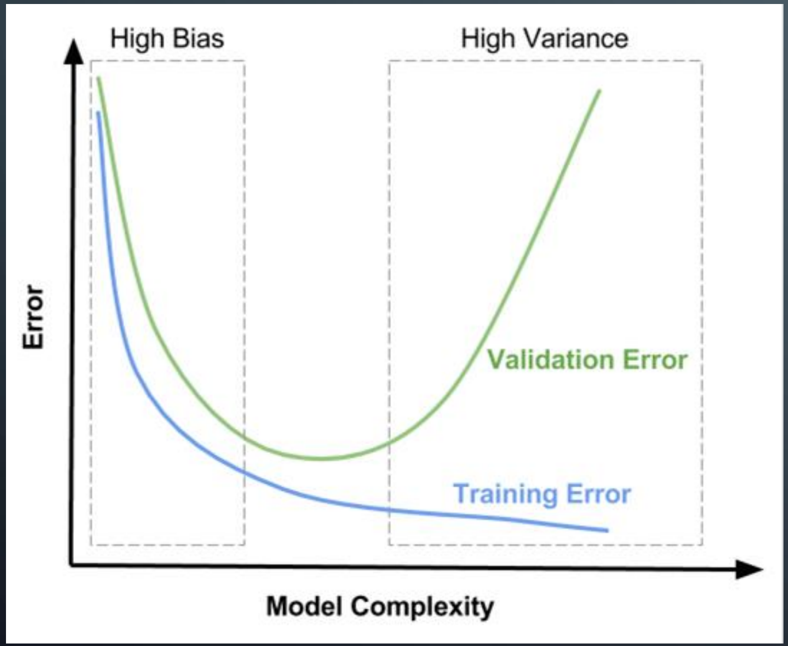
Source: https://dziganto.github.io/cross-validation/data%20science/machine%20learning/model%20tuning/python/Model-Tuning-with-Validation-and-Cross-Validation/

