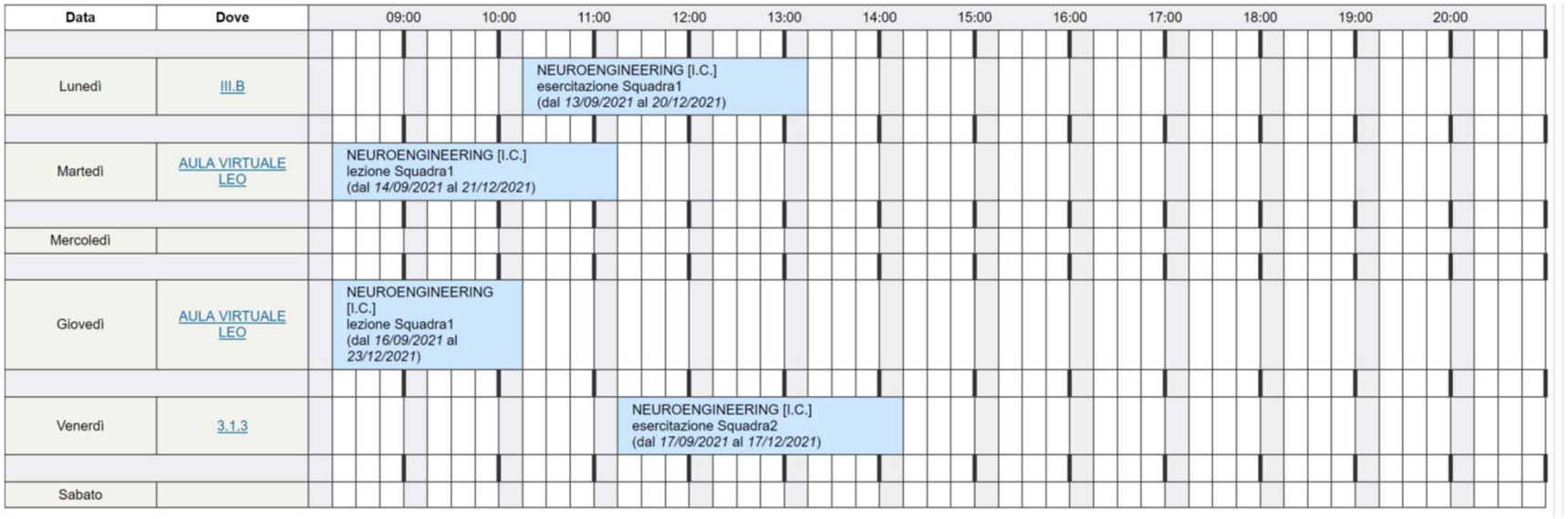
POLITECNICO DI MILANO

Neuroengineering part I
class topics: 2021-2022

Prof. Pietro Cerveri
pietro.cerveri@polimi.it

Course schedule (part I – Prof. CERVERI)



Data	Dove	09:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00
Lunedì	III.B			NEUROENGINEERING [I.C.] esercitazione Squadra1 (dal *13/09/2021* al *20/12/2021*)									
Martedì	AULA VIRTUALE LEO	NEUROENGINEERING [I.C.] lezione Squadra1 (dal *14/09/2021* al *21/12/2021*)											
Mercoledì													
Giovedì	AULA VIRTUALE LEO	NEUROENGINEERING [I.C.] lezione Squadra1 (dal *16/09/2021* al *23/12/2021*)											
Venerdì	3.1.3				NEUROENGINEERING [I.C.] esercitazione Squadra2 (dal *17/09/2021* al *17/12/2021*)								
Sabato													

Week 1 to week 5: Frontal classes, practise and seminar

Week 6 to week 9: Frontal classes and seminar (Part II, Prof. Pedrocchi)

Week 10 to week 15: Project Workshop activities

Teaching assistants:

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Luca Marsilio (luca.marsilio@polimi.it)

Course organization and time table (part I)

Weeks 1-5

Part I
CERVERI

→

Weeks 5-9

Part II
PEDROCCHI

→

Weeks 10-15

Project
Workshops (PW)

		MONDAY (PRESENCE 3 hrs)	TUESDAY (VIRTUAL 3hrs)	THURSDAY (VIRTUAL 2hrs)	FRIDAY (PRESENCE 3 hrs)
13/09/2021	W1	Course presentation	Artificial neural networks (ANN)	Perceptron, learning and delta rule	PRACTISE basic NN (group 2)
20/09/2021	W2	PRACTISE basic NN (group 1)	Multi-layer ANN and backpropagation	Deep learning paradigm	PRACTISE FFNN (group 2)
27/09/2021	W3	PRACTISE FFNN (group 1)	Convolutional neural networks (CNN)	Autoencoder NN	Master thesis presentation
04/10/2021	W4	SEMINAR Python/TensorFlow (group 1)	GRADUATION	Encoding/Decoding networks	SEMINAR Python/TensorFlow (group 2)
11/10/2021	W5	Generative Adversarial Net (non duplicated)	Concepts of explainable AI		
18/10/2021	W6				
25/10/2021	W7	NEURO part II - Porf- Pedrocchi			
01/11/2021	W8				
08/11/2021	W9				
15/11/2021	W10	PROJECT WORKSHOPS			
22/11/2021	W11				
29/11/2021	W12				
06/12/2021	W13	HOLIDAYS	HOLIDAYS		
13/12/2021	W14	Videoclip delivery			
20/12/2021	W15	Public presentation of finalist projects			

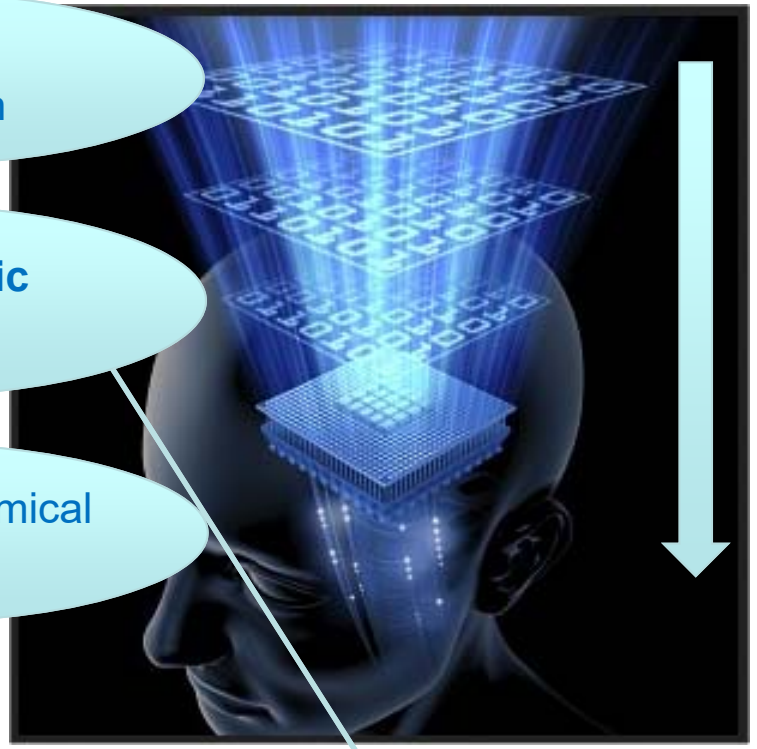
Neuroengineering and AI

Brain abilities

- Perception
- Reasoning
- Motor Control
- Computation
- …

Biological structures

- Single neuron
- Neural networks
- Population networks
- Brain areas and functions



Part I topic

- Focusing on data processing based on models emulating the neuron and neural structures
- Improving brain knowledge by studying artificial neural network
- Exploring biomedical applications of artificial intelligence (AI)

Cognition, Modeling and Engineering

- Sub-symbolic computation
  - Mathematical methods for representing mental processes and brain abilities (e.g. learning, extrapolation, recognition,..)
  - Simulation of biological neurons from information processing point of view (not bio-physics)
  - Artificial neural networks (ANN) are a biologically-inspired programming paradigm which enables a computer to learn a model from data

Cognition, Modeling and Engineering

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- Neural connectionism
  - Formal model of the neuron (input/output processing)
  - Interconnecting neurons into a network: what for?
    - Pattern classification, Function modeling and approximation, Data compression, encoding/decoding, reconstruction, mimicking data
  - Time dynamics in neural networks
    - Recurrent networks and associative memories

