A brief Introduction to AI for Image processing

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PHENET-EMPHASIS Data Management Training

Paris, 4-6 December 2024

Roadmap

…boring part...

PHENET
PHENOTYPING & ENVIROTYPING SOLUTIONS FOR AGROECOLOGY

EMPHASIS

PHENET-EMPHASIS Data Management Training

Paris, 4-6 December 2024

Part 1- Theorietical introduction to AI, Deep Learning and MathXAI

…exciting part...

Part 2 - Laboratory of CNN

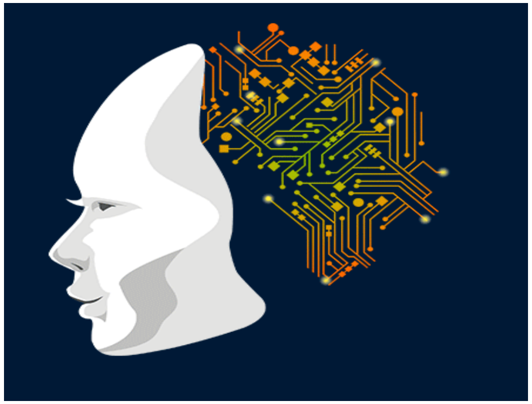
Part 3 - Laboratory of AI for Image processing and PHENotyping data extraction

python + colab

What is Artificial Intelligence (AI) ?

A1 Artificial Intelligence is the ability for a computer to think, learn and simulate human mental processes, such as perceiving, reasoning, and learning.

A2 It can also independently perform complex tasks that once required human input.

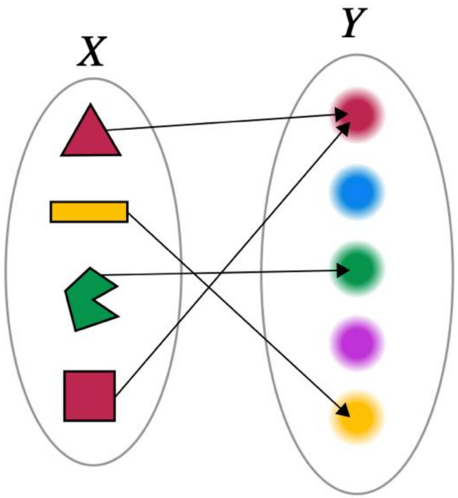


The power of a machine to copy intelligent human behavior!

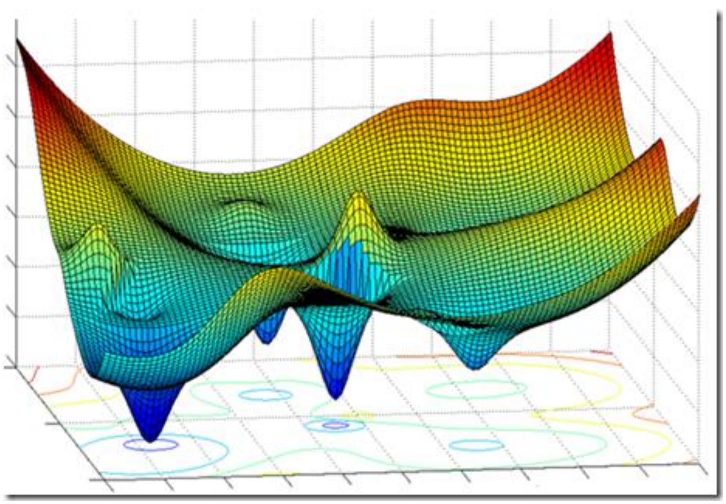
AI is a MODEL that clould be able to «think»

Rough Idea of a Model

✓ In a level 0 math course



✓ In an advanced course



Function

$$x \mapsto f(x)$$

Examples by domain and codomain

$\mathbf{X} \to \mathbf{B}$, $\mathbf{B} \to \mathbf{X}$, $\mathbf{B}^n \to \mathbf{B}$

$\mathbf{X} \to \mathbf{Z}$, $\mathbf{Z} \to \mathbf{X}$

$\mathbf{X} \to \mathbf{R}$, $\mathbf{R} \to \mathbf{X}$, $\mathbf{R}^n \to \mathbf{X}$

$\mathbf{X} \to \mathbf{C}$, $\mathbf{C} \to \mathbf{X}$, $\mathbf{C}^n \to \mathbf{X}$

Classes/properties

Constant · Identity · Linear · Polynomial · Rational · Algebraic · Analytic · Smooth · Continuous · Measurable · Injective · Surjective · Bijective