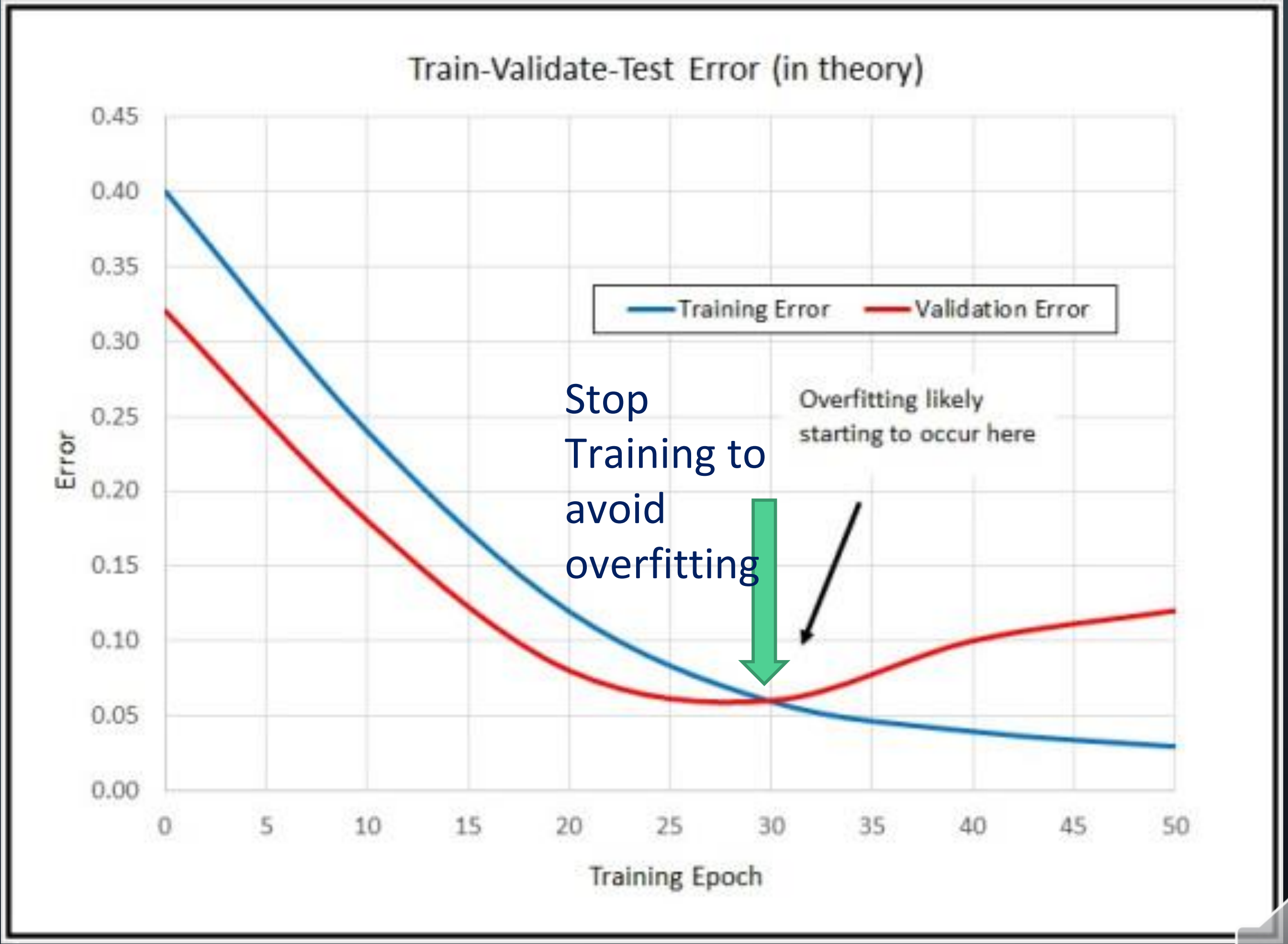
PERFORMANCE CURVES VS. ITERATIONS:
WHEN TO STOP THE LEARNING PROCESS



https://dziganto.github.io/cross-validation/data%20science/machine%20learning/model%20tuning/python/Model-Tuning-with-Validation-and-Cross-Validation/

PERFORMANCE CURVES VS. ITERATIONS: *WHEN TO STOP THE LEARNING PROCESS*





https://dziganto.github.io/cross-validation/data%20science/machine%20learning/model%20tuning/python/Model-Tuning-with-Validation-and-Cross-Validation/

After manual introduction to ANN from well-known sources,
some original examples of projects using Machine Learning (ML) & Artificial Neural Networks (ANN), in the area of Biomedical Engineering from our team, as motivation for PhD students.

Proceedings of the 5th International Conference on Information Technology and Application in Biomedicine, in conjunction with
The 2nd International Symposium & Summer School on Biomedical and Health Engineering
Shenzhen, China, May 30-31, 2008

Feature extraction for improving the support vector machine biomedical data classifier performance

Pawel S. Kostka, Ewaryst J Tkacz, *Member, IEEE*

TABLE I
RESULTS OF DIFFERENT CLASSIFIER STRUCTURES COMPARISON

CLASSIFIER STRUCTURE TYPE	SENSITIVITY	SPECIFICITY
SVM without FE (*Polyn. kernel*)	0.69	0.70
SVM without FE (*Gaussian. kernel*)	0.75	0.70
SVM + FE (*Polyn. kernel*)	0.82	0.80
SVM + FE (*Gaussian. kernel*)	0.88	0.85

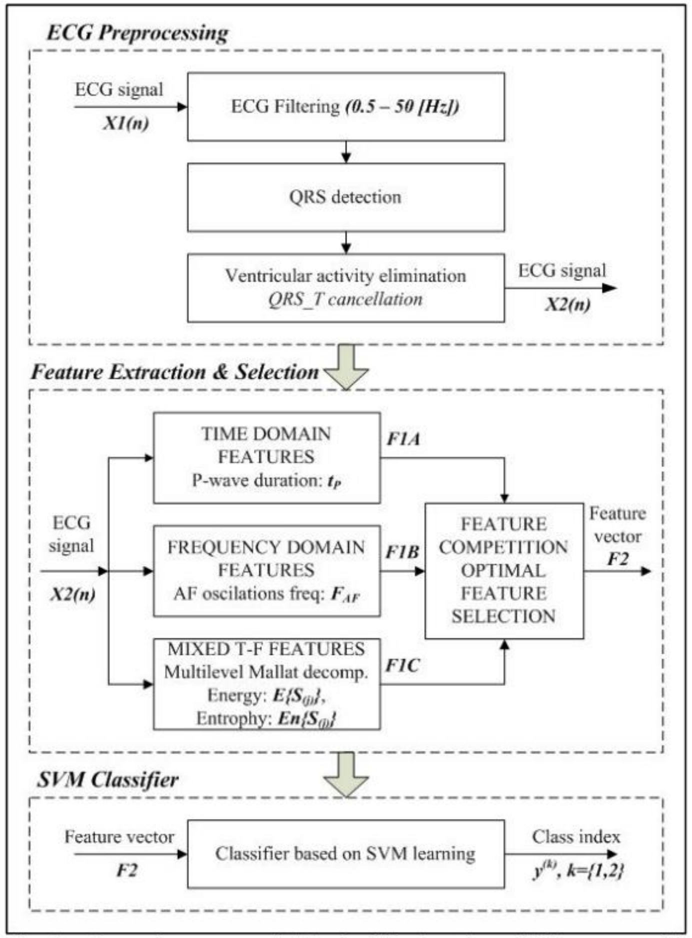


Fig. 1. General structure of AF classifier based on SVM system with feature extraction.