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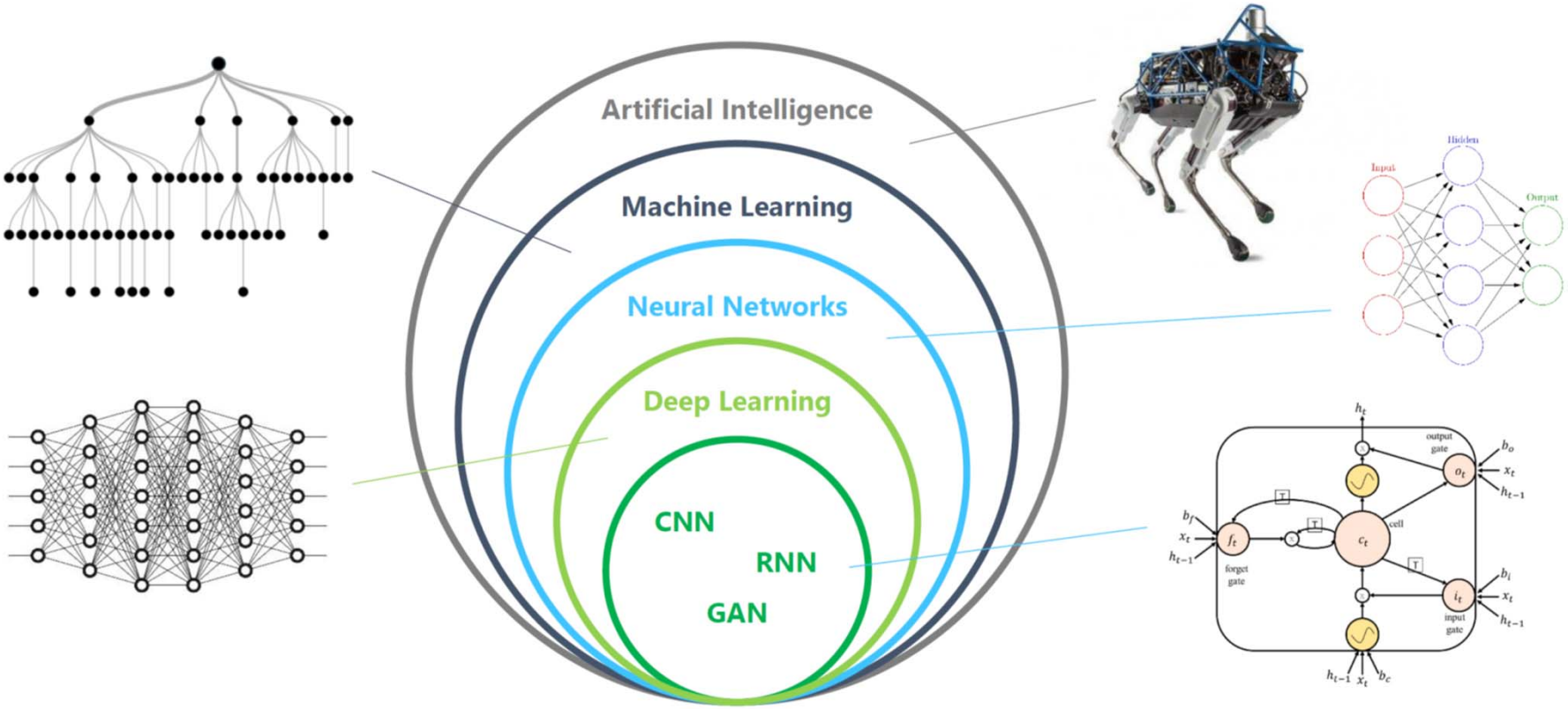
    - *Recurrent networks and associative memories*
- Brain-mediated principles of learning in artificial intelligence models
  - ANN parameters learned from data (no analytical functions, no ARMA, …)
  - Automated training algorithms as supervised backpropagation
  - Layered networks enable domain-dependent feature discovery (deep learning)

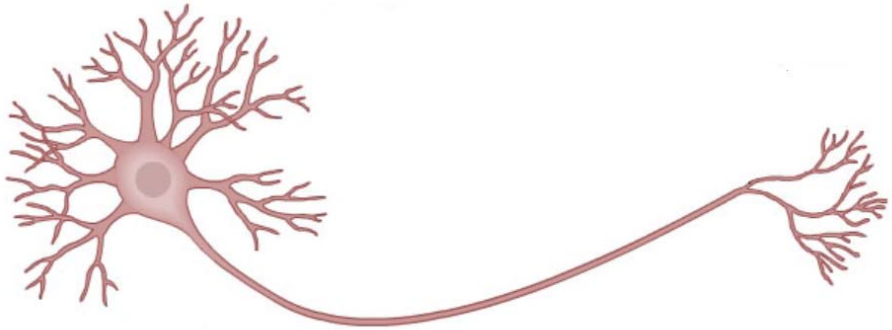
Context of AI models

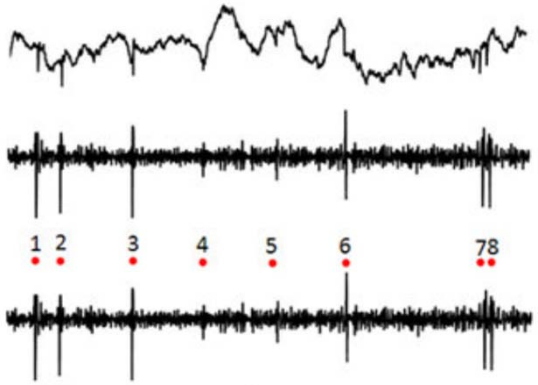


Systems that can solve non-algorithmic tasks

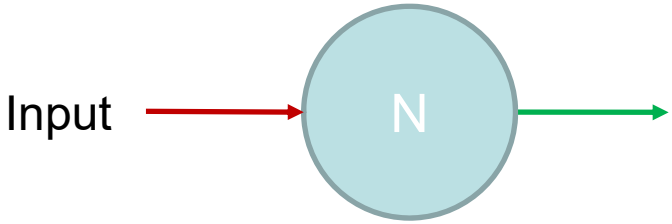
From biological to artificial neuron

Information processing point of view





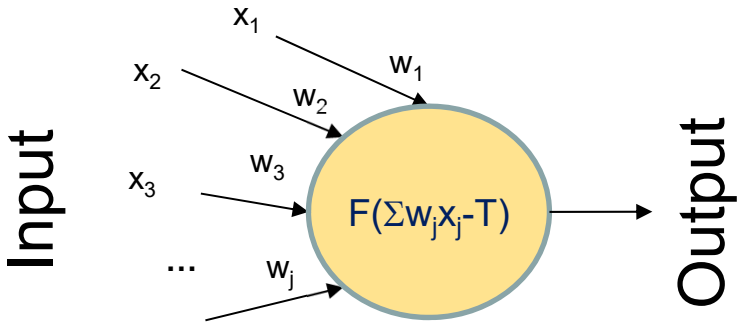
Information encoding: spike frequency, spike sequence pattern, ….



Black-box approach

Information encoding: real-valued scalar

Artificial neural networks (ANN)