Constructions

Restriction · Composition · λ · Inverse

Generalizations

Partial · Multivalued · Implicit

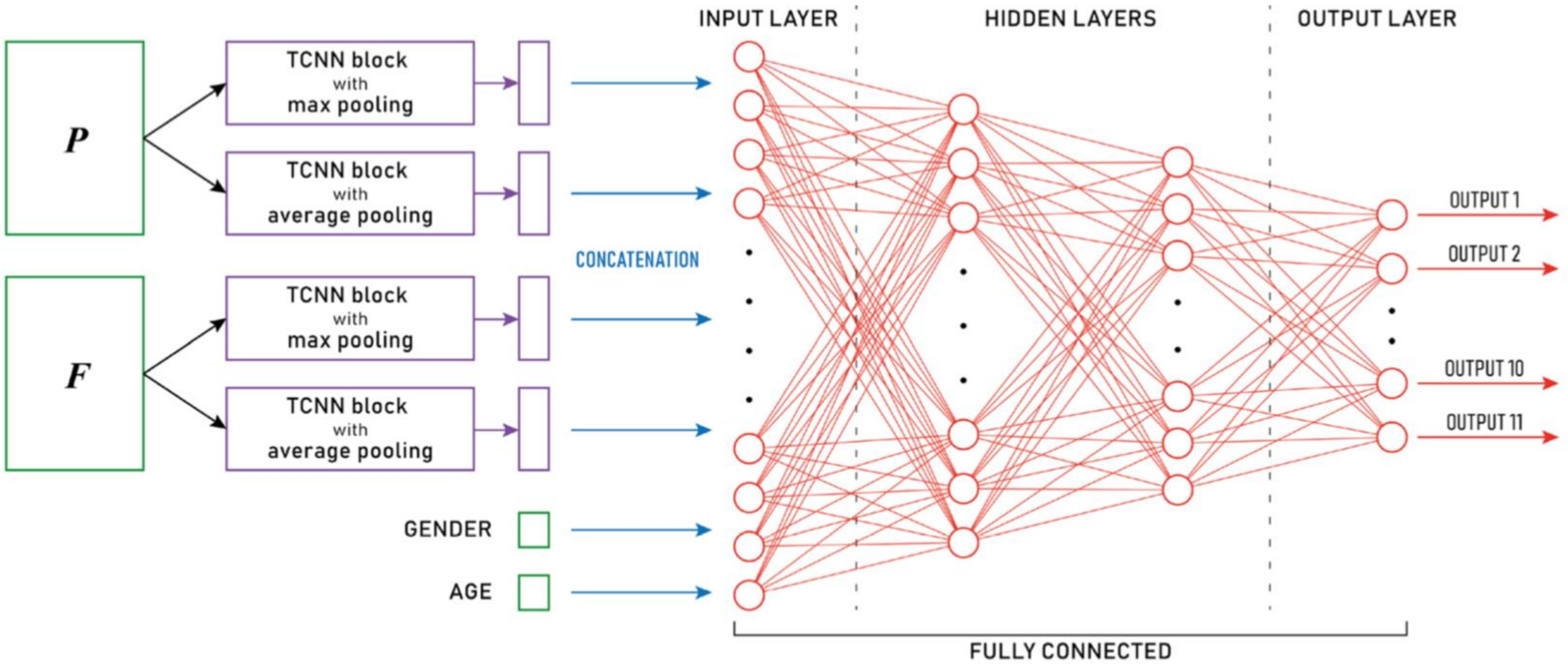
V · T · E

Rough idea of Data

		Types of data		
		Continuous attributes	**Categorical attributes**	**Mixed attributes**
Cardinality of Relationship	**Univariate** Described by indi-vidual attributes (independence)	Type I Extreme value anomaly	Type II Rare class anomaly	Type III Simple mixed data anomaly
	Multivariate Described by multi-dimensionality (dependence)	Type IV Multidimensional numerical anomaly	Type V Multidimensional rare class anomaly	Type VI Multidimensional mixed data anomaly

Relation between Data and Models

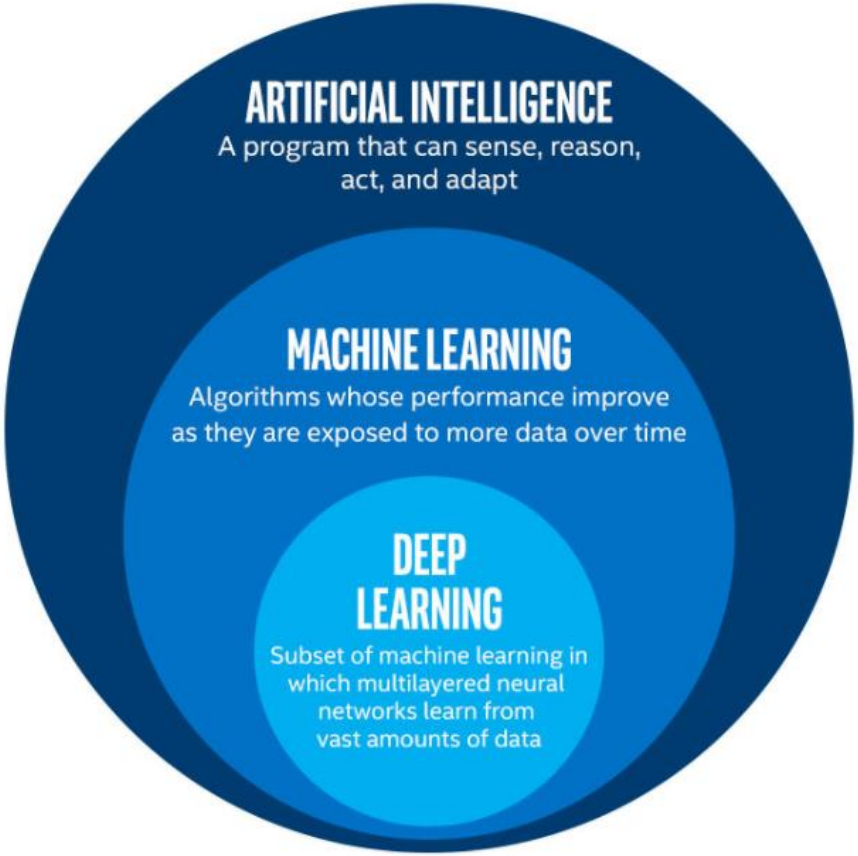
Nelle applicazioni



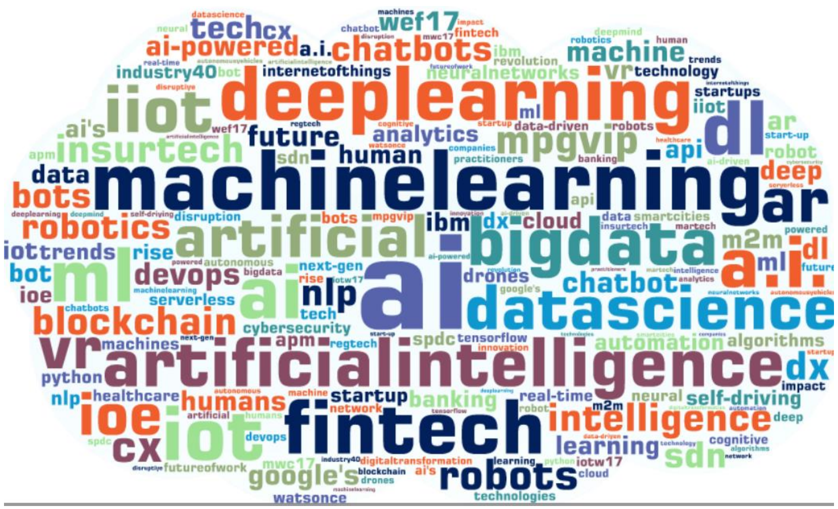
Modello

Credits: Piccialli, F., Cuomo, S., Crisci, D., Prezioso, E., & Mei, G. (2020). ***A deep learning approach for facility patient attendance prediction based on medical booking data.*** *Scientific Reports*, *10*(1), 1-11.

