Artificial Neural Networks

by

Dr. Vera DAMERJIAN PIETERS

DSTI
Data ScienceTech Institute

Plan :

- Introduction to Artificial Intelligence
- What are ANNs ?
- The Artificial Neuron
- ANN Layers
- The Perceptron
- Weights and Biases
- Activation Functions
- Forward Propagation

Plan :

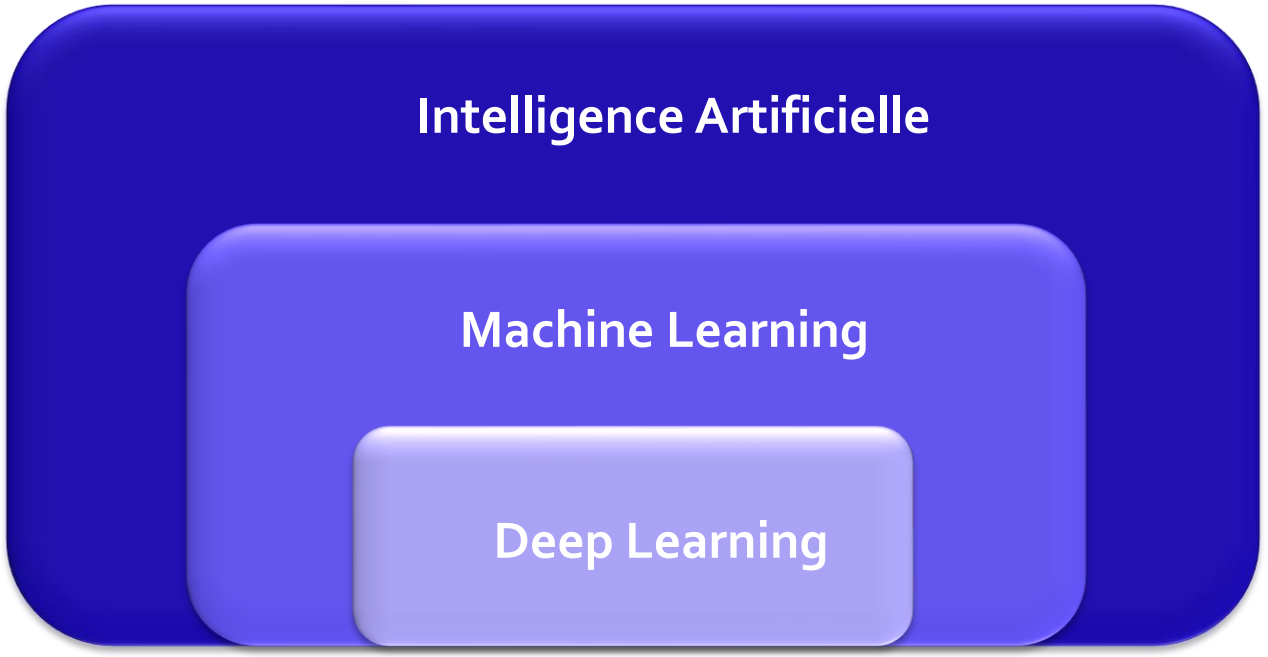
- Classification and Regression
- Cost Functions
- Optimizers
- Backpropagation
- The Learning Mechanism

Plan :

- Underfitting
- Overfitting
- Learning, Validation and Testing
- Regularisation
- Practice with Keras and TensorFlow

Introduction to Artificial Intelligence

Introduction to Artificial Intelligence



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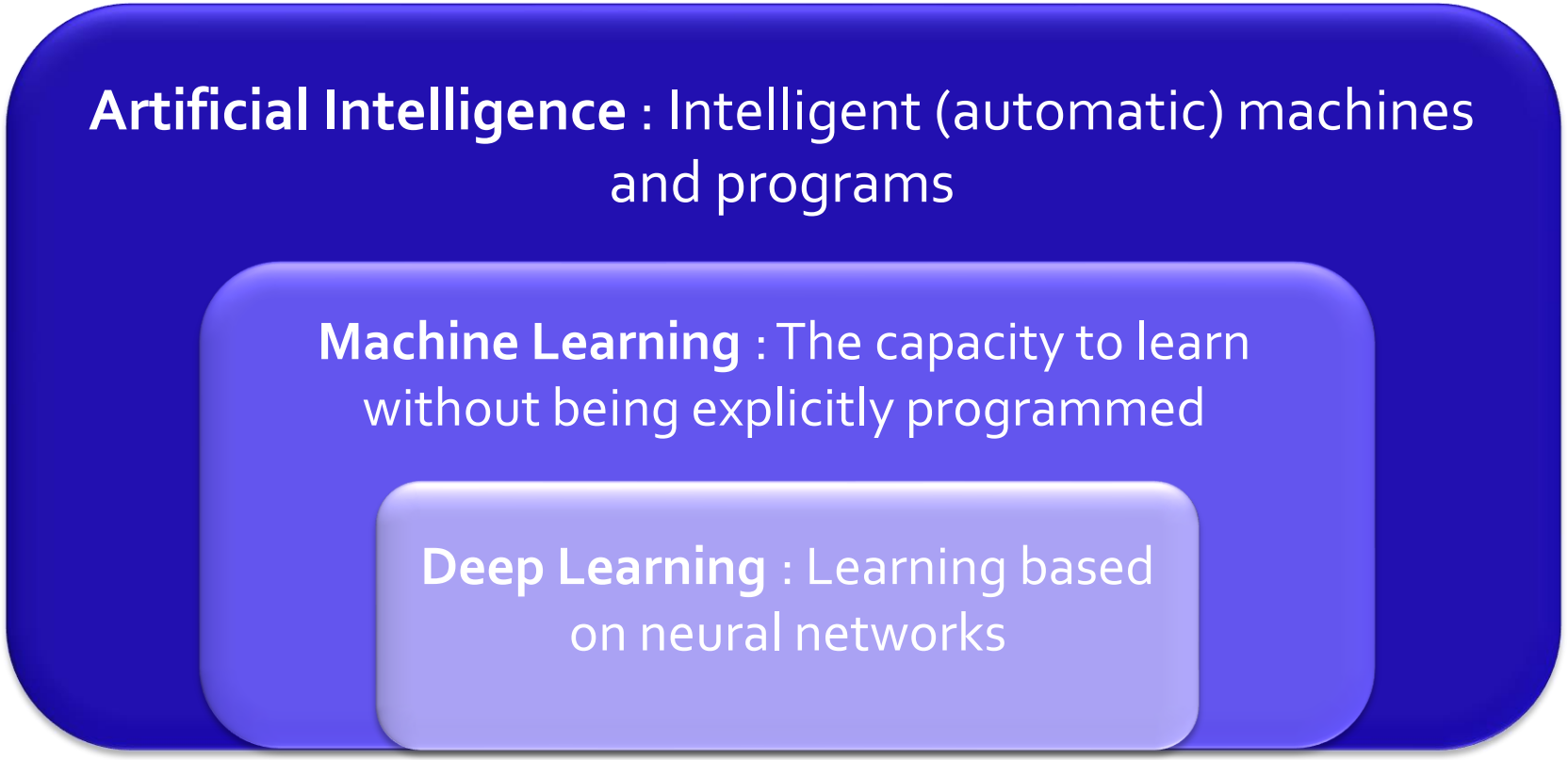

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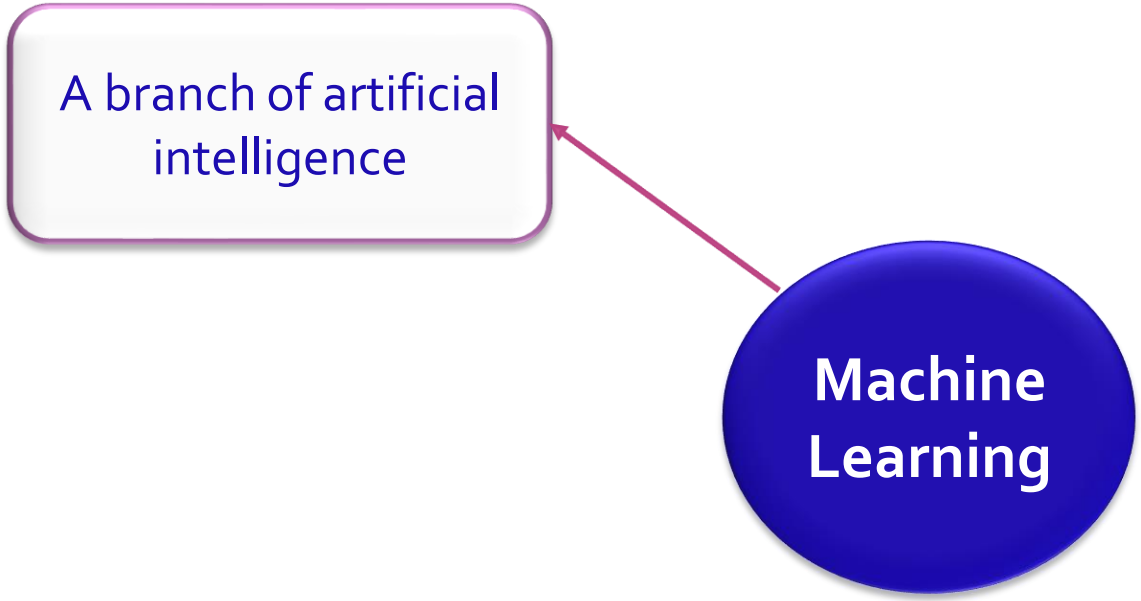