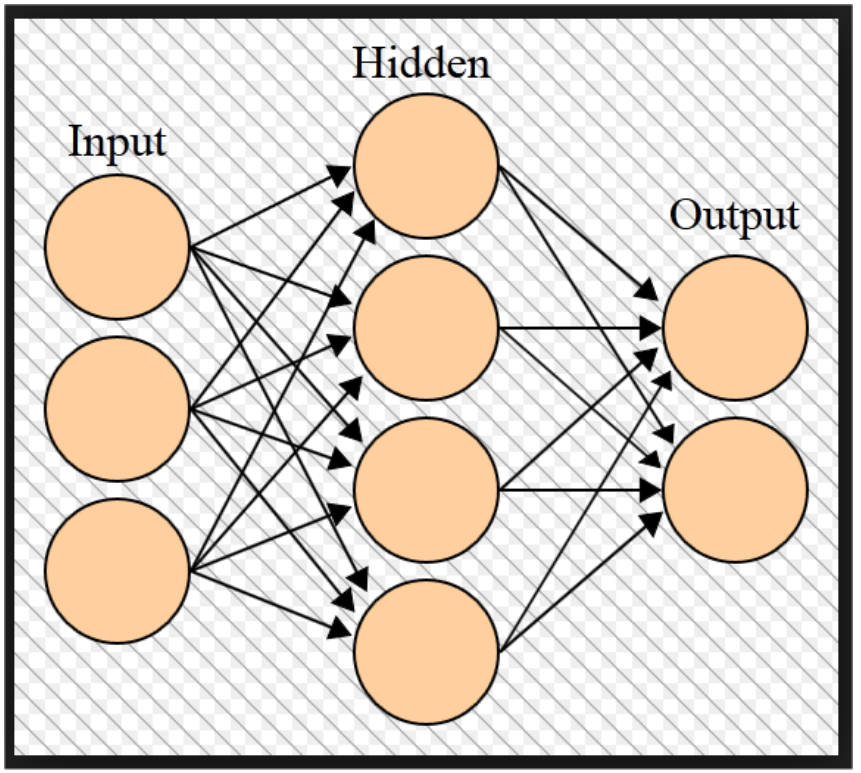


1. Input integration (weighted sum)
2. Reference to the neural threshold T
3. Activation function

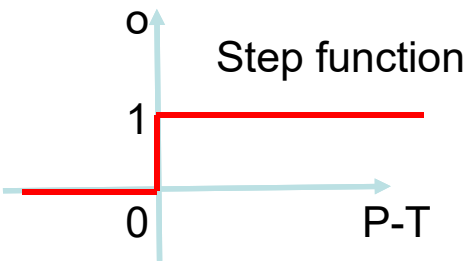
Network of interconnected neurons

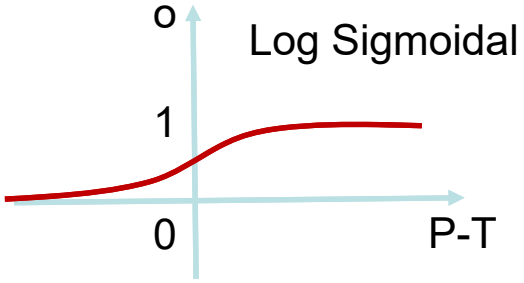
Topology: structure and connections

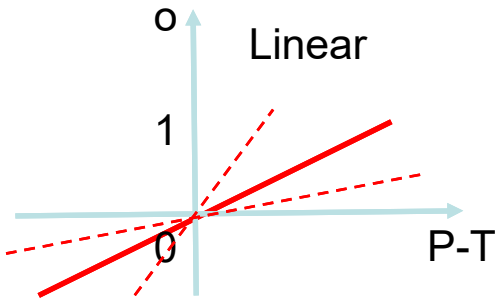
Principle of Emergent Properties

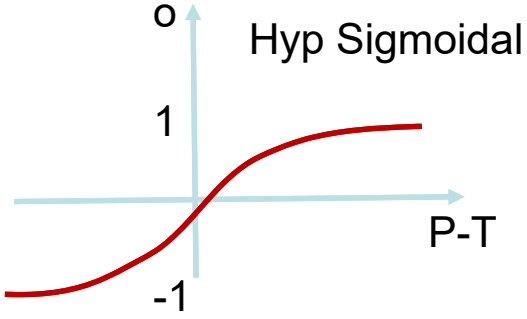


Activation functions









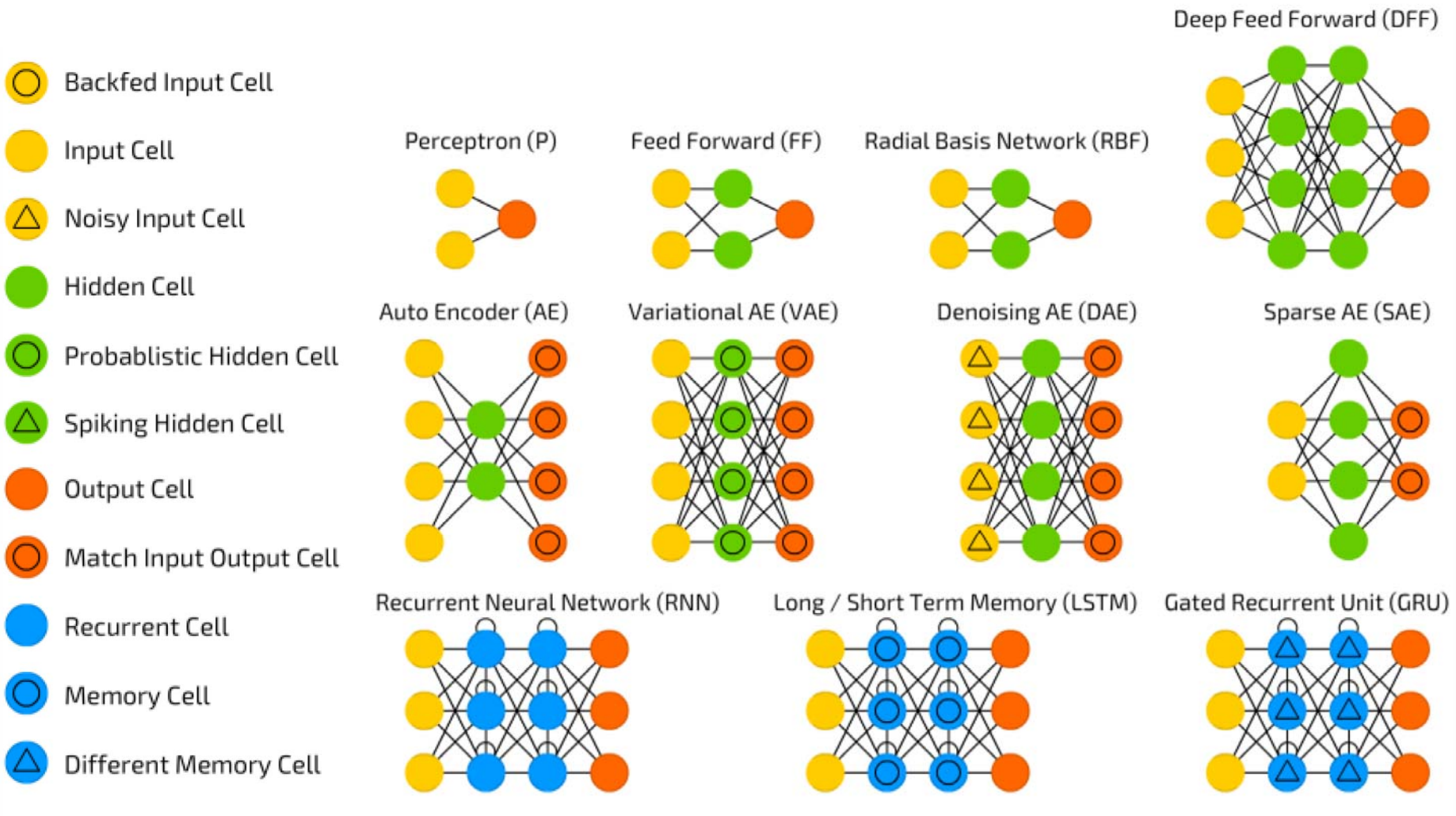
Activation function determines the neuron behavior and to a large extent the network function

Input/output: binary, discrete, continuous real values

Changes of the neuron parameters produce dramatic differences in the output

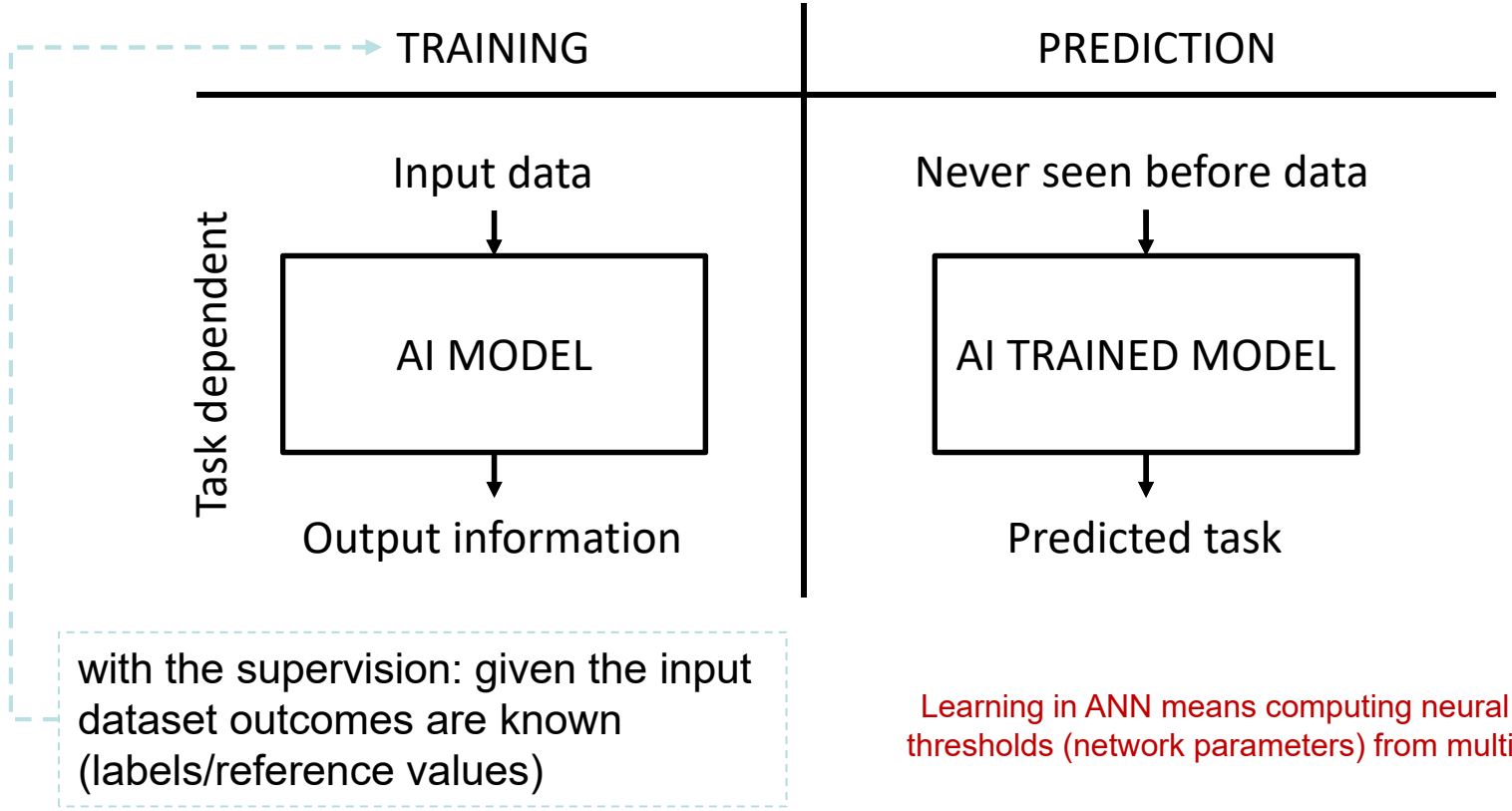
- Input range
- Strength of the response (sensitivity)
- Increase/decrease output