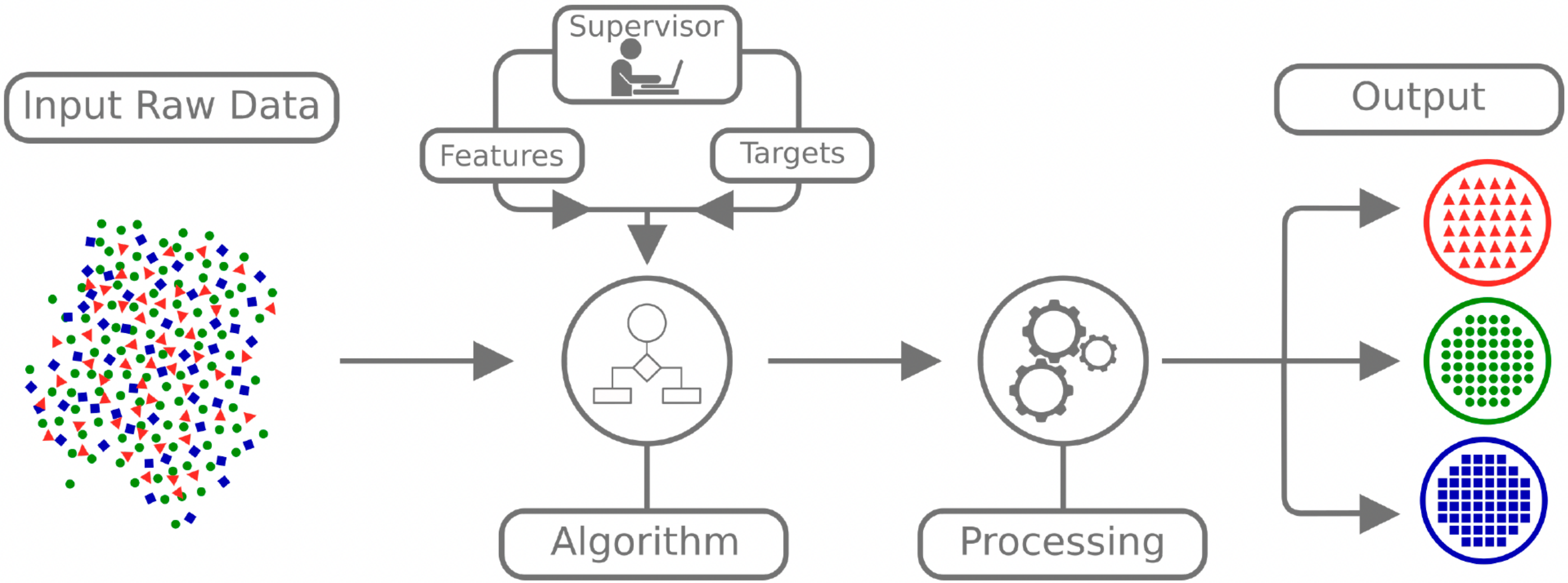
AI e Math



«Learning the theoretical background for data science or machine learning can be a daunting experience, as it **involves multiple fields of mathematics**, Linear Algebra, Optimization Methods, Stochastic Calculus, Probability Theory, Approximation Theory, ….»