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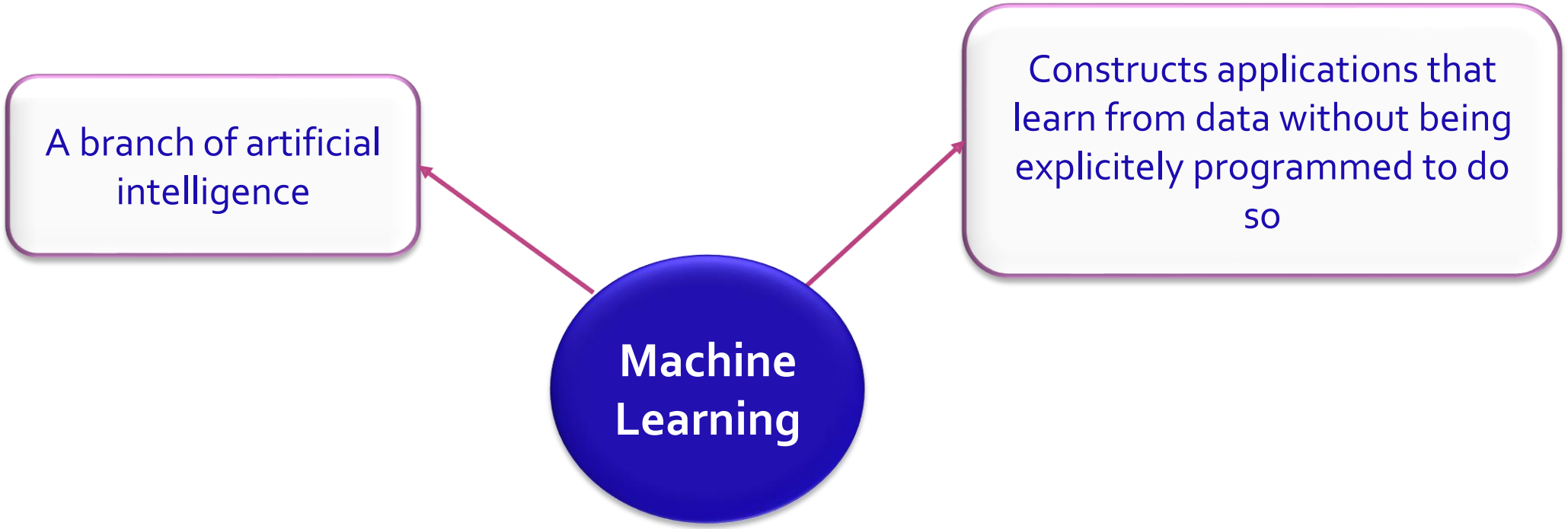

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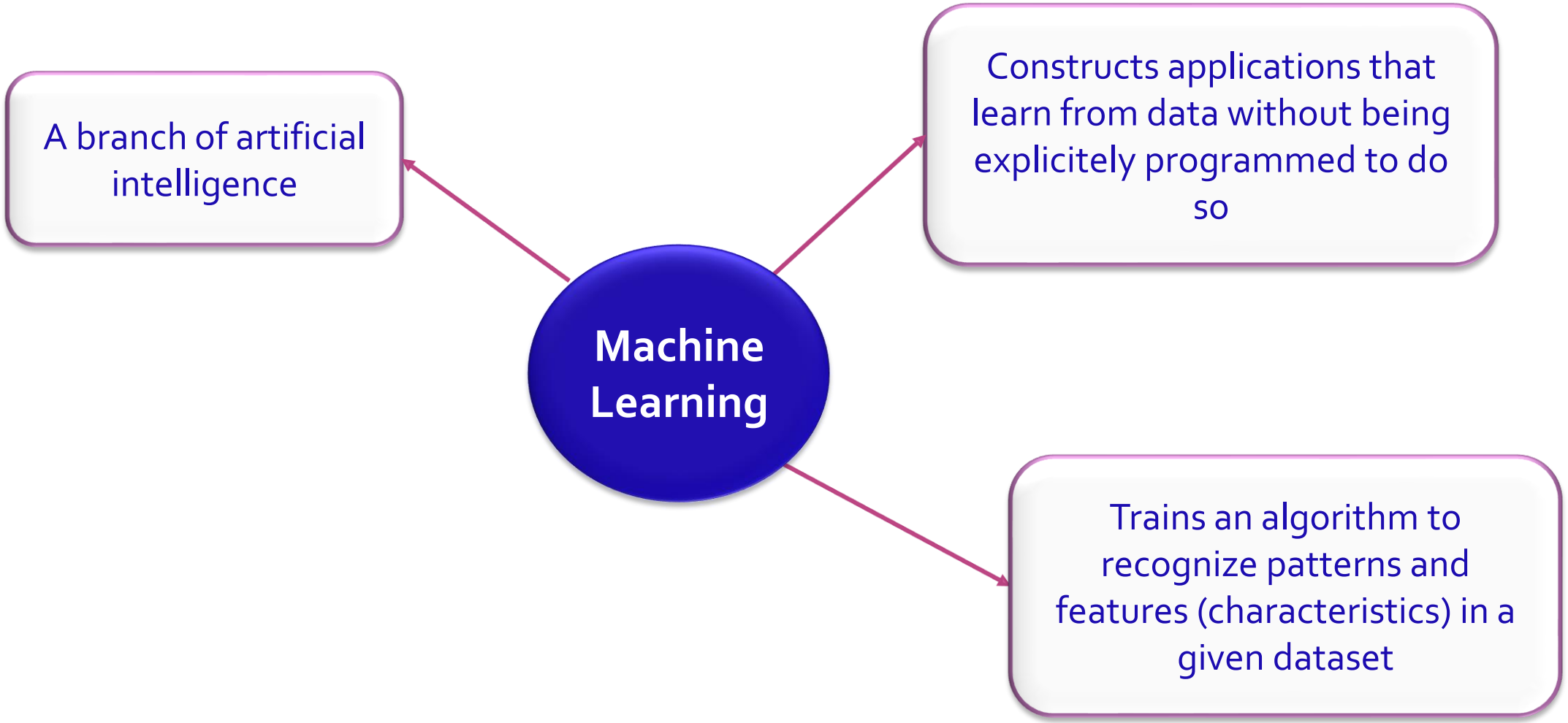

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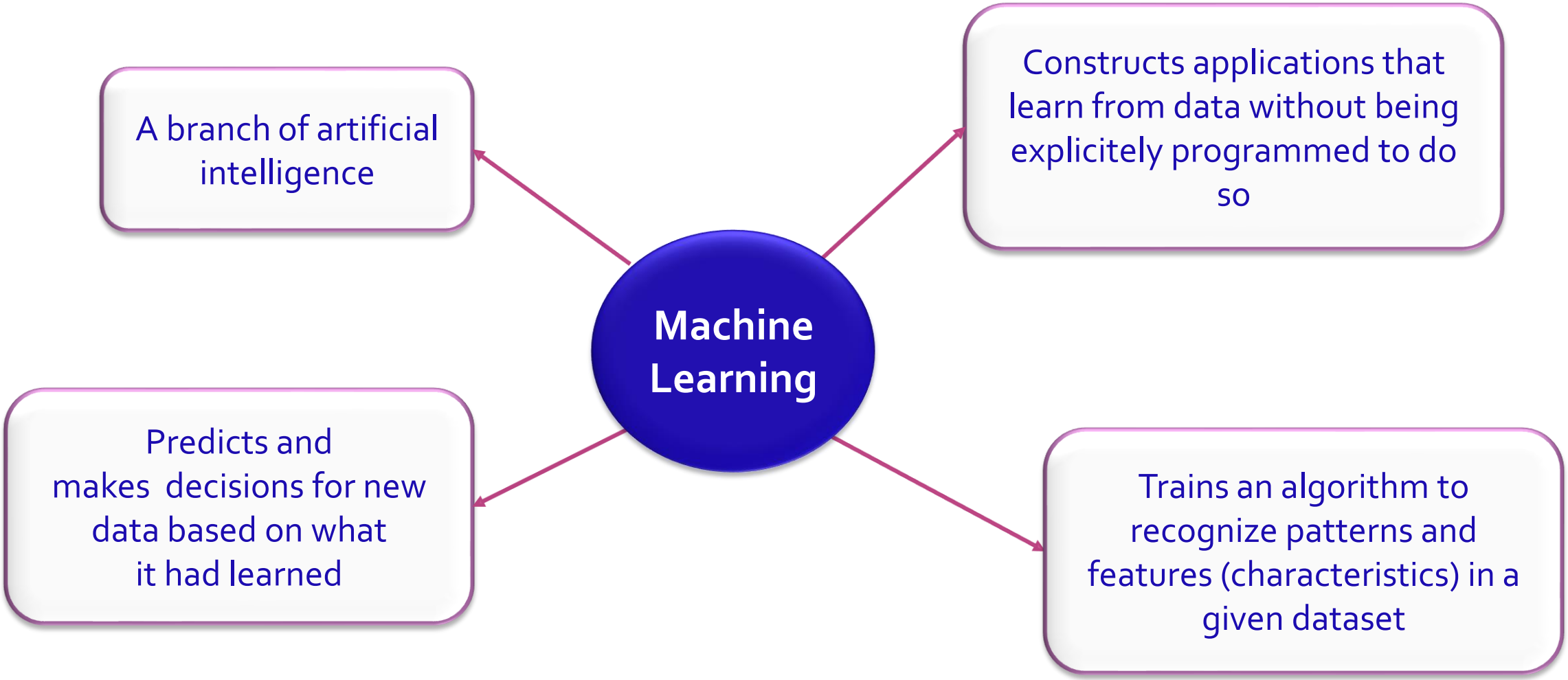


Introduction to Artificial Intelligence

Machine Learning applications :

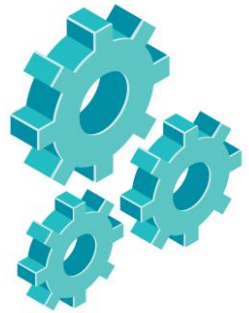
- Vocal assistance (Siri, Alexa, etc.)
- Recommendation systems (advertisements, movies, music, …)
- Medical image analysis and disease detection (tumors)
- Spam detection
- ⋮

Introduction to Artificial Intelligence

How does Machine Learning work ?

Introduction to Artificial Intelligence

How does Machine Learning work ?



1. Database preparation for training/learning

Introduction to Artificial Intelligence

How does Machine Learning work ?