Source: Feature extraction for improving the support vector machine biomedical data classifier performance | IEEE Conference Publication | IEEE Xplore

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some original examples of projects using Machine Learning (ML) & Artificial Neural Networks (ANN), in the area of Biomedical Engineering from our team, as motivation for PhD students.

31st Annual International Conference of the IEEE EMBS
Minneapolis, Minnesota, USA, September 2-6, 2009

Rules extraction in SVM and Neural Network Classifiers of Atrial Fibrillation Patients with Matched Wavelets as a Feature Generator.

Pawel S Kostka, Ewaryst J Tkacz, *Member, IEEE*

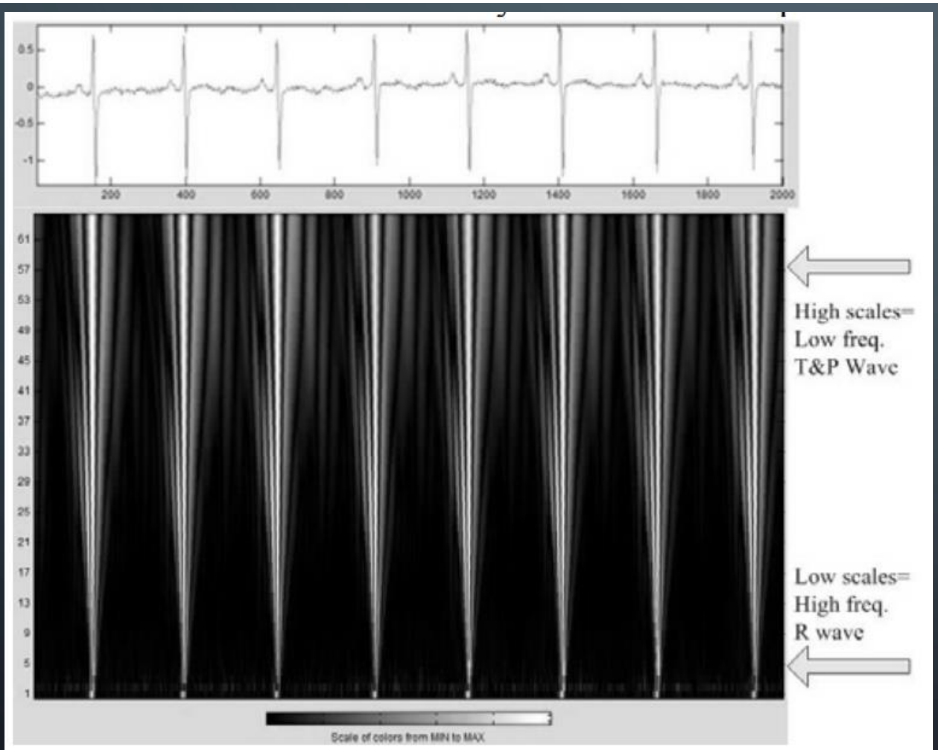
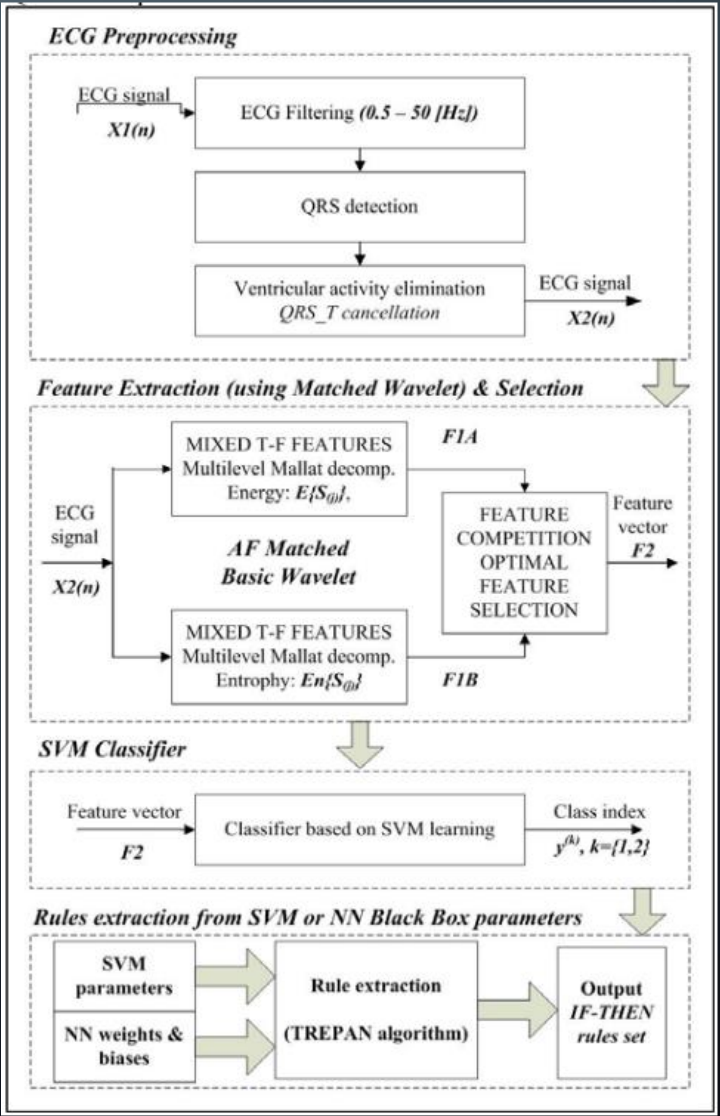