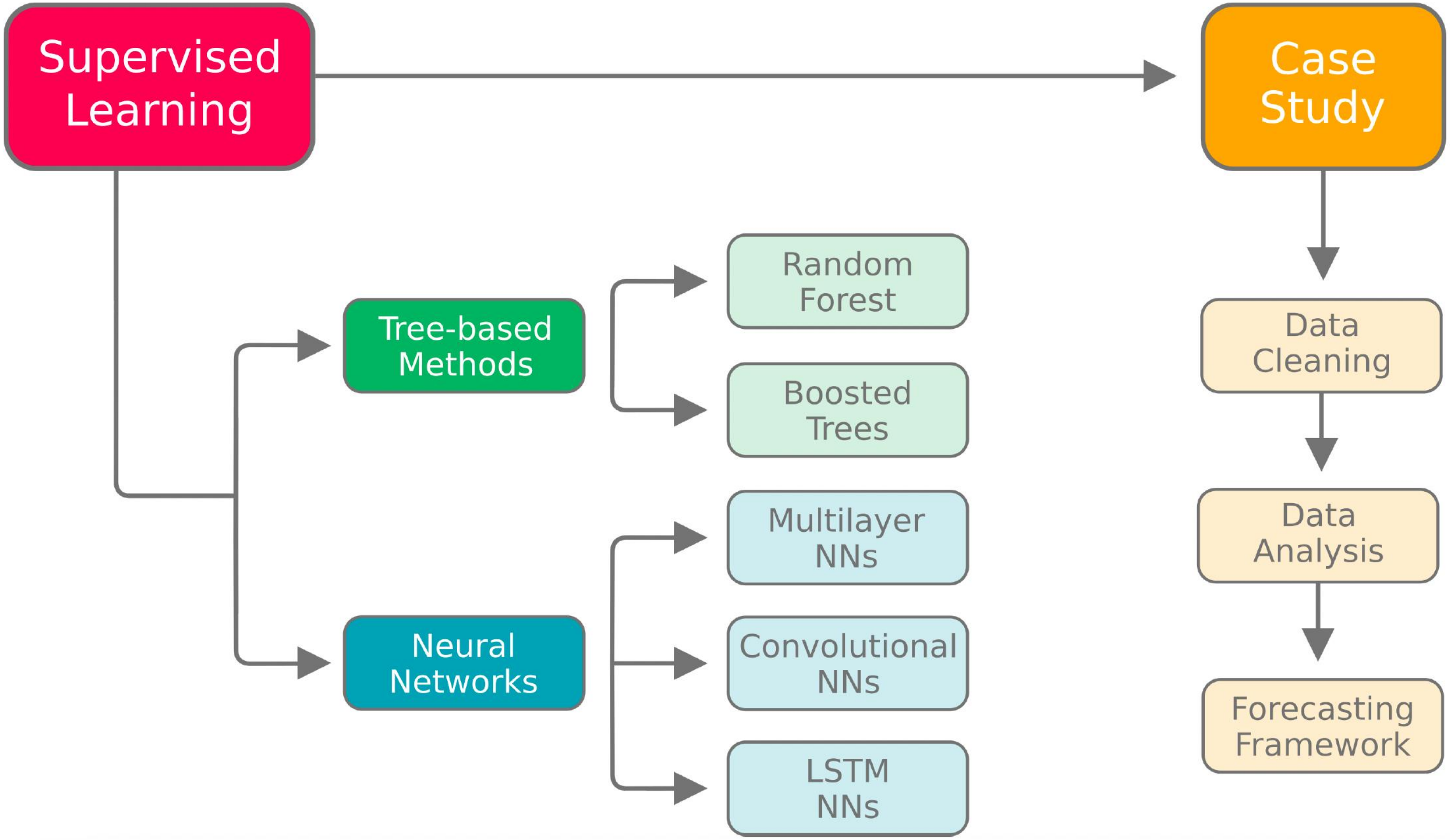


ML:Supervised Learning

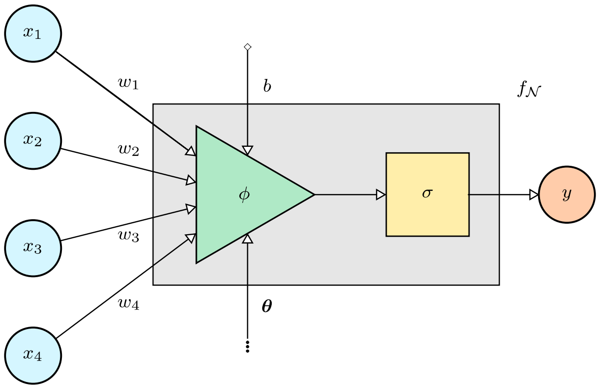


Supervised Learning is an area of ML wherea set of independent variables are used to analyse dependent variables and relations between them.

How are Neural Networks



A Neuron



Definition (Neuron)

A neuron is defined as the set $\mathcal{N} = \{\mathcal{M}, \boldsymbol{w}, b, \boldsymbol{\theta}, \phi, \sigma\}$

- $\mathcal{M} \subseteq \mathbb{R}^N$ *is the input set;*
- $\boldsymbol{w} \in \mathbb{R}^N$ *is the weights vector;*
- $b \in \mathbb{R}$ *is the bias;*
- $\boldsymbol{\theta} \in \mathbb{R}^P$ *are additional parameters of the neuron;*
- $\phi : \mathcal{M} \to \mathbb{R}$ *is a parametric function with parameters* $\boldsymbol{w}$, b *and* $\boldsymbol{\theta}$, *named the aggregation function;*
- $\sigma : \mathbb{R} \to \mathbb{R}$ *is the activation function of the neuron.*

Definition (Action of a neuron)

Given a neuron $\mathcal{N} = \{\mathcal{M}, \boldsymbol{w}, b, \boldsymbol{\theta}, \phi, \sigma\}$, *the action of a neuron is defined as the following function* $f_{\mathcal{N}} : \mathcal{M} \to \mathbb{R}$ *such that:*

$$\boldsymbol{x} \mapsto f_{\mathcal{N}}(\boldsymbol{x}; \boldsymbol{w}, b, \boldsymbol{\theta}) = \sigma(\phi(\boldsymbol{x}; \boldsymbol{w}, b, \boldsymbol{\theta})) \tag{1}$$

Feed Forward Neural Network

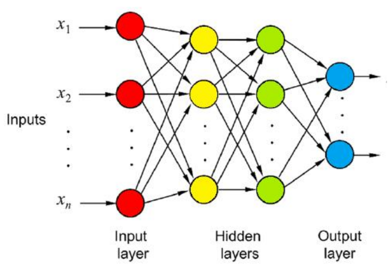
Let be

$$\eta^l = \begin{bmatrix} \eta_1^l \\ \vdots \\ \eta_{\mathrm{n}_l}^l \end{bmatrix} \in \mathbb{R}^{1\times \mathrm{n}_l}, \quad \theta^l = \begin{bmatrix} \theta_1^l \\ \vdots \\ \theta_{\mathrm{n}_l}^l \end{bmatrix} \in \mathbb{R}^{1\times \mathrm{n}_l}, \quad W^l = \left(w_{ij}^l\right)_{ij} \in \mathbb{R}^{\mathrm{n}_l \times \mathrm{n}_{l-1}},$$

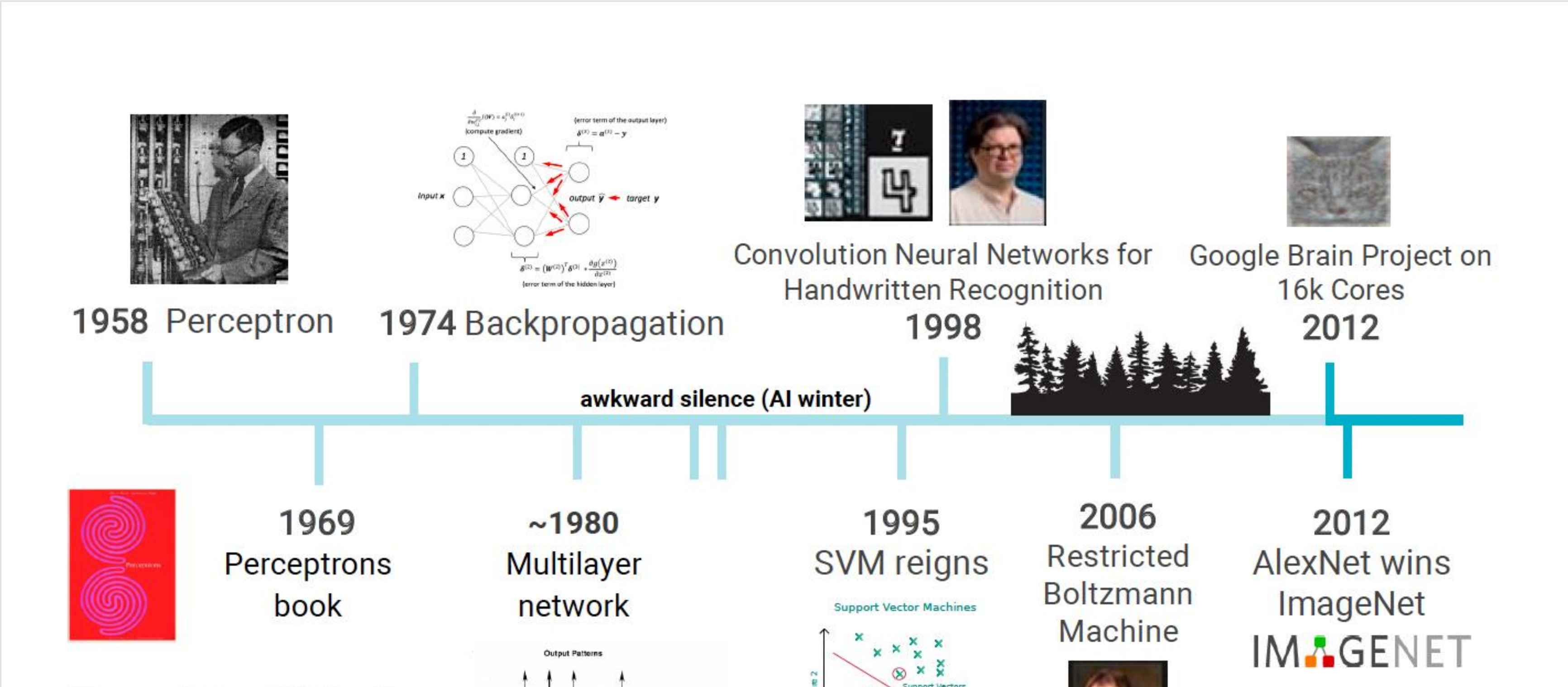
- l layer output: $\eta^l = \mathcal{F}_a\left(W^l \cdot \eta^{l-1} + \theta^l\right)$
- defined: $\mathcal{W}^l : x \in \mathbb{R}^{\mathrm{n}_{l-1}} \longmapsto W^l \cdot x + \theta^l \ \in \mathbb{R}^{\mathrm{n}_l}$