1. Database preparation for training/learning

2. Machine Learning algorithm selection

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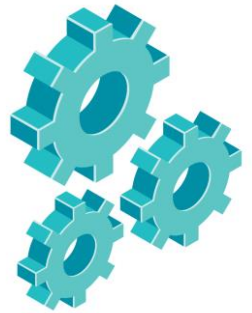
How does Machine Learning work ?



1. Database preparation for training/learning

2. Machine Learning algorithm selection

3. Algorithm training (learning) to obtain the model

Introduction to Artificial Intelligence

How does Machine Learning work ?

1. Database preparation for training/learning

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3. Algorithm training (learning) to obtain the model

4. Using the trained model

Introduction to Artificial Intelligence

How does Machine Learning work ?

1. Database preparation for training/learning

Training database :

Data that we use to teach our model

in order to solve a certain problem

Labeled :

The classes or categories of our data

are specified by humans

Introduction to Artificial Intelligence

How does Machine Learning work ?

1

Database preparation for training/learning

Training database :

Data that we use to teach our model

in order to solve a certain problem

Labeled :

The classes or categories of our data

are specified by humans

Non-Labeled :

The model extracts the features and

defines the categories by itself

Introduction to Artificial Intelligence

How does Machine Learning work ?

1. Database preparation for training/learning

➡ Labeled data - Example 1 :

Input	Labels (classes)
	dog
	dog
	cat
	cat

Classes to learn are defined by humans

Introduction to Artificial Intelligence

How does Machine Learning work ?

1. Database preparation for training/learning

➡ Labeled data - Example 2 :

Age	Smoker	Nodule size (mm)	Location	Label
70	1	5	Top left	malignant
40	0	8	Top left	benign
45	1	2	Bottom middle	benign
65	1	4	Bottom right	benign

Classes to learn are defined by humans

Introduction to Artificial Intelligence

How does Machine Learning work ?

1 Database preparation for training/learning

➡ Labeled data - Example 3 :

Area	Number of rooms	Distance from train station	city	Price (label)
32	3	5	Amiens	60 000
25	1	8	Lille	70 000
80	4	10	Versailles	600 000
55	3	10	Nice	450 000

Classes to learn are defined by humans

Introduction to Artificial Intelligence

How does Machine Learning work ?

1. Database preparation for training/learning

➡ Unlabeled data - Example 1 :

The model extracts the characteristics then defines the classes itself, with no human intervention

Input



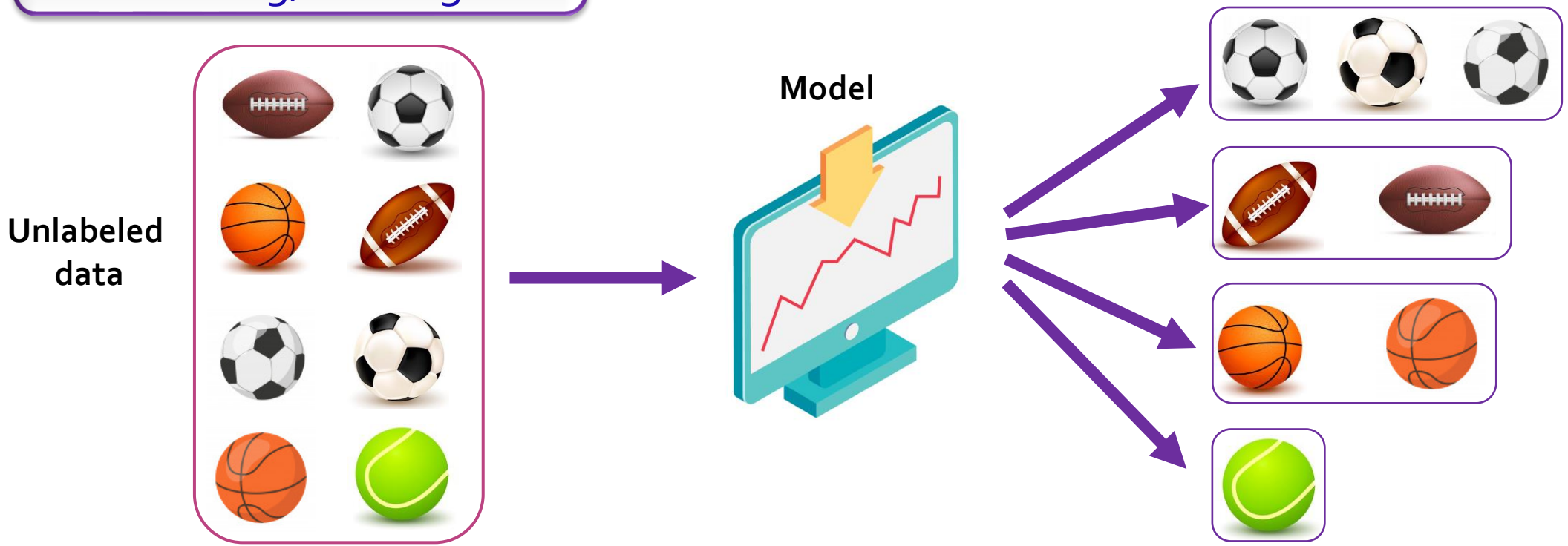
Introduction to Artificial Intelligence

How does Machine Learning work ?

1

Database preparation for training/learning

Unlabeled data - Example 2 :



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How does Machine Learning work ?

1. Database preparation for training/learning

- Learning database
  - balanced (unbiased)
  - random
  - No duplicates

Introduction to Artificial Intelligence

How does Machine Learning work ?

1. Database preparation for training/learning

Database :

- Learning database
- Validation (testing) database

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How does Machine Learning work ?

2

Machine Learning algorithm selection

Machine Learning types :

- Unsupervised Learning (Self-Supervised Learning)
- Semi-Supervised Learning
- Supervised Learning
- Reinforcement Learning

Introduction to Artificial Intelligence

How does Machine Learning work ?

2

Machine Learning algorithm selection

Supervised Learning

- Labeled database
- Human supervision and guidance
- Detection of pre-determined information

Introduction to Artificial Intelligence

How does Machine Learning work ?

2

Machine Learning algorithm selection

Supervised Learning

- Labeled database
- Human supervision and guidance
- Detection of pre-determined information

Good prediction quality

Introduction to Artificial Intelligence

How does Machine Learning work ?

2

Machine Learning algorithm selection

Supervised Learning

- Labeled database
- Human supervision and guidance
- Detection of pre-determined information

Good prediction quality

Dataset labeling is done by hand :
➔ *Slow and expensive procedure*

A great quantity of information is needed (millions sometimes)

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How does Machine Learning work ?

2

Machine Learning algorithm selection

Unsupervised Learning
(Self-Supervised Learning)

- Unlabeled database
- No human supervision
- Detection of information that has not been specified previously

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How does Machine Learning work ?

2

Machine Learning algorithm selection

Unsupervised Learning (Self-Supervised Learning)

- Unlabeled database
- No human supervision
- Detection of information that has not been specified previously

Saving money, time and energy

Introduction to Artificial Intelligence

How does Machine Learning work ?

2

Machine Learning algorithm selection

Unsupervised Learning (Self-Supervised Learning)

- Unlabeled database
- No human supervision
- Detection of information that has not been specified previously

Saving money, time and energy

More complex algorithms

Less predictable

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How does Machine Learning work ?

2

Machine Learning algorithm selection

Semi-supervised Learning

- Labeled + unlabeled data
- Labeled data size is smaller

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How does Machine Learning work ?

2

Machine Learning algorithm selection

Semi-supervised Learning

- Labeled + unlabeled data
- Labeled data size is smaller

Useful when data is sparse, difficult to obtain or rare

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How does Machine Learning work ?

2

Machine Learning algorithm selection

Semi-supervised Learning

- Labeled + unlabeled data
- Labeled data size is smaller

Useful when data is sparse, difficult to obtain or rare

Lower accuracy

Unstable

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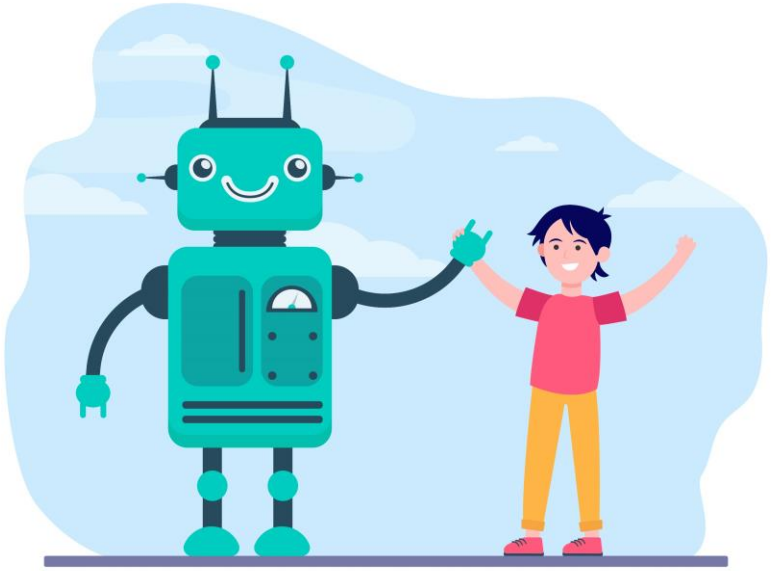
How does Machine Learning work ?