Some nice ANN designs



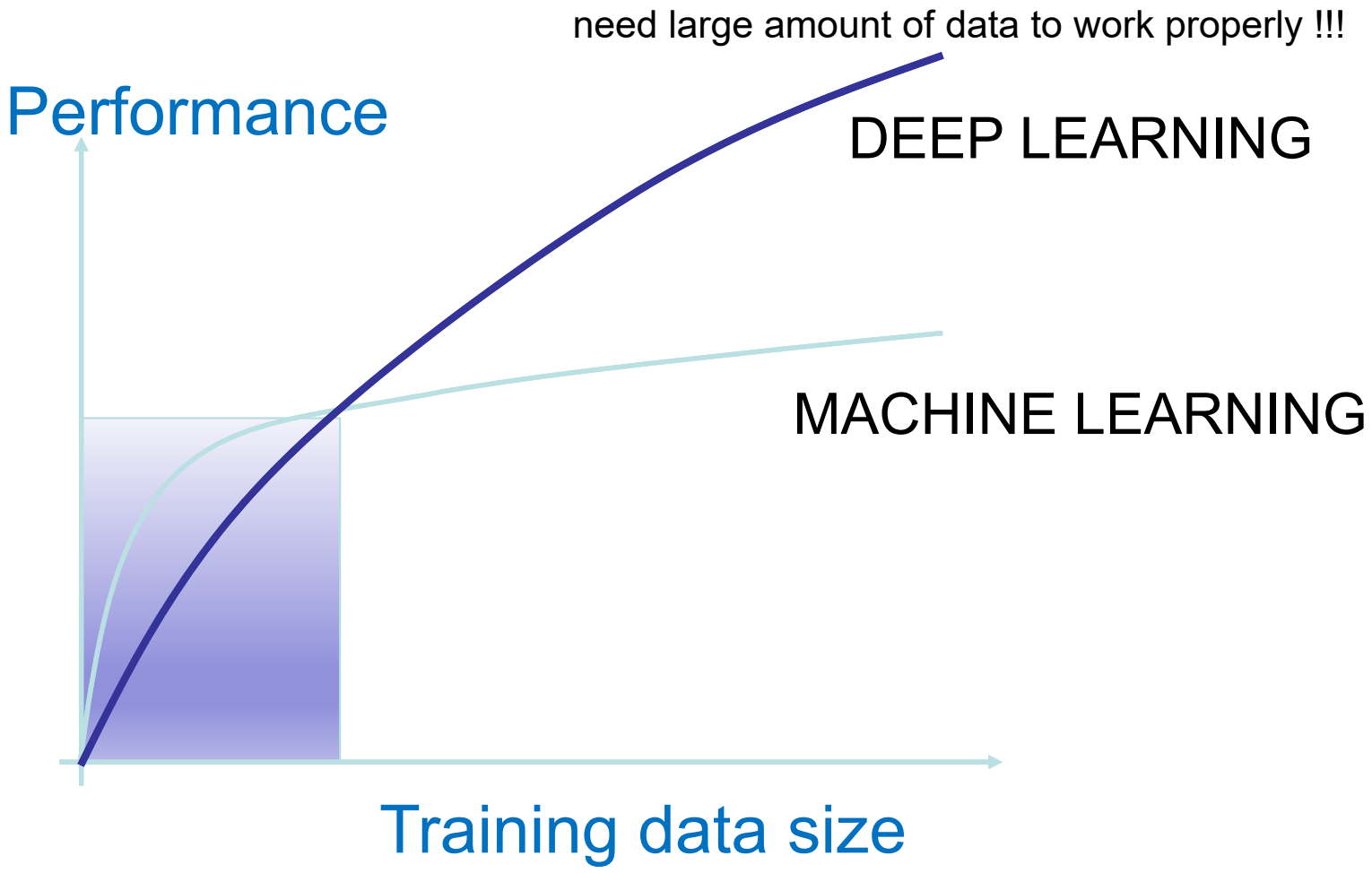
Machine Learning (data-driven)

- a computer technique that builds or train a predictive model from input data
- applied to heterogeneous data types: text, numerical, images, audios, video, …



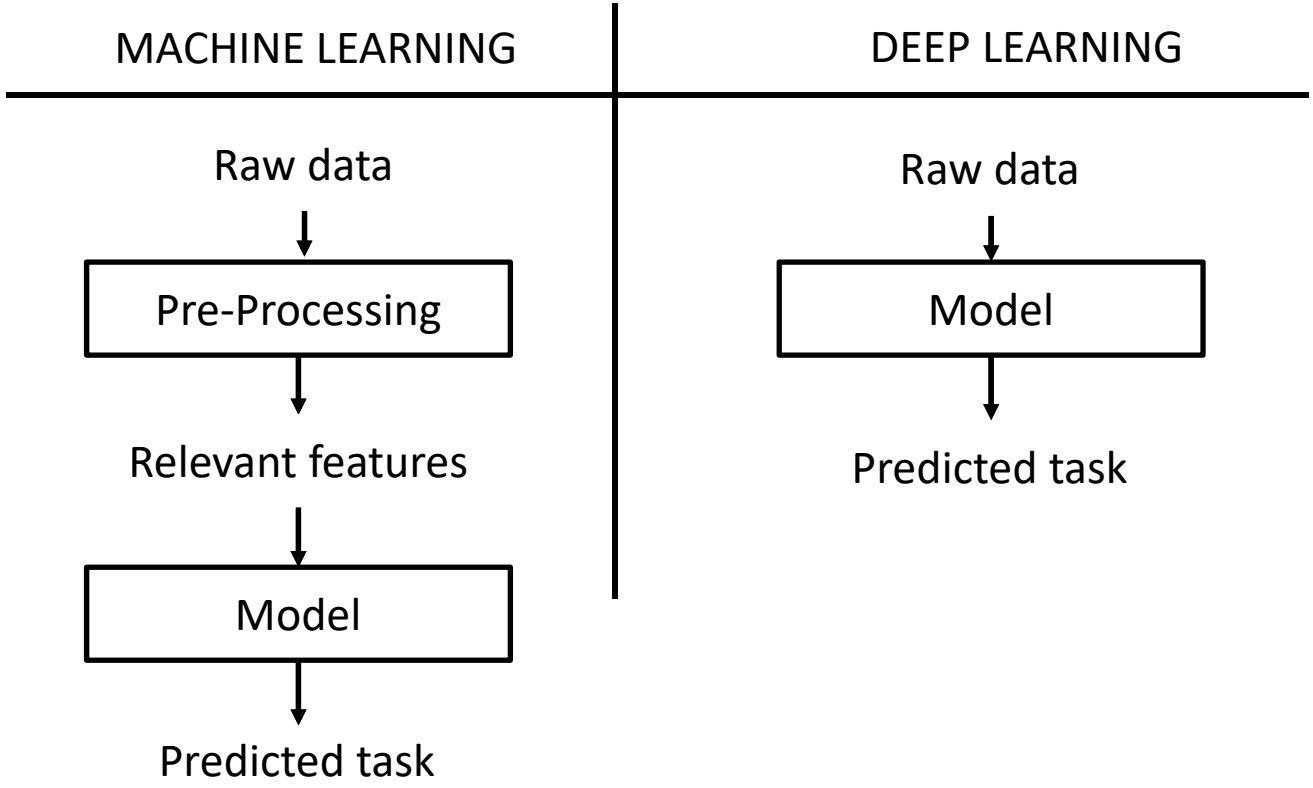
Learning in ANN means computing neural weights and thresholds (network parameters) from multiple examples

Amount of available data …..