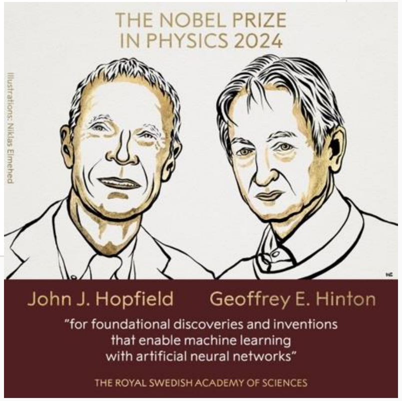
The NN with L layers is $F_{NN} : \mathbb{R}^n \to \mathbb{R}^m$:

$$\begin{aligned} F_{NN}(x; \boldsymbol{W}, \boldsymbol{\theta}) &= \hat{y} = \mathcal{F}_a\left(W^L \cdot \eta^{L-1} + \theta^L\right) = \\ &= \mathcal{F}_a\left(W^L \cdot \mathcal{F}_a\left(W^{L-1} \cdot \eta^{L-2} + \theta^{L-1}\right) + \theta^L\right) = \ldots = \\ &= \left(\mathcal{F}_a \circ \mathcal{W}^L \circ \mathcal{F}_a \circ \mathcal{W}^{L-1} \circ \cdots \circ \mathcal{F}_a \circ \mathcal{W}^2\right)(x) \end{aligned}$$



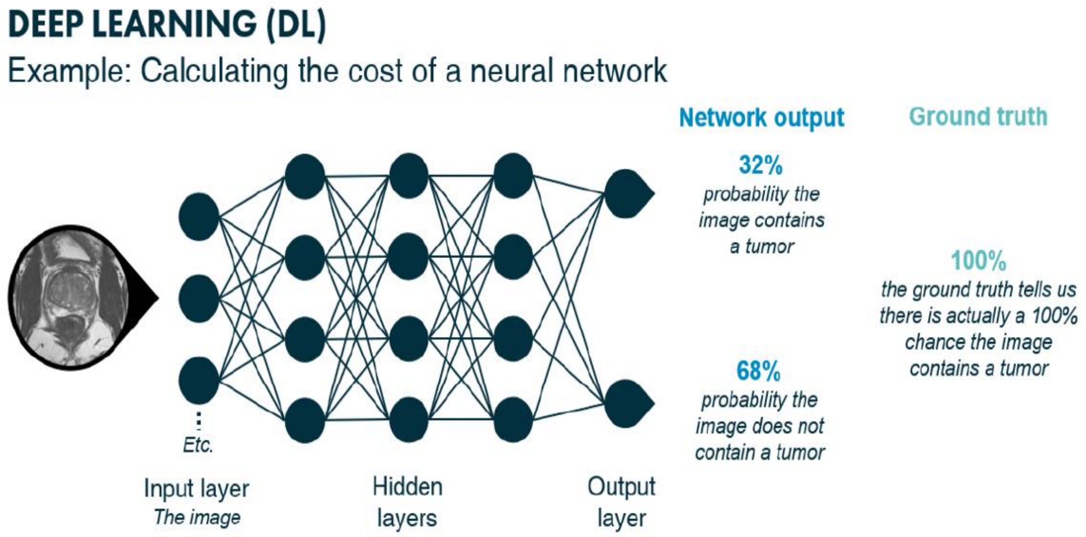
Time line of the Deep Learning (DL)



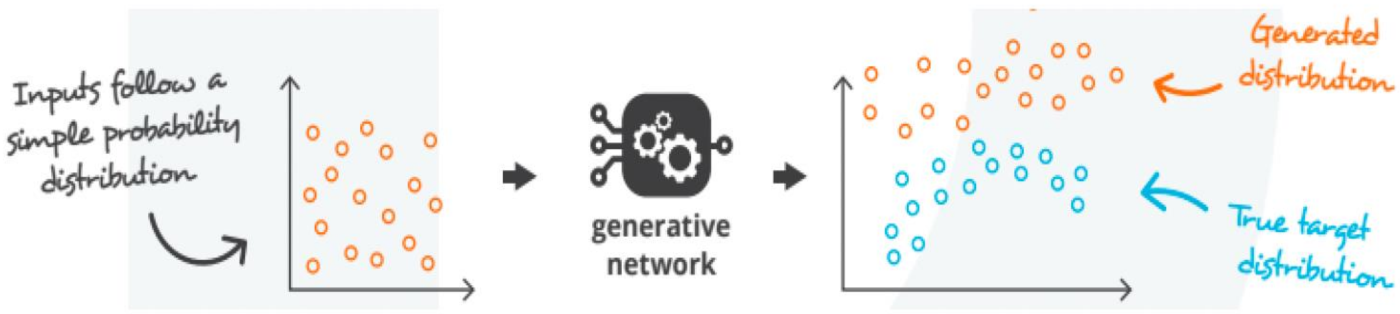


(Source: Lucas Masuch & Vincent Lepetit)