2

Machine Learning algorithm selection

Reinforcement Learning

- The system makes a **decision** with respect to its present state and receives a positive or a negative **reward** in response to its decision
- The system generates an optimal **strategy** to maximise the obtained rewards
- **Iterative** procedure
- Used in robotic training

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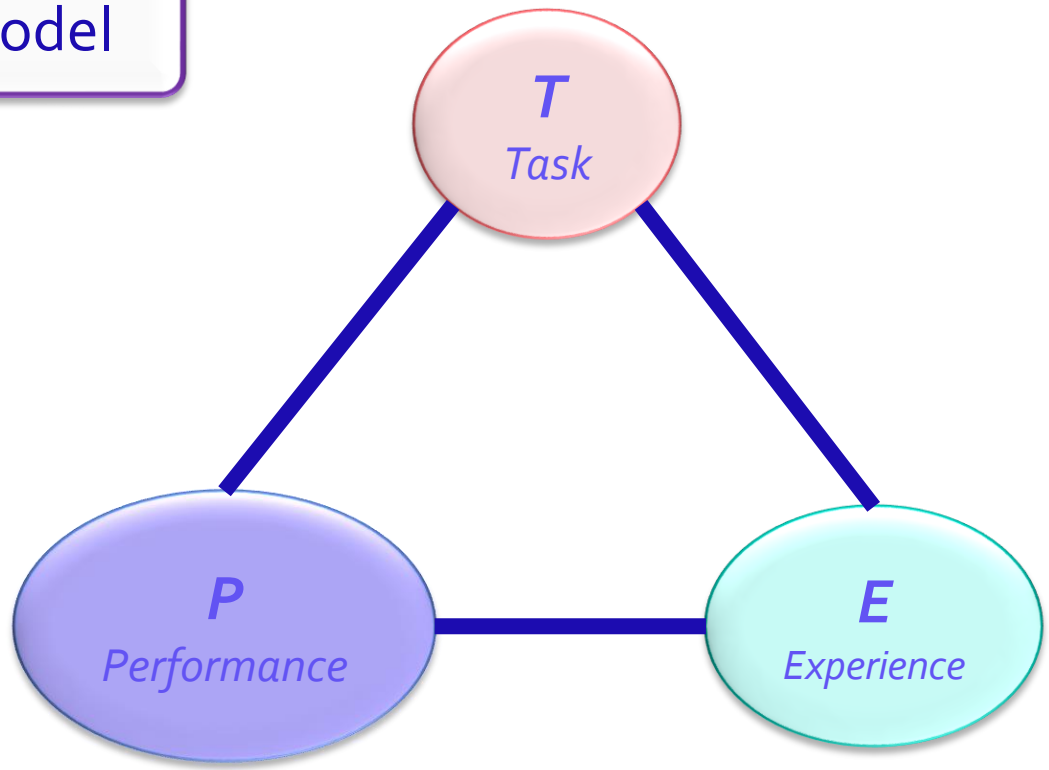
How does Machine Learning work ?

3

Algorithm training (learning) to obtain the model

*« **Machine learning** is the study of computer **algorithms** that allow computer programs to automatically improve through experience. »*

Tom Mitchell
Machine Learning, 1997



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How does Machine Learning work ?

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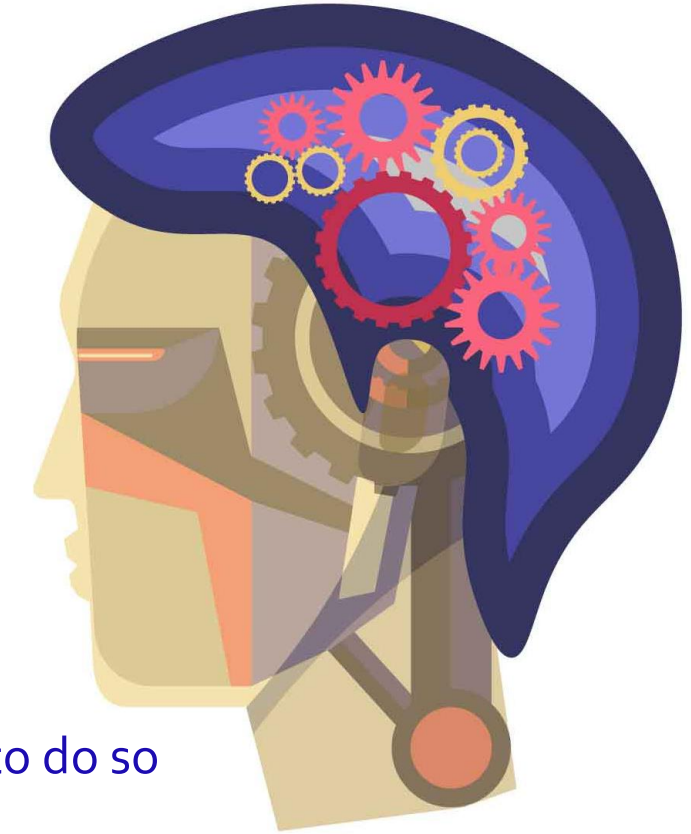
Algorithm training (learning) to obtain the model



Machine Learning creates an algorithm that :

→ Learns with time and experience

→ Has the capacity to learn without being explicitely programmed to do so

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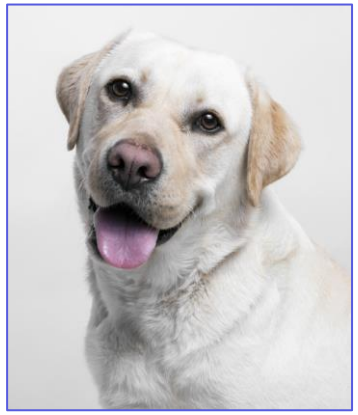
How does Machine Learning work ?

4

Using the trained model

Input



Model of cat/dog classification

Trained Model

Output

« Dog »

Introduction to Artificial Intelligence

How does Machine Learning work ?

4

Using the trained model

Input

Area = 43

Number of rooms = 3

Distance from train station = 7

City = Strasbourg

Regression model
(house price predictor)

Trained Model

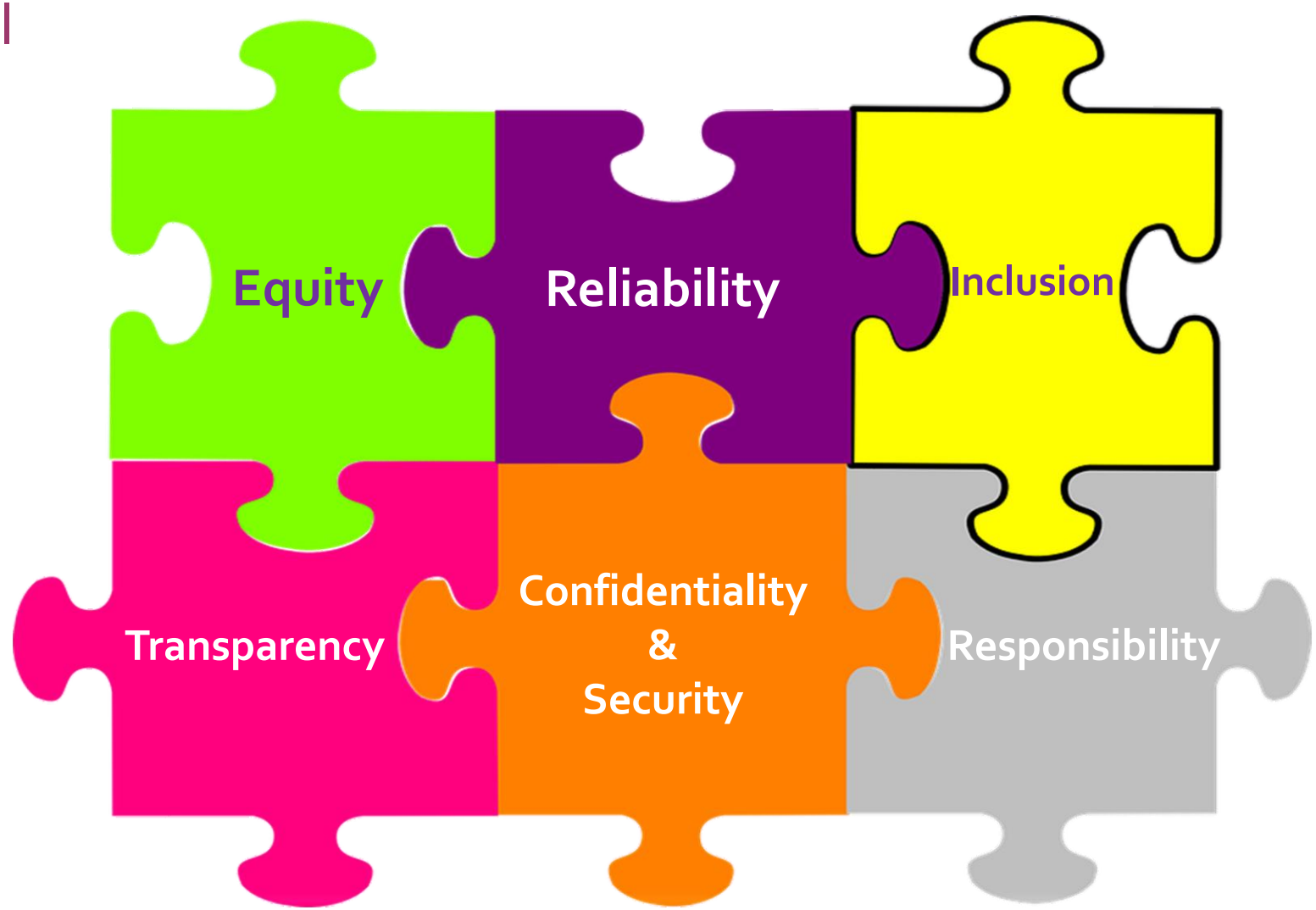
Output

210 000 €

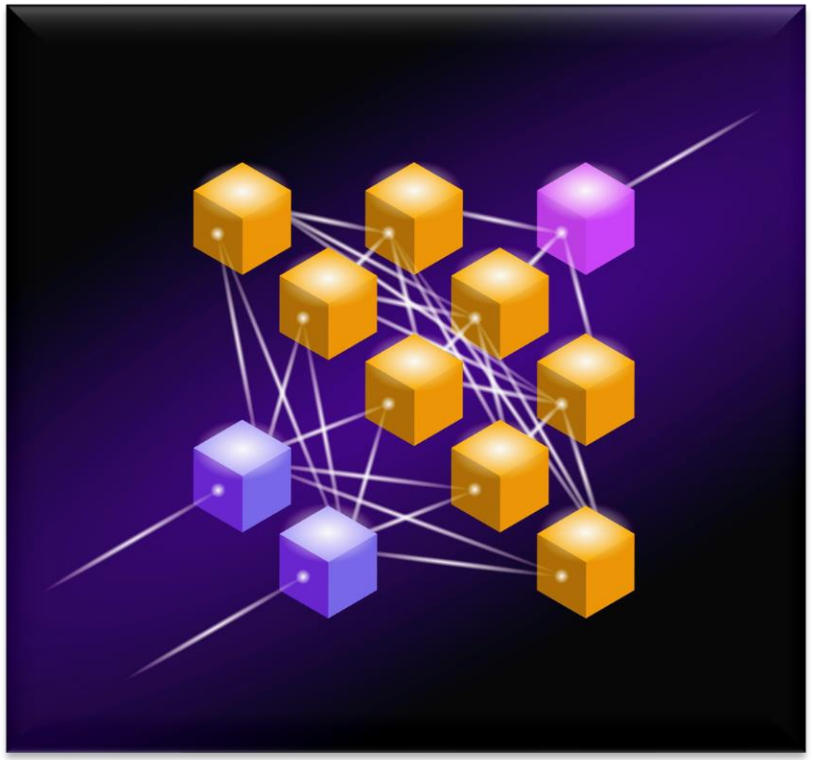
Introduction to Artificial Intelligence

Ethical and Responsible AI

En ethical AI system is one that has:



What are Artificial Neural Networks ?

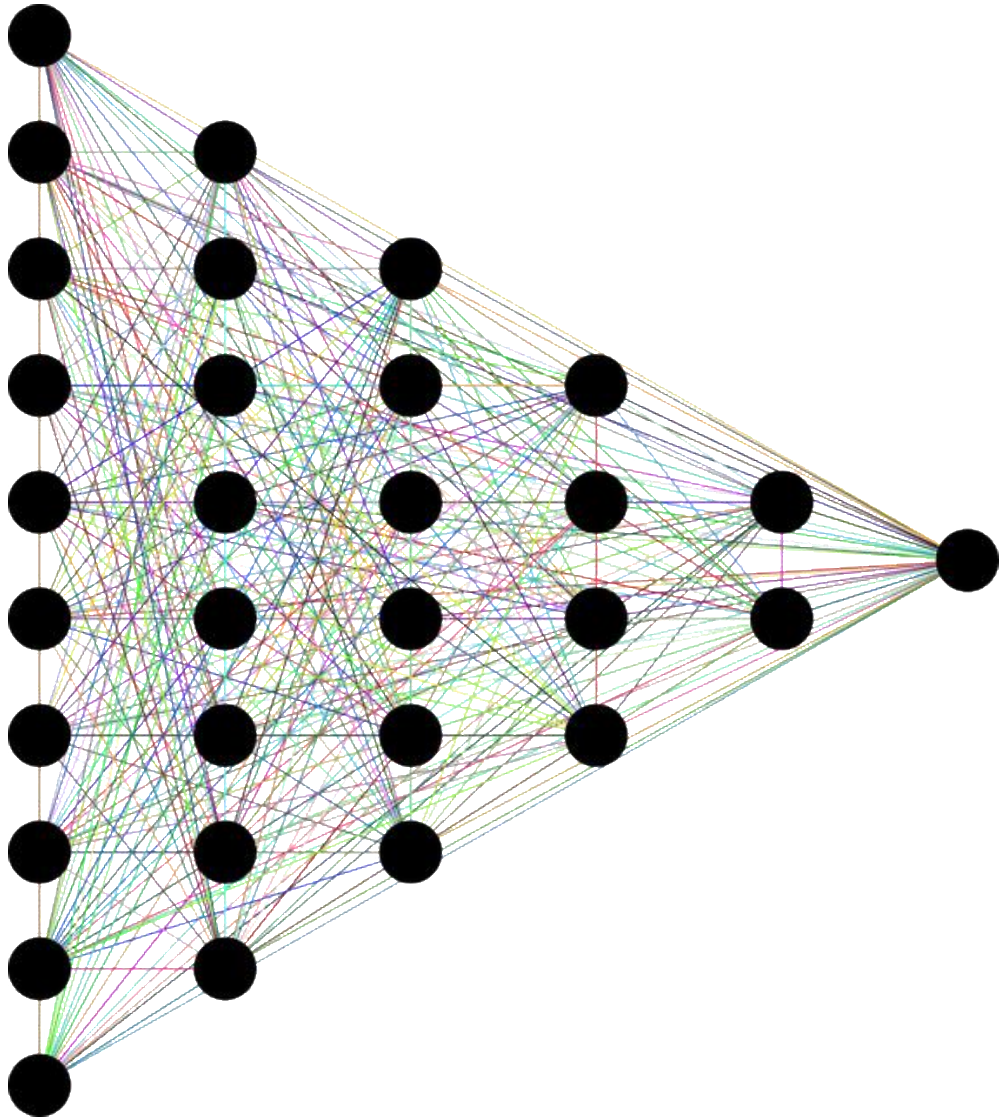


What are Artificial Neural Networks ?

Artificial Neural Networks (**ANNs**), or

simply **Neural Networks**, are :

- A subset of Machine Learning
- At the core of Deep Learning



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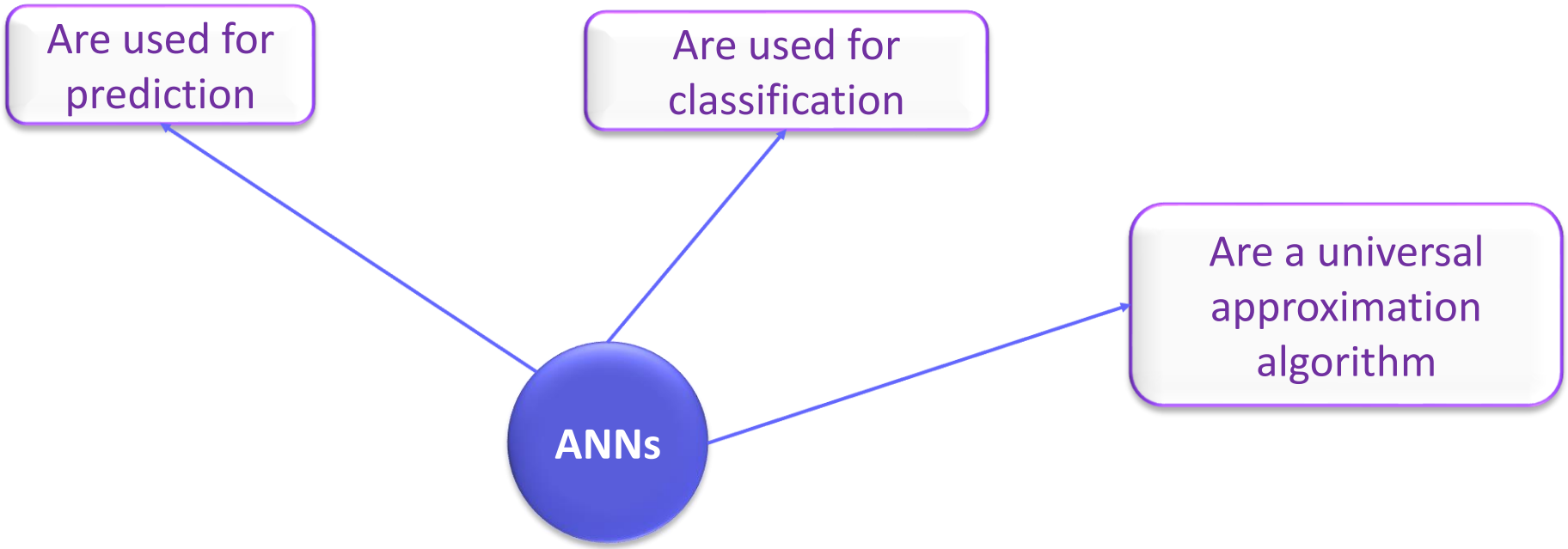

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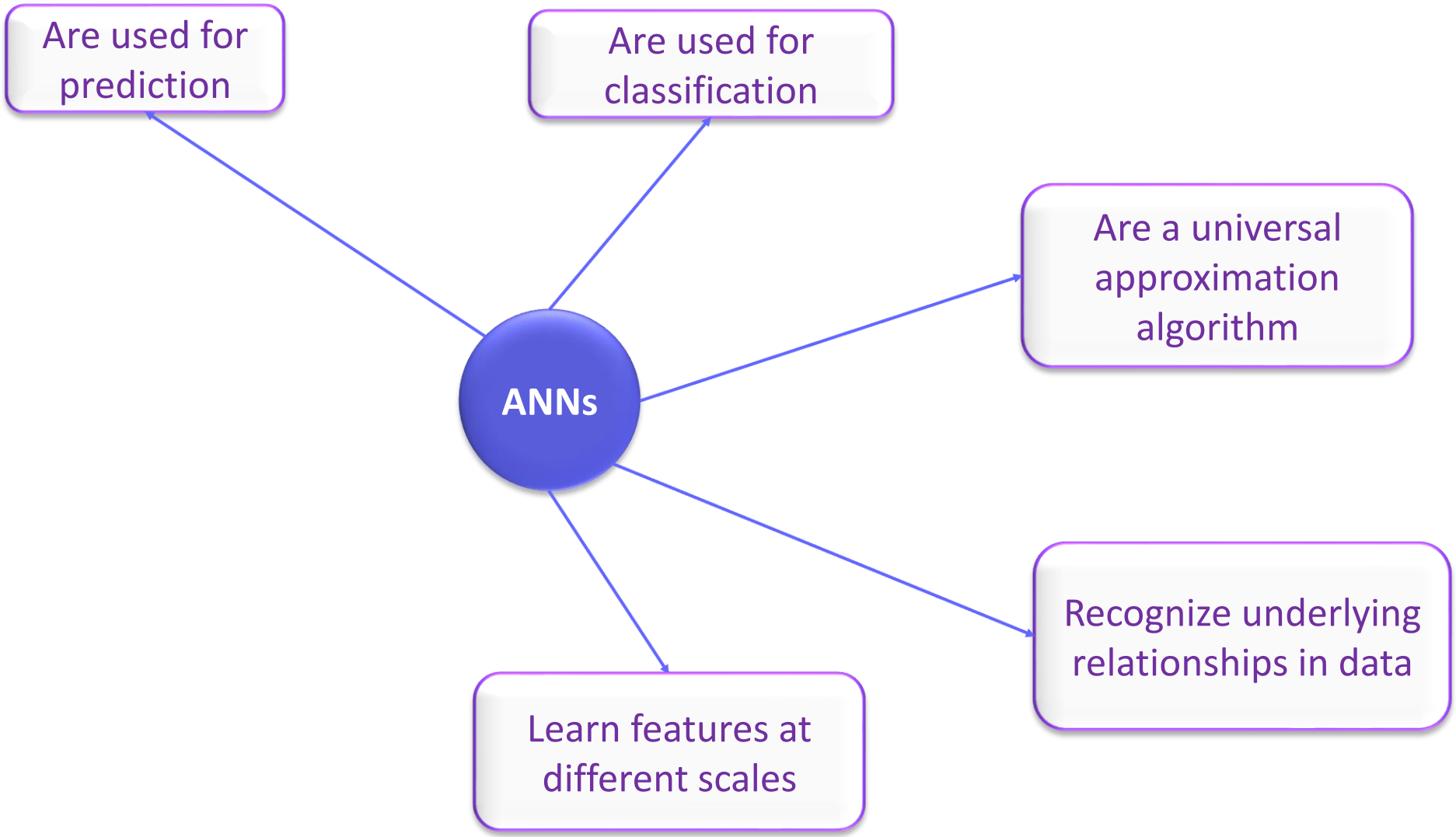