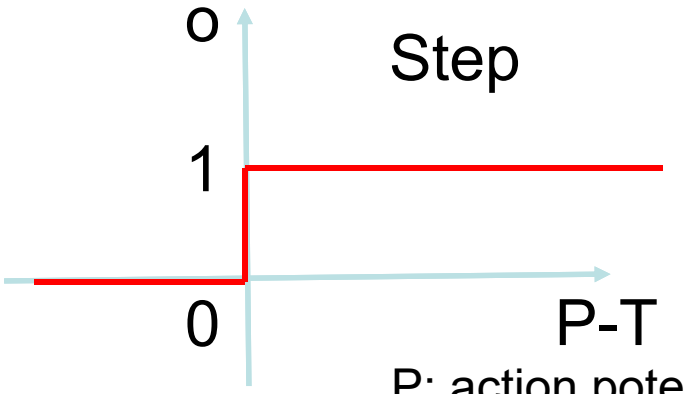


Machine Learning against Deep Learning

- Machine learning techniques apply to well-know quantities (relevant features)
- when we do not know exactly what are the features that determine the task we can apply deep networks



ANN able to take decisions



P: action potential
T: neuron threshold

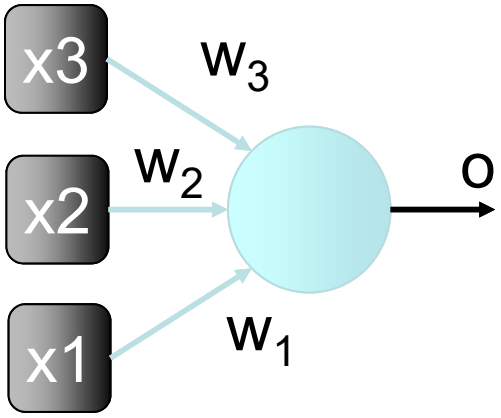
ANN paradigm: combine the three conditions using a neuron with Step activation function

$$\text{output} = \begin{cases} 0 & \text{if } \sum_j w_j x_j \leq \text{ threshold} \\ 1 & \text{if } \sum_j w_j x_j > \text{ threshold} \end{cases}$$

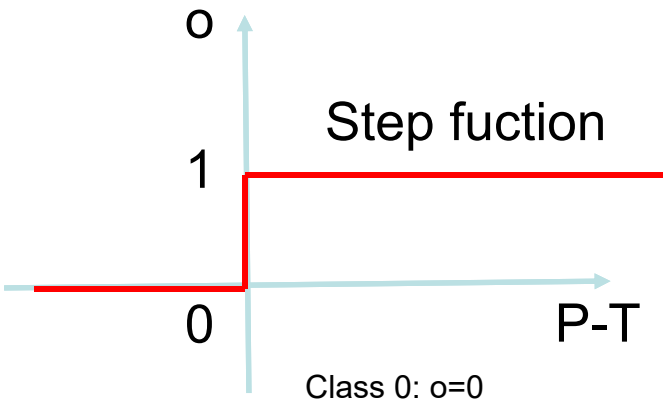
Patient status and exam results are available
How to decide whether administering either drug A or B?