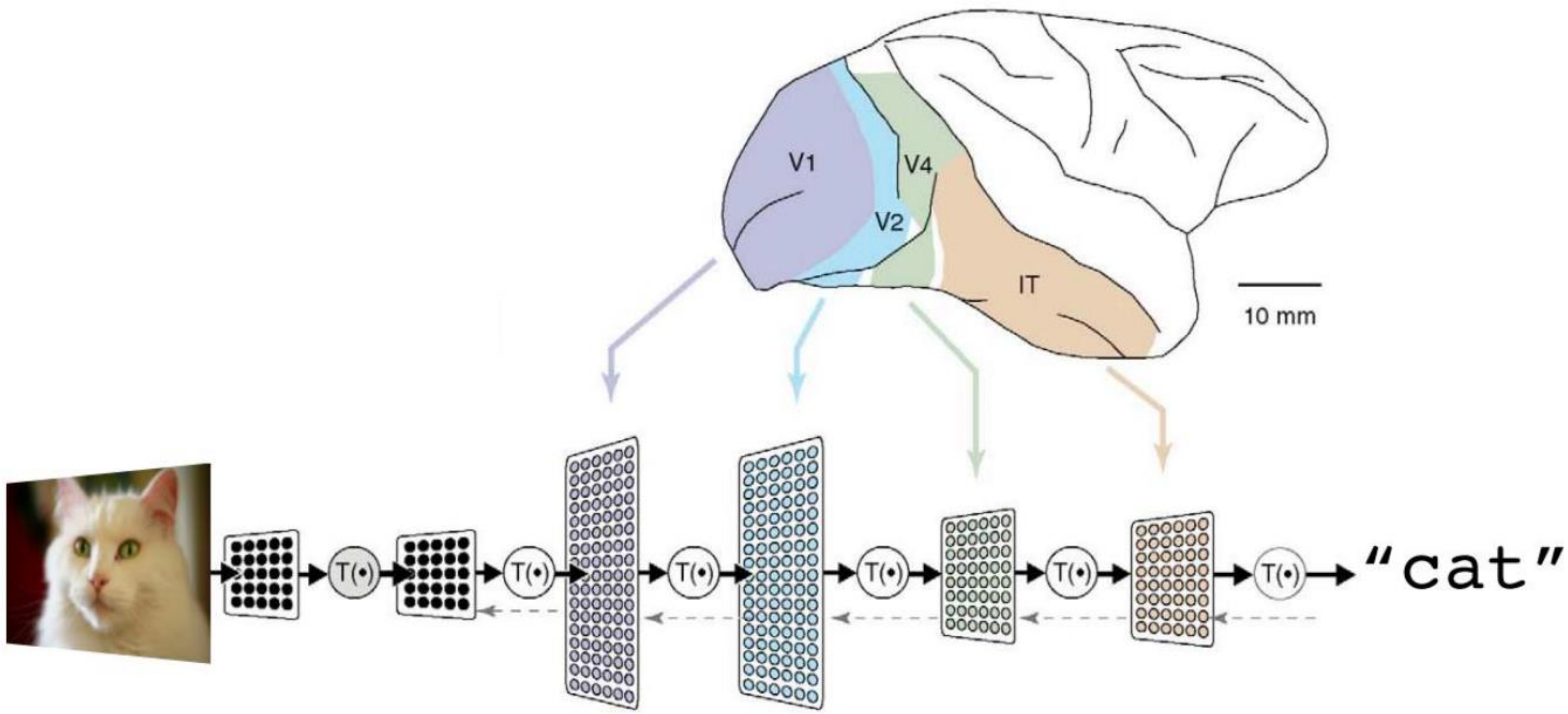
DL – AI models



GANs are a class of **deep learning** methods



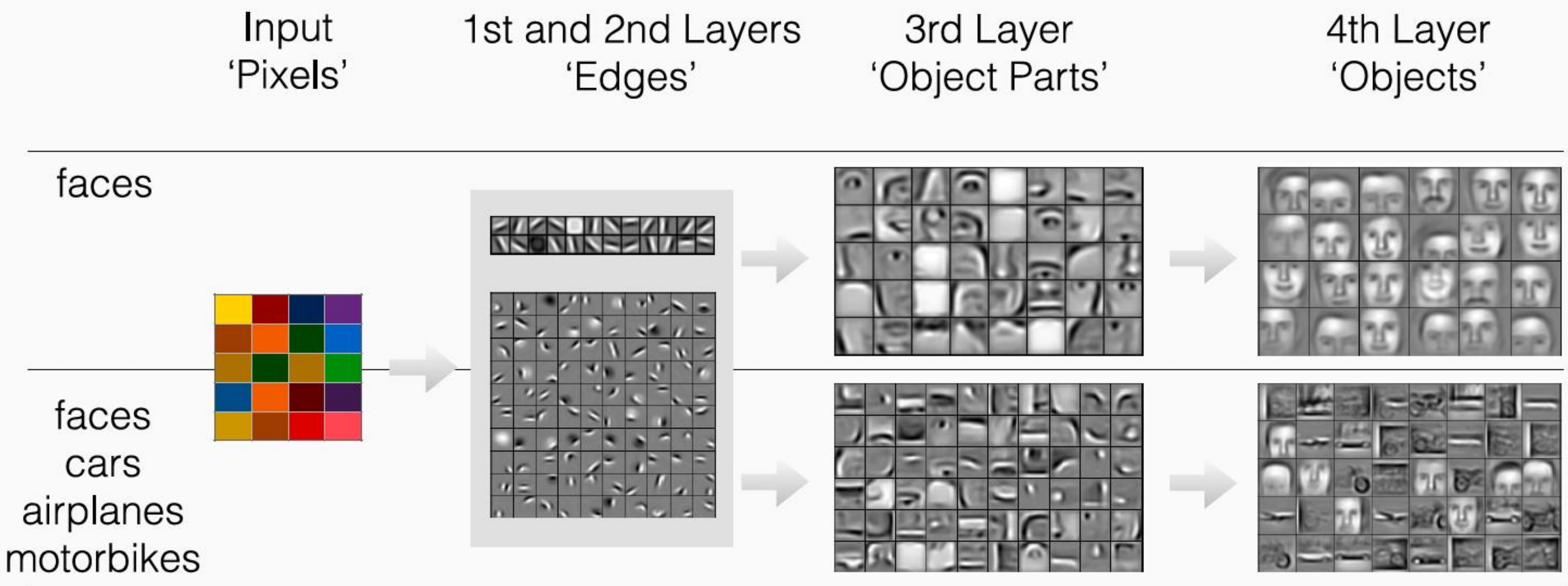
DL basic architecuture



A deep neural network consists of a hierarchy of layers, whereby each layer transforms the input data into more abstract representations (e.g. edge -> nose -> face). The output layer combines those features to make predictions.