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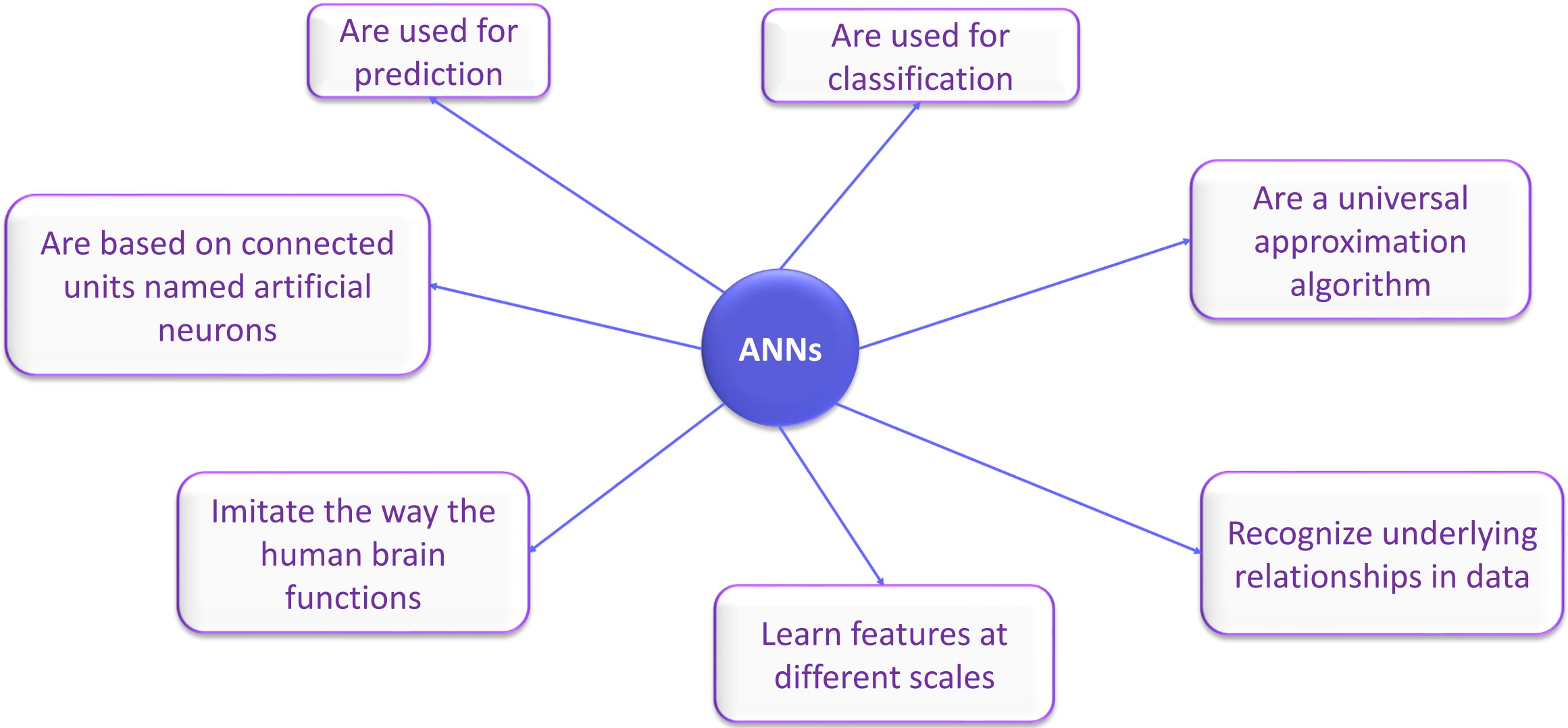

What are Artificial Neural Networks ?

A brief history

1943

McCulloch & Pitts model a basic NN using electric circuits

1957

Rosenblatt starts his work on the Perceptron

1962

Widrow & Hoff develop the Least Mean Squared learning rule

1979

Fukushima uses the very first convolutional NN

1982

Hopfield creates bi-directional networks

1983

Hinton & Sejnowski invent Boltzmann Machines, unsupervised NN

1985

Rumelhart, Hinton & Williams : backpropagation can be used in NNs & the introduction of RNNs

What are Artificial Neural Networks ?

A brief history

1997

Hochreiter & Schmidhuber develop the long short-term memory (LSTM)

1998

LeCun publishes : Stochastic gradient descent with backpropagation are very successful in deep learning

2000

Bengio's work kickstarts Natural Language Processing

2009

Fei-Fei Li creates the ImageNet database used in image recognition research

2011

Krizhevsky, Sutskever & Hinton use a CNN with ReLU and dropout regularization

2014

Goodfellow & Bengio publish the paper 'Generative Adversarial Nets', a revolution in computer vision

2017

Google's AI teams propose transformers based on attention mechanisms

What are Artificial Neural Networks ?

ACM A. M. Turing Award Laureates

Fathers of the Deep Learning Revolution :

Yoshua Bengio

Geoffrey Hinton

Yann LeCun

Source : https://awards.acm.org/about/2018-turing

What are Artificial Neural Networks ?

ACM A. M. Turing Award Laureates

Fathers of the Deep Learning Revolution :

Yoshua Bengio

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Yann LeCun

The A.M. Turing Award :

- *is ACM's most prestigious award.*
- *rewards major contributions of long-term interest to computing.*
- *was created in 1966*

* ACM = Association for Computing Machinery

Source : https://awards.acm.org/about/2018-turing

What are Artificial Neural Networks ?

Andrew Ng is **Founder & CEO of Landing AI, Founder of deeplearning.ai, Co-Chairman and Co-Founder of Coursera, and is currently an Adjunct Professor at Stanford University**. He was also Chief Scientist at Baidu Inc., and Founder & Lead for the Google Brain Project.

https://hai.stanford.edu › people › andrew-ng

Andrew Ng | Stanford HAI

The Artificial Neuron

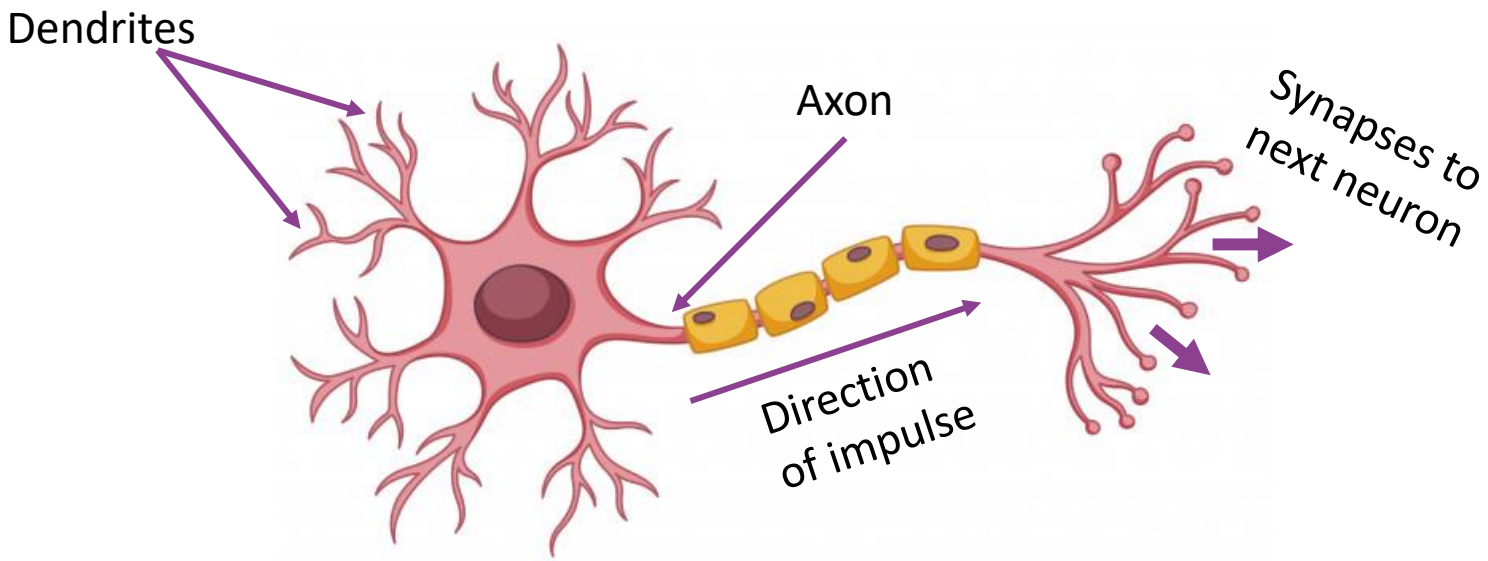
The Artificial Neuron

The purpose of neural networks :

imitation of the biological brain

Recreate the basic unit of our nervous system :