1. Is blood red cell level normal?
2. Is patient temperature higher than normal?
3. Is breath flow lower than normal?

You must assign a score/weight to each possibility

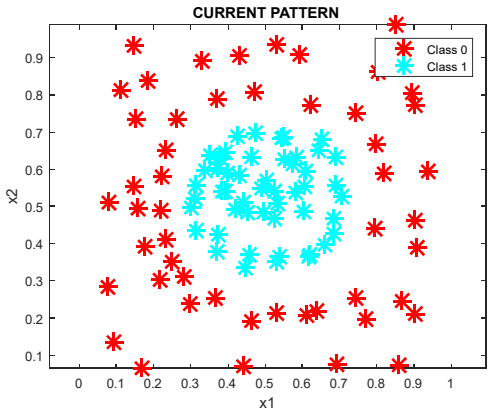


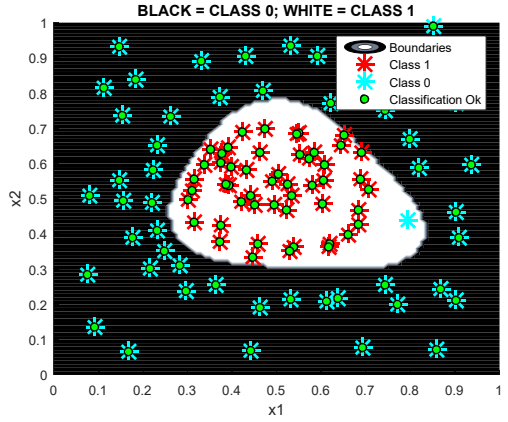
ANN able to discriminate data

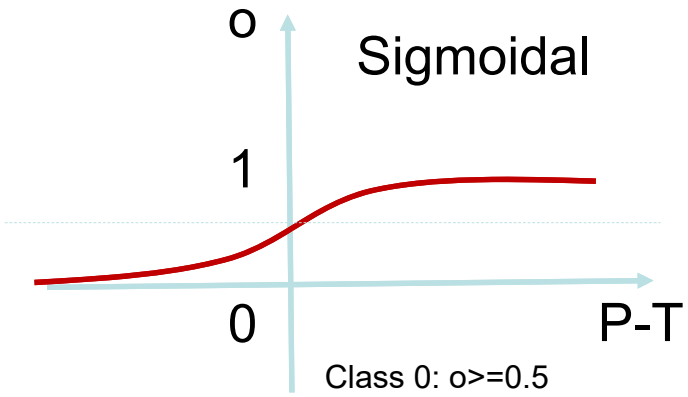


Class 0: o=0
Class 1: o=1

Setting non-linear boundaries

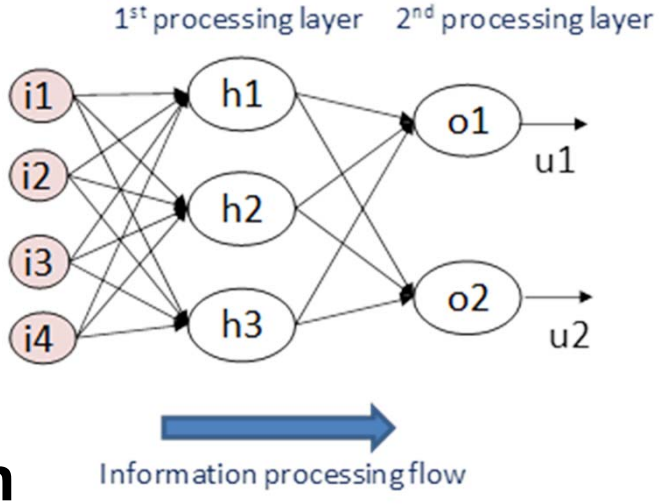






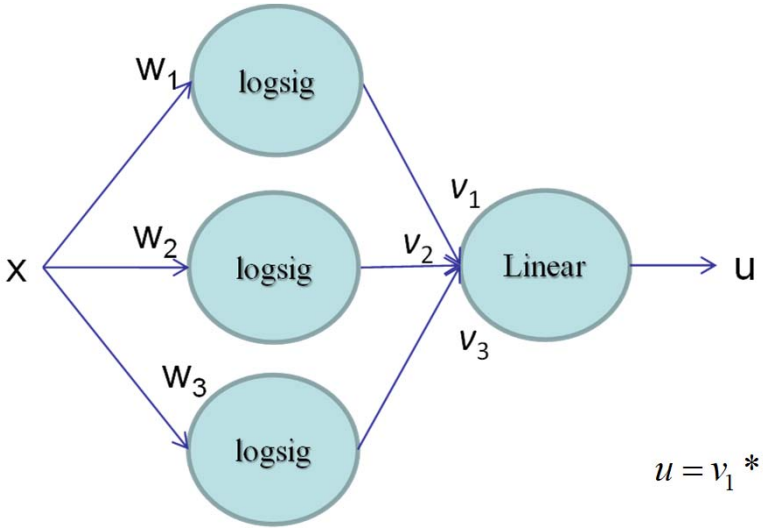
Class 0: o>=0.5
Class 1: o<0.5

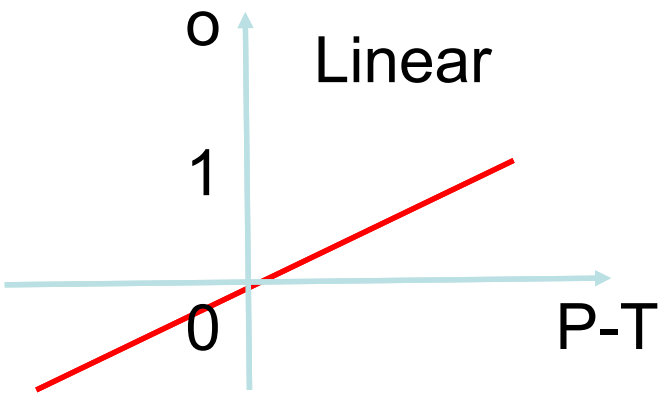
Multi-layered feedforward networks



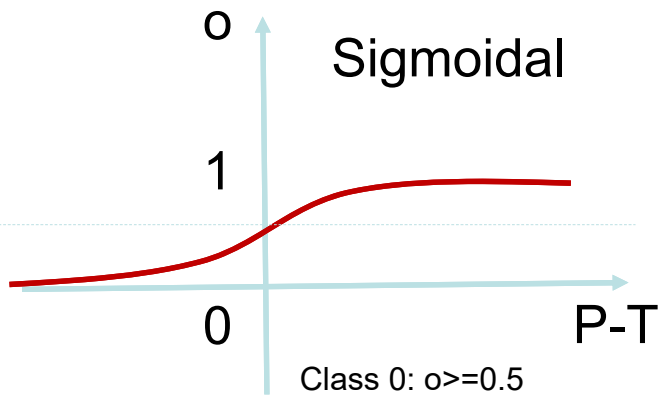
Pattern classification

ANN able to approximate data





$$u = v_1 * \log sig(w_1 x - T_1) + v_2 * \log sig(w_2 x - T_2) + v_3 * \log sig(w_3 x - T_3) - T_4$$



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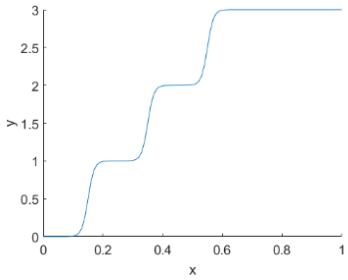
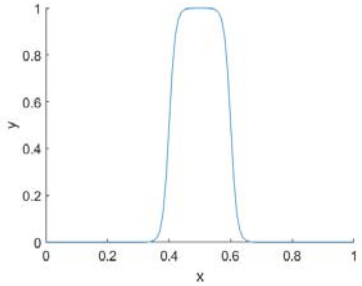
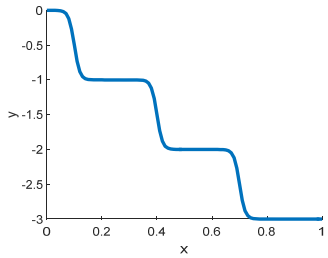
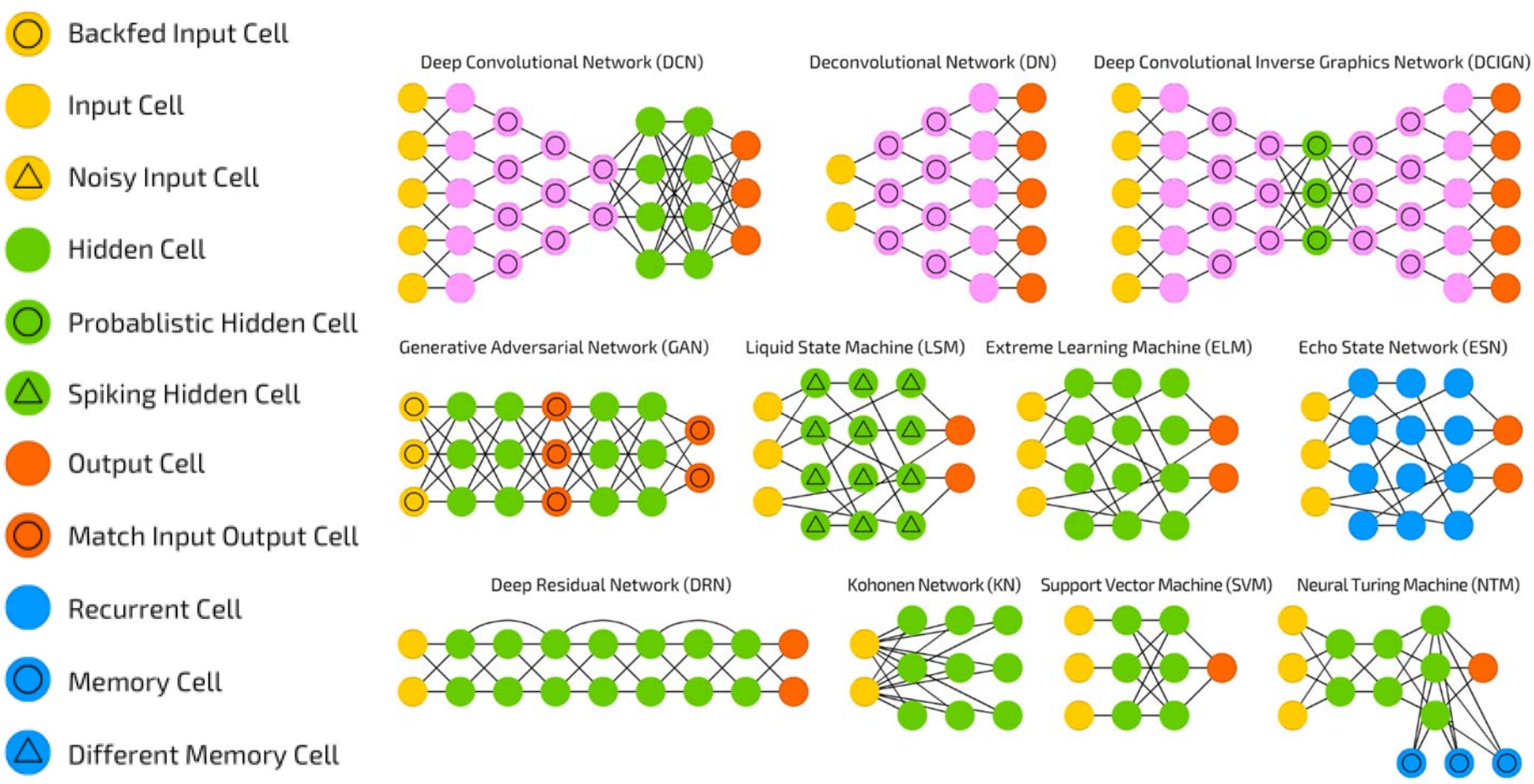




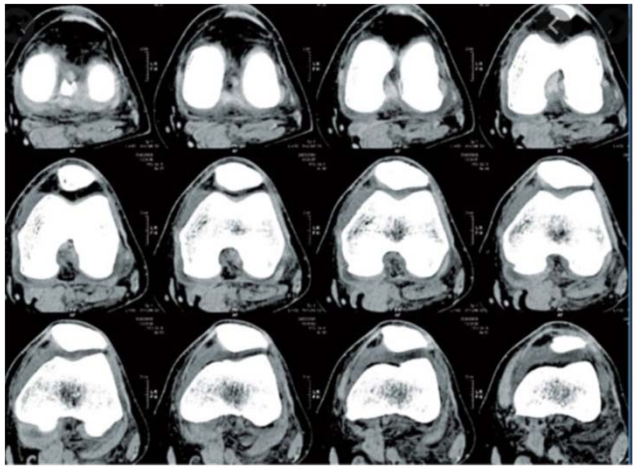


other wonderful designs

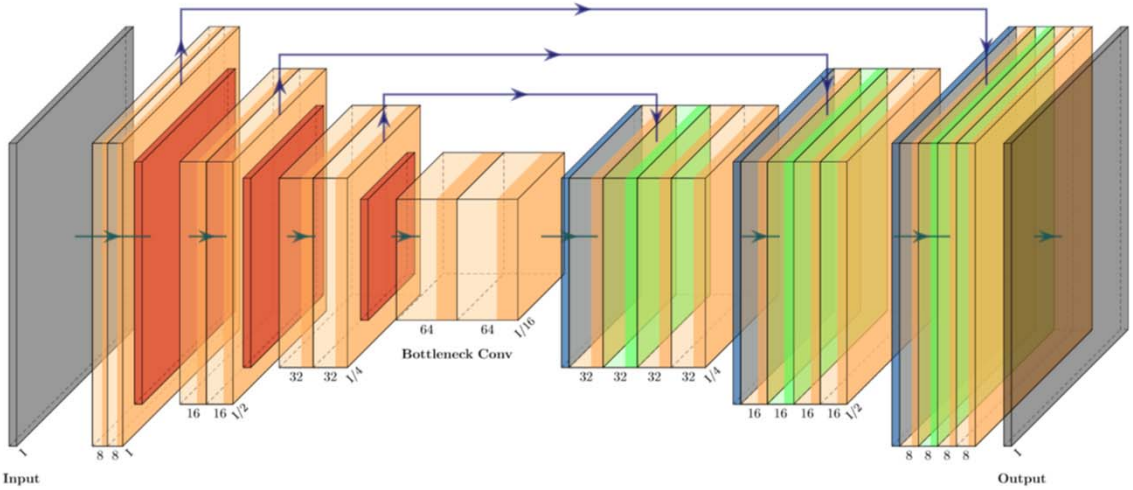


ANN able to process complex data

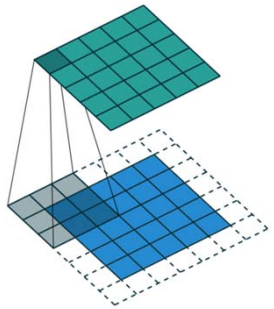
- Dealing with 3D image scans
- The network learns to reconstruct a modified version of the original scan
- Denoising, semantic segmentation, filling, ….