Fig.2. ECG: P, R, T waves activity, which can be seen on different regions of Time-Scale (Frequency) diagram of CWT ECG signal decomposition.



Source: https://ieeexplore-1ieee-1org-12vdogrkc0089.han.polsl.pl/document/5334220/

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some original examples of projects using Machine Learning (ML) & Artificial Neural Networks (ANN), in the area of Biomedical Engineering from our team, as motivation for PhD students.

An Application of Wavelet Neural Network for Classification Patients with Coronary Artery Disease Based on HRV Analysis

E.J. Tkacz[1], P. Kostka[1]

WNN structure Number	Method sensitivity [%]	
	WT – 1	WT – 2
IV	67	78
V	61	69
II	57	60
III	54	56
I	40	43

WNN structure Number	Method specificity [%]	
	WT – 1	WT – 2
IV	75	83
V	68	74
II	65	68
III	59	62
I	45	48

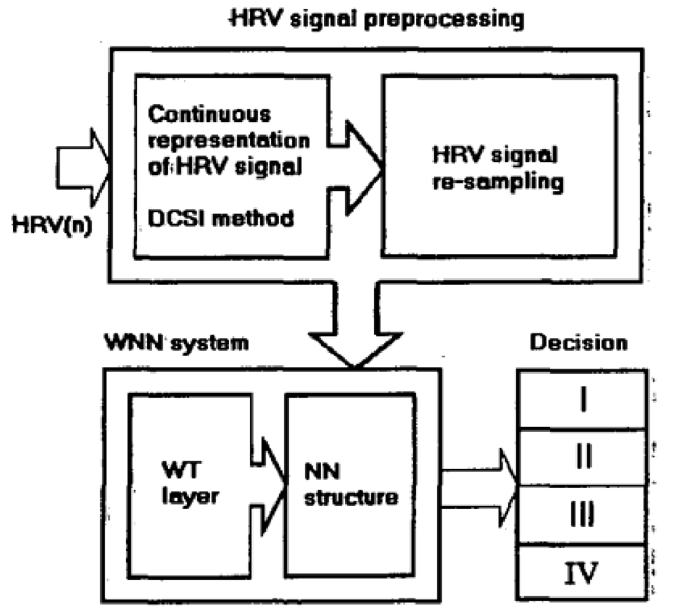

Fig.1. Block diagram of the HRV signal based patient's classification with the help of WNN system

Source: https://ieeexplore-1ieee-1org-12vdogrkc0089.han.polsl.pl/document/897999

Source database for key manuals and free development tools of „Community" for creating neural network systems:

1) 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/
2) https://github.com/ageron
3) https://www.analyticsvidhya.com/
4) https://purnasaigudikandula.medium.com/a-beginner-intro-to-neural-networks-543267bda3c8

1) https://www.python.org/
2) https://www.anaconda.com/
3) https://www.tensorflow.org/
4) https://keras.io/
5) https://www.kaggle.com/datasets
6) https://matplotlib.org/stable/gallery/
7) https://scikit-learn.org/stable/

VIBE Project

Virtual biomedical engineering and stem/steam education

Basic information

Project ID: VIBE
Project start date: 1 November 2021
Project end date: 31 October 2024
Coordinator: University of Pécs, Pécs, Hungary

Partners

Universidade do Porto, Porto, Portugal

DEX Innovation Centre, Liberec, Czech Republic

Silesian Univ. of Technology, BE faculty, Poland.

https://vibe-project.pte.hu/

Project outcomes

- Spreading and widening the knowledge and awareness of VR/AR-based learning
- Higher number of students interested in STEM/STEAM or medical fields and increased level of diversity
- More immersive and overall improved VR environment
- A completely new curriculum (Biomedical Engineering BSc) developed using the VR platform as a co-creation and collaboration tool.
- Maintaining the international cooperation network established in the project beyond the scope of EU funding.

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I would like to thank our partners very much for:

- *cooperation,* ✓
- *support,* ✓
- *motivation* ✓