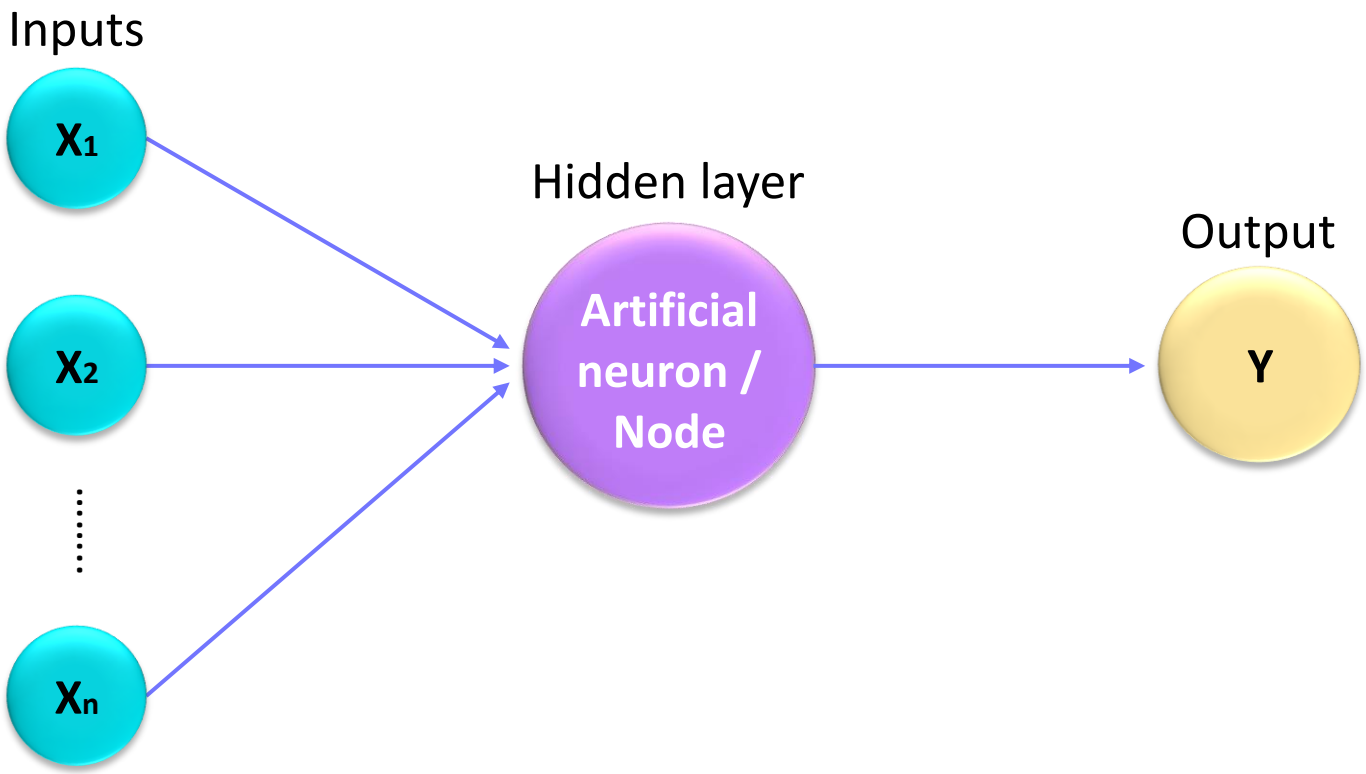
the **neuron**



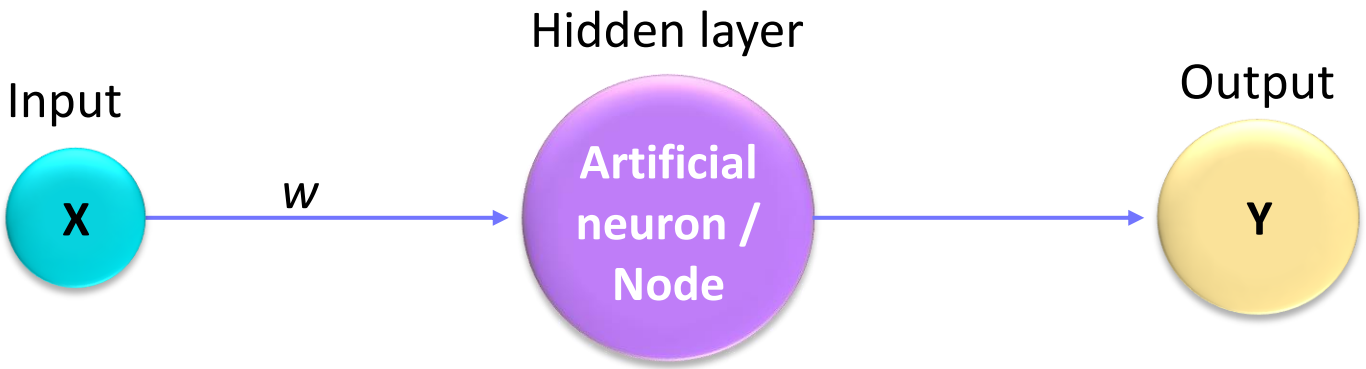
The Artificial Neuron

The artificial neuron :

- *The building block of neural networks*
- *Computational unit that takes inputs and yields outputs*



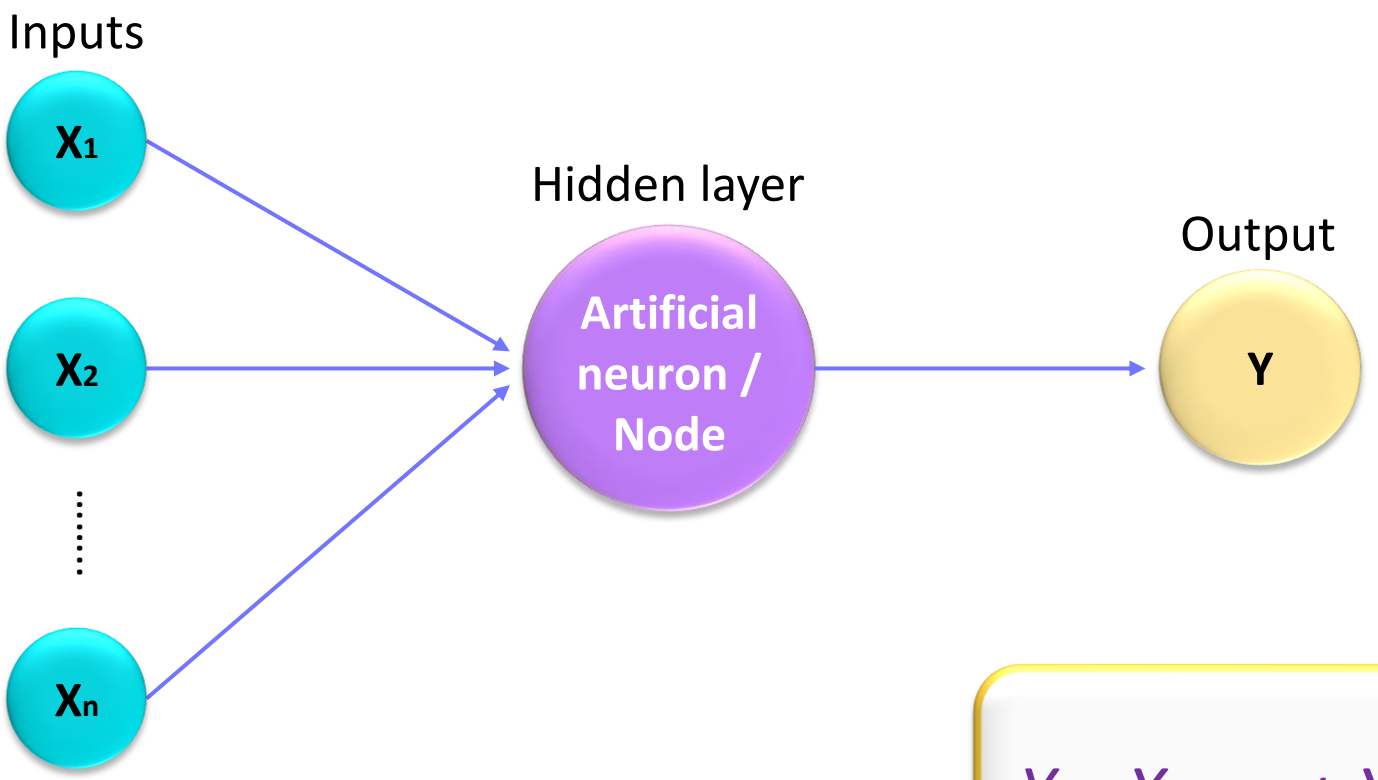
The Artificial Neuron



$$Y = Input \times weight$$

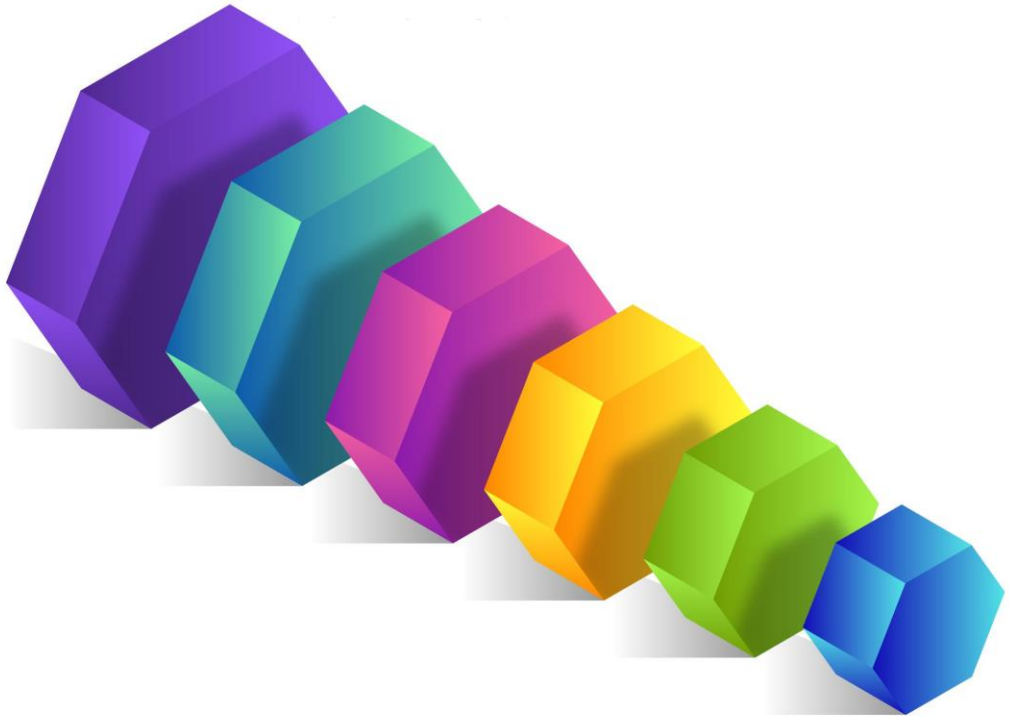
$$Y = X \times w$$

The Artificial Neuron



$$Y = X_1 w_1 + X_2 w_2 + \ldots + X_n w_n$$

ANN Layers

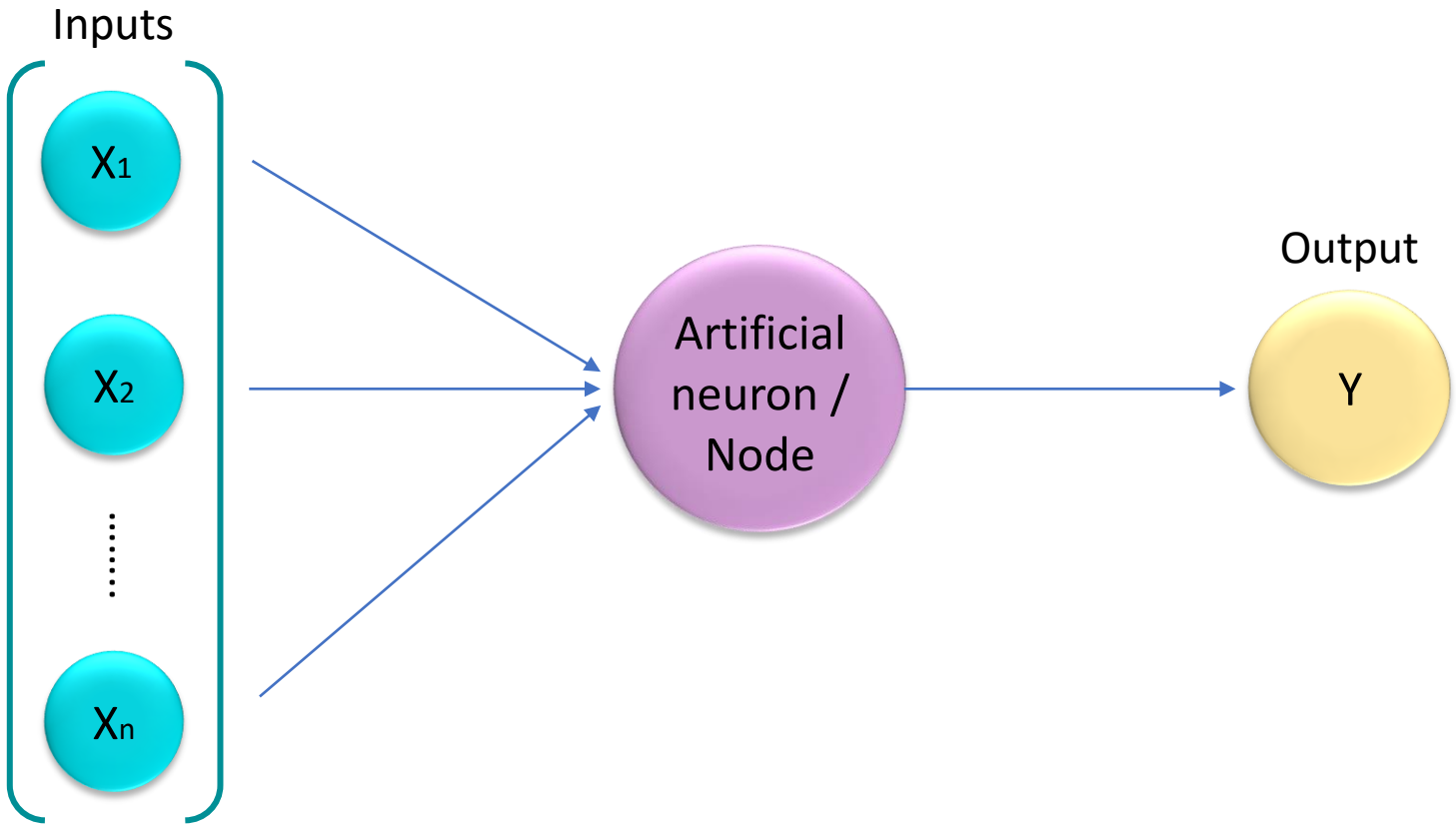


ANN Layers : Inputs

The inputs: Independent variables for a single observation

The input features (independent variables) can be :

- categorical
- numeric



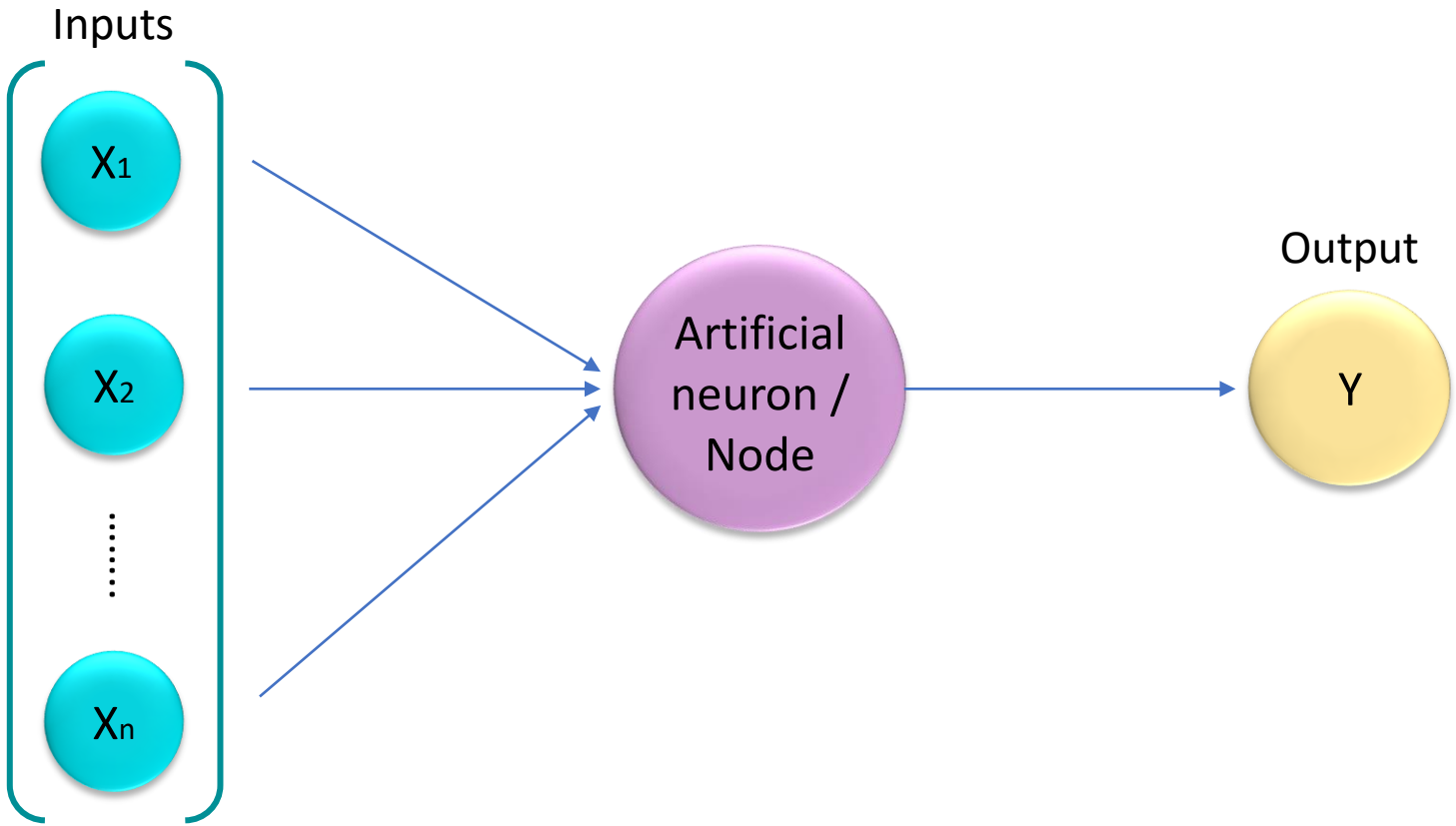
ANN Layers : Inputs

The inputs: Independent variables for a single observation

Categorical input features :

Inputs are labels (categories)

→ cats & dogs