(Source: Lucas Masuch)

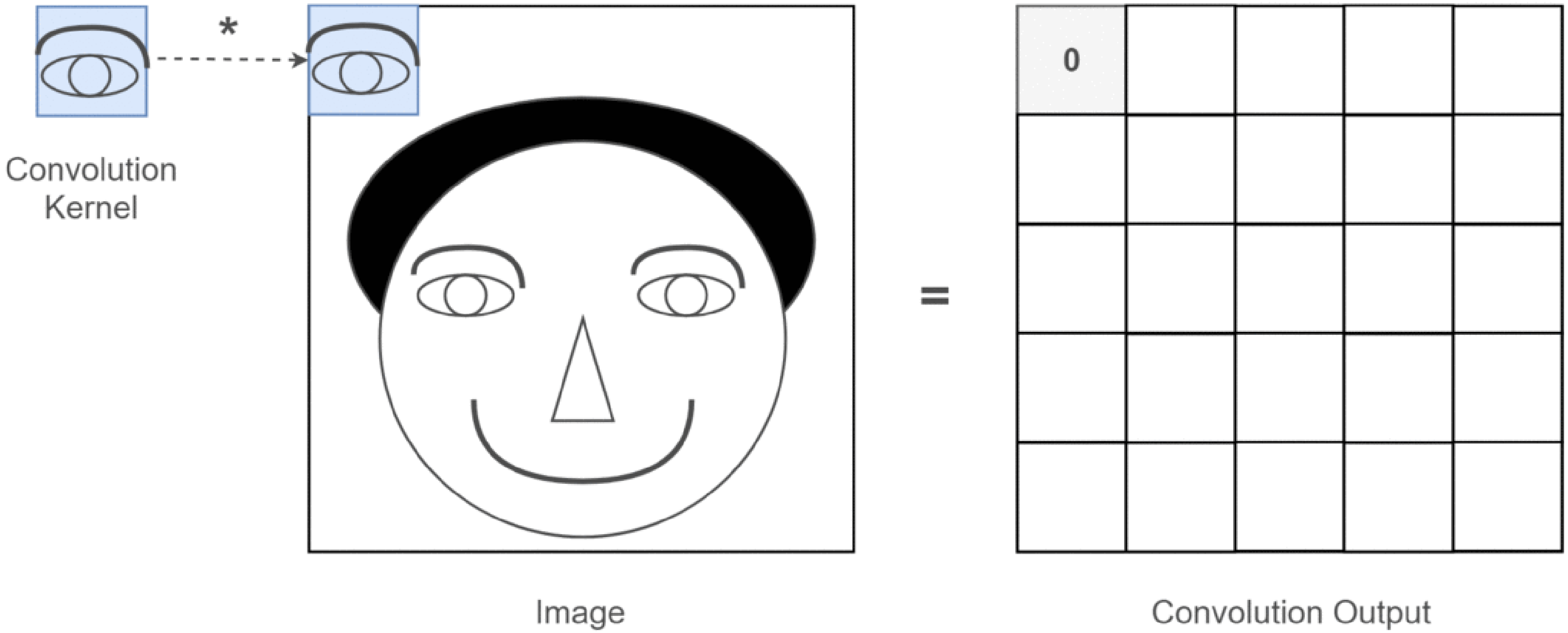
DL feature hierarchy

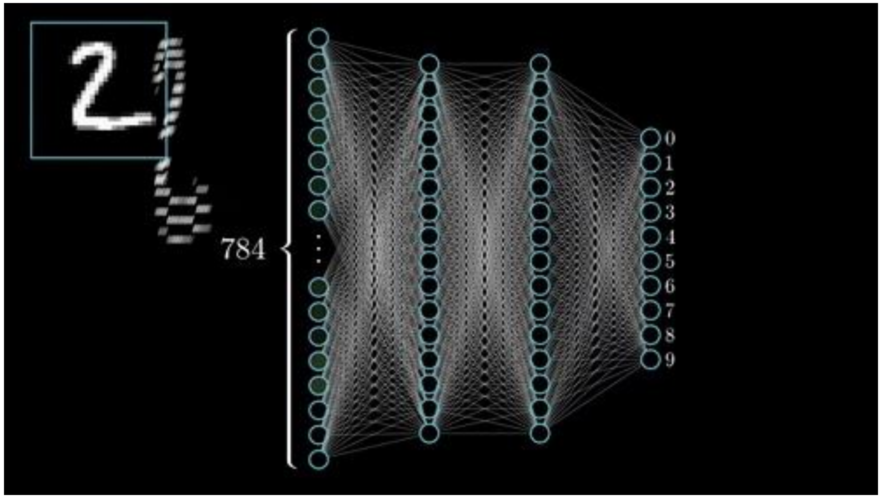


Each layer progressively extracts higher level features of the input until the final layer essentially makes a decision about what the input shows. The more layers the network has, the higher level features it will learn.