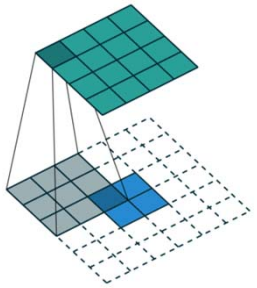
Convolution/deconvolution networks



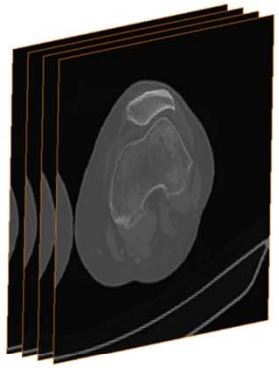
Convolution filter



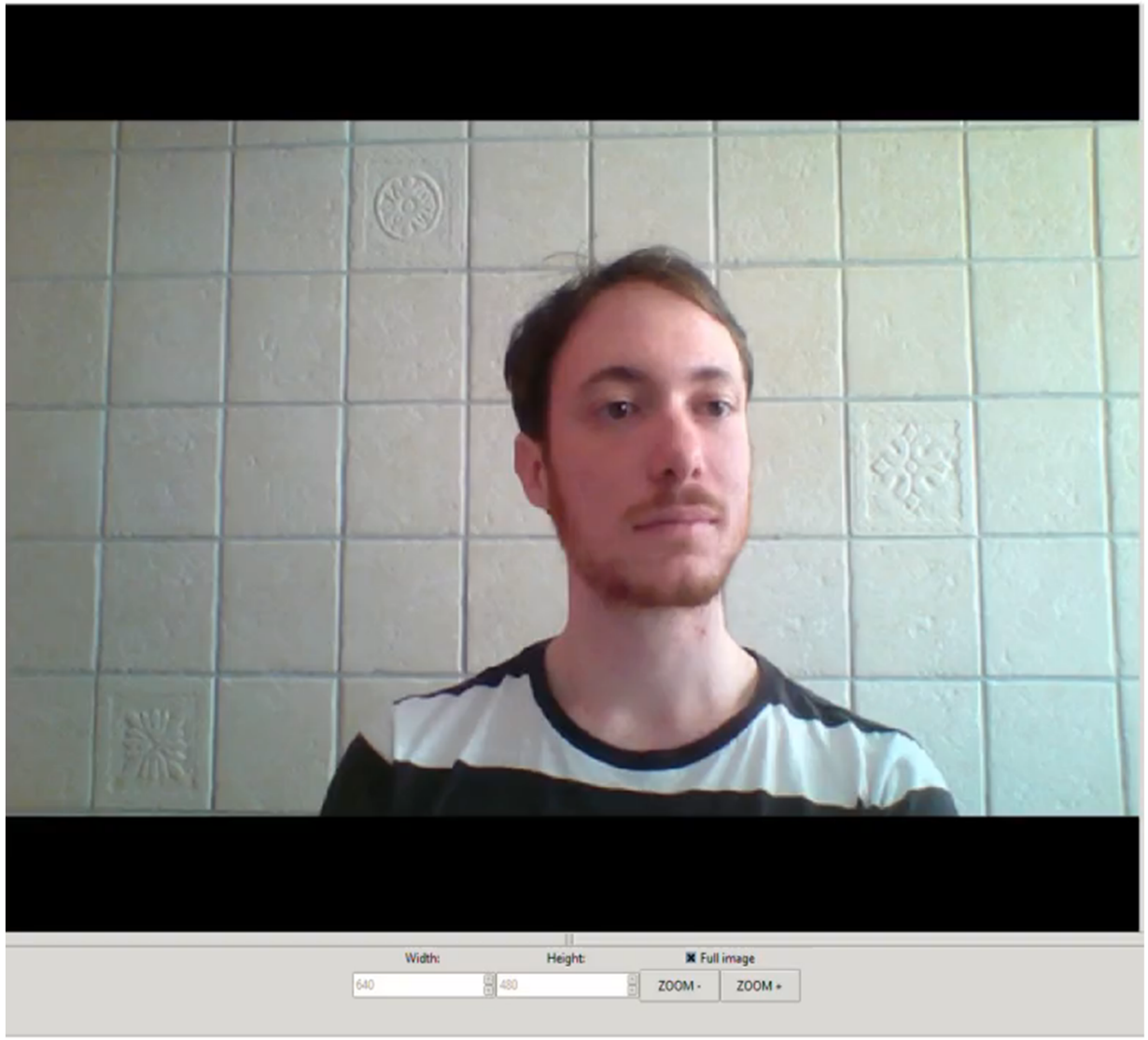
Deconvolution filter



Neural image segmentation



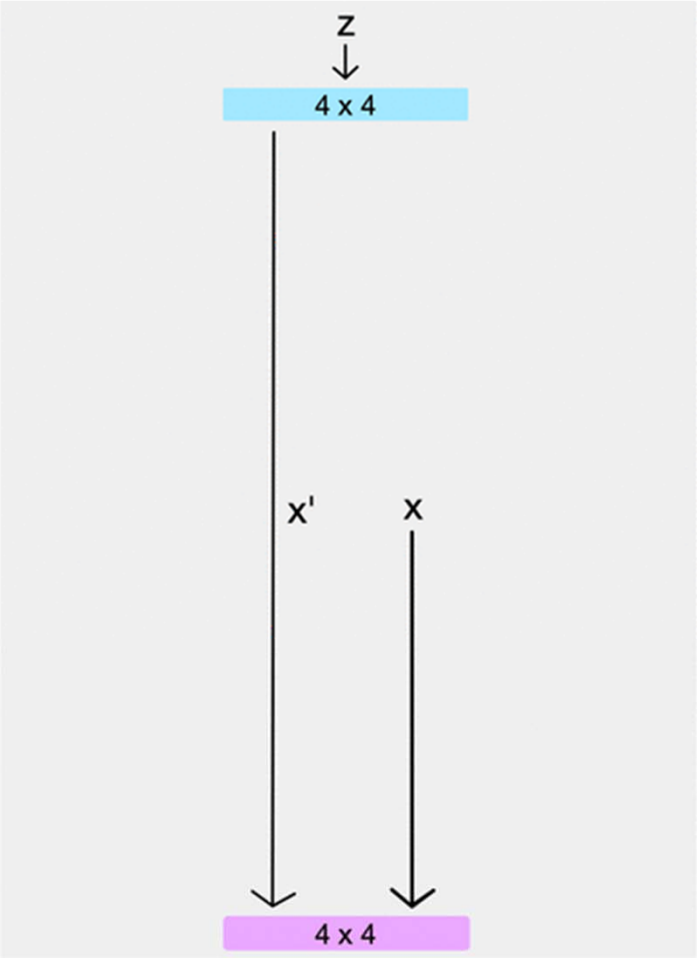
ANN able to recognize emotions

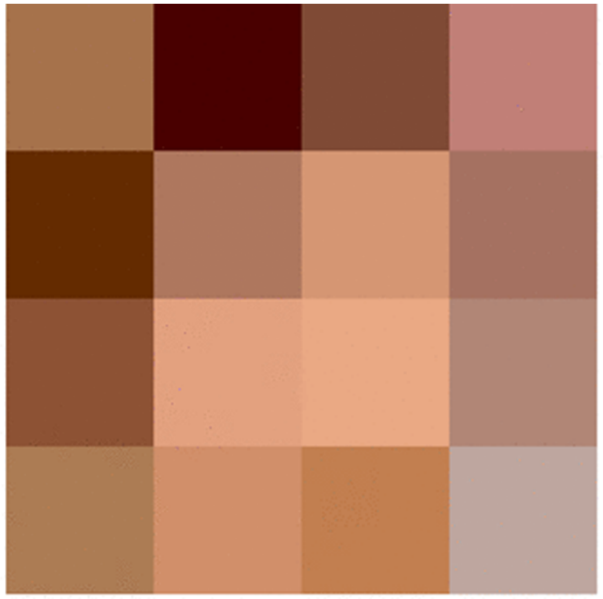


ANN to extend human-robot interaction

ANN able to imagine

ANN able to create new data





Training time: 0 days
4x4 resolution

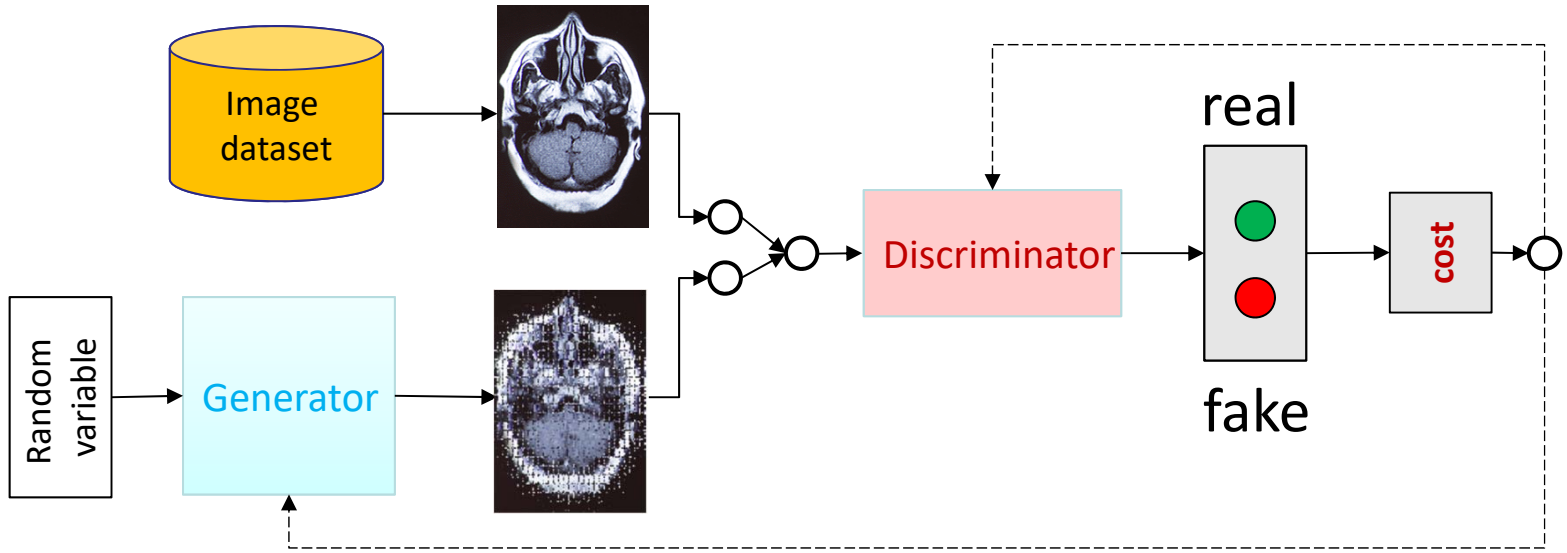
Generator
Discriminator

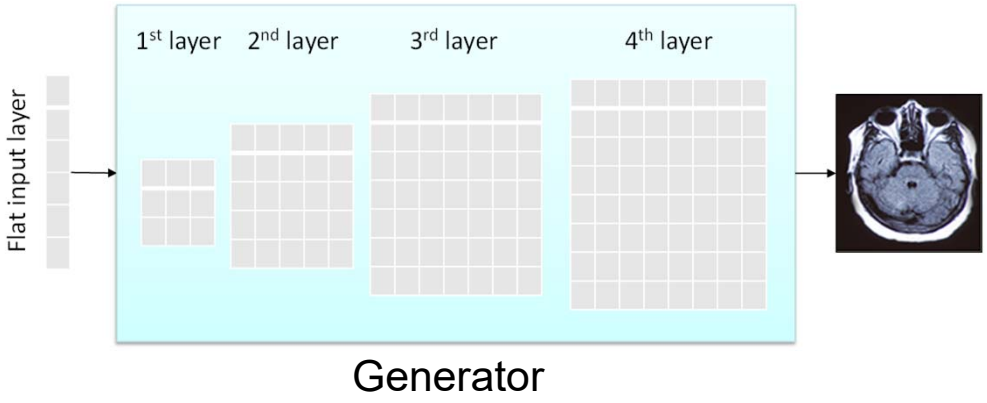
z = random code
x = real image
x' = generated image

ANN able to create data (robot artist)

The probability distribution of the random variable is learnt from a a set of data (e.g. images) to generate similar data through two-player game

Generative adversarial networks



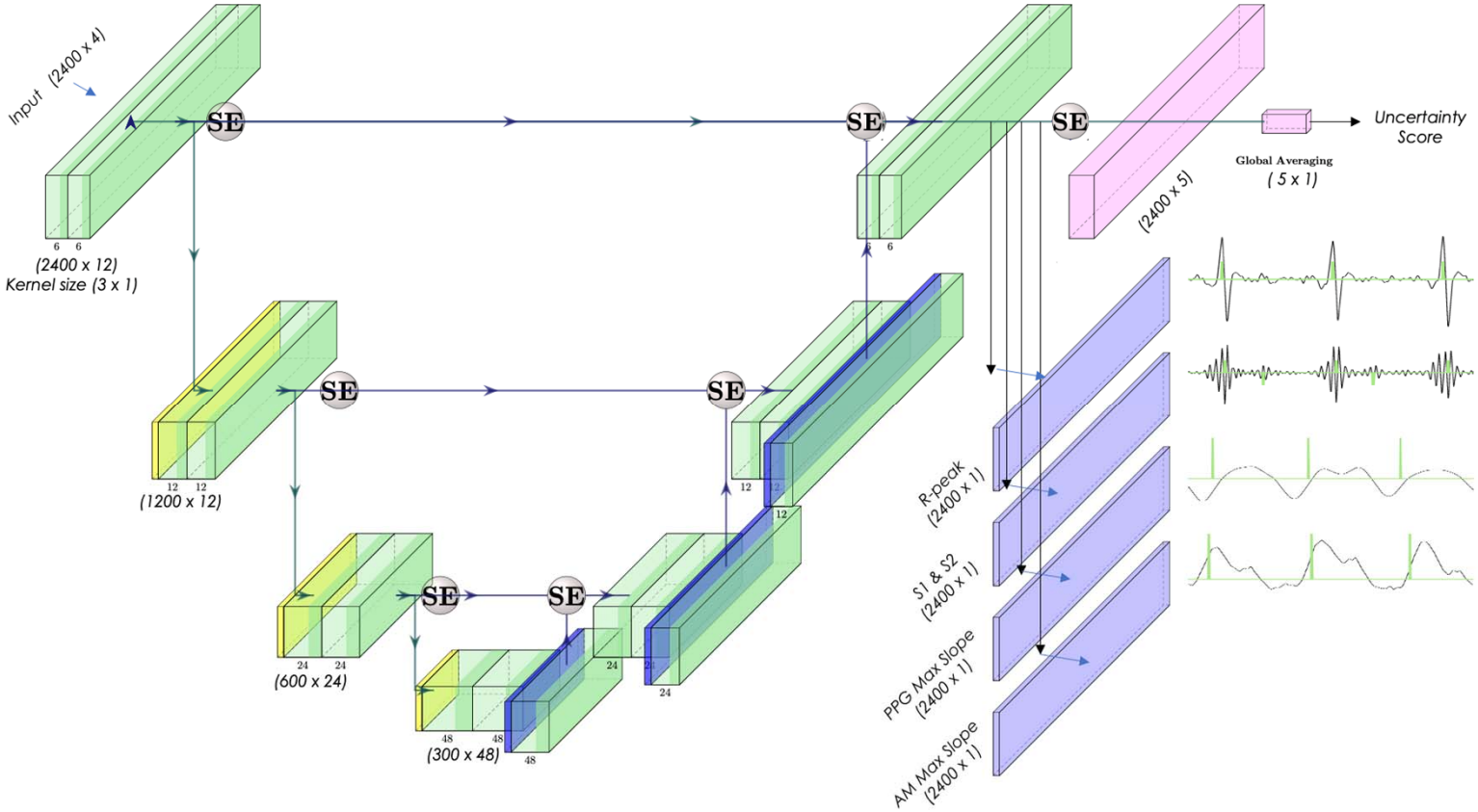


Generator

1.Simulation
2. Action planning.
3. Generating missing data
4. High-quality data generation
5. Information safety

Additional themes in AI

- **Explainable AI (XAI)**
  - large number of parameters (even several millions) distributed over several layers
  - making interpretable at human level what is really doing a complex multi-layer network (ida-research.net)



Lectures and Exercise

Support materials available on WeBeep

Lesson slides
Lesson reports
Exercise reports
Written exam examples with solutions
SW scripts for PW activities

Research materials

Bibliography for specific subjects

Project workshop development

Python programming language

Keras/pyTorch libraries (ANN implementation)
Tensorflow (Back-end for maths)
Supporting cloud platforms: Colab Google

Testing data

Signal/image biomedical data (in-house and publicly available data)