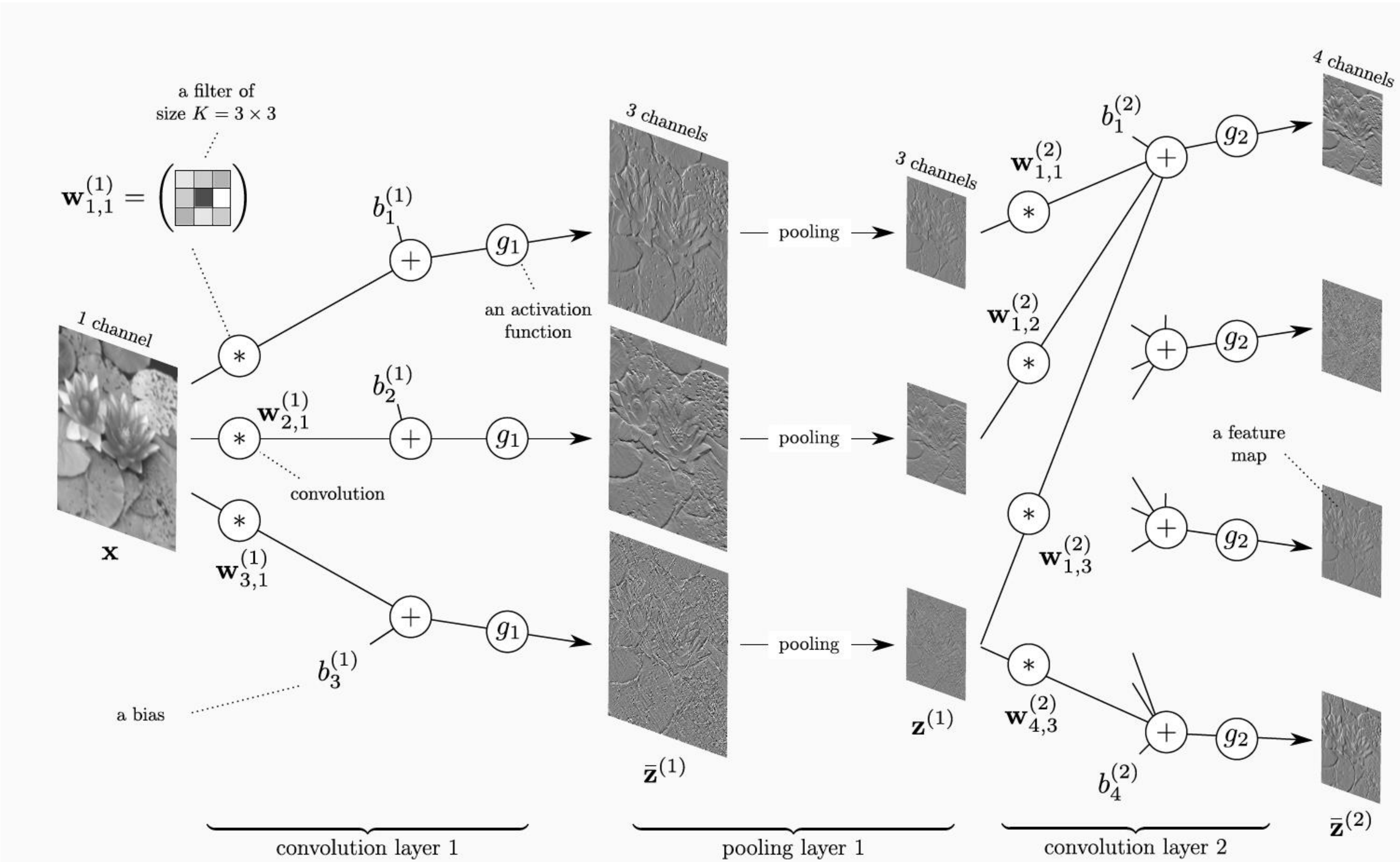
(Source: Andrew Ng & Lucas Masuch & Caner Hazırbaş)

Convolutional Neural Networks

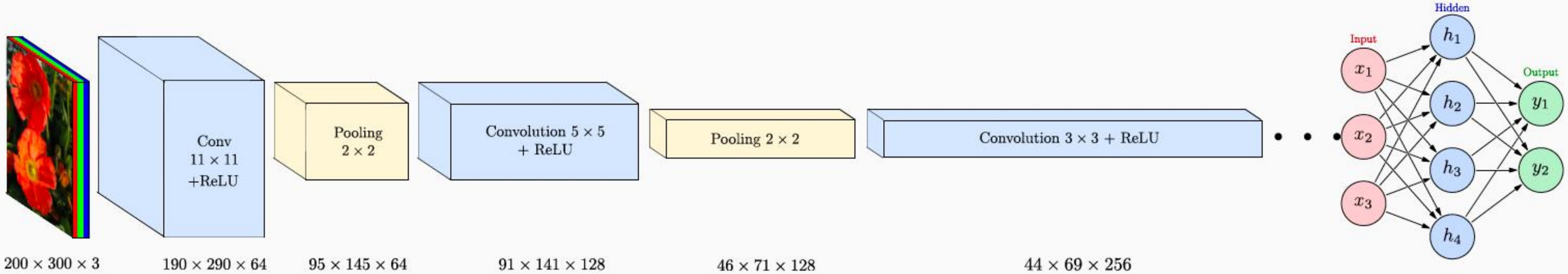




CNN for Image Processing



CNN main concepts



CNN: Alternate:
Conv + ReLU + pooling

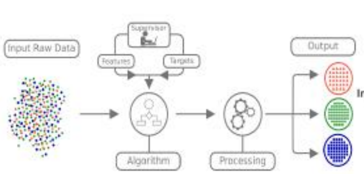
End of network:
Plug a standard neural network:
Fully connected hidden layers
(linear) + ReLU

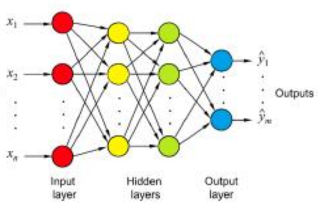
Full network:

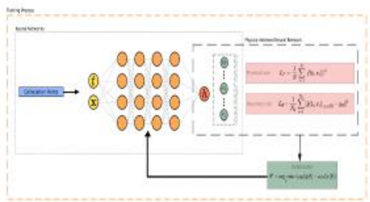
- **CNN:** Extract features specific to spatial data
- **Fully connected part:** Use CNN features for specific regression/classification task
- **Training:** Learn regression/classification and feature extraction **jointly**

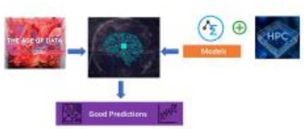
Math and AI

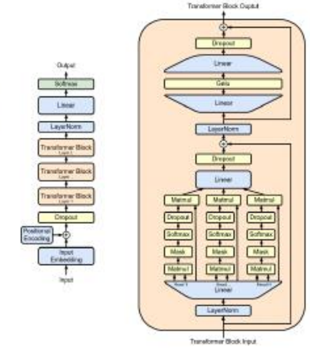
ML | ML+ NN | PINNs | SciML | Generative AI Models











About **Mathematical Aspects**

…end of the first part…

M·O·D·A·L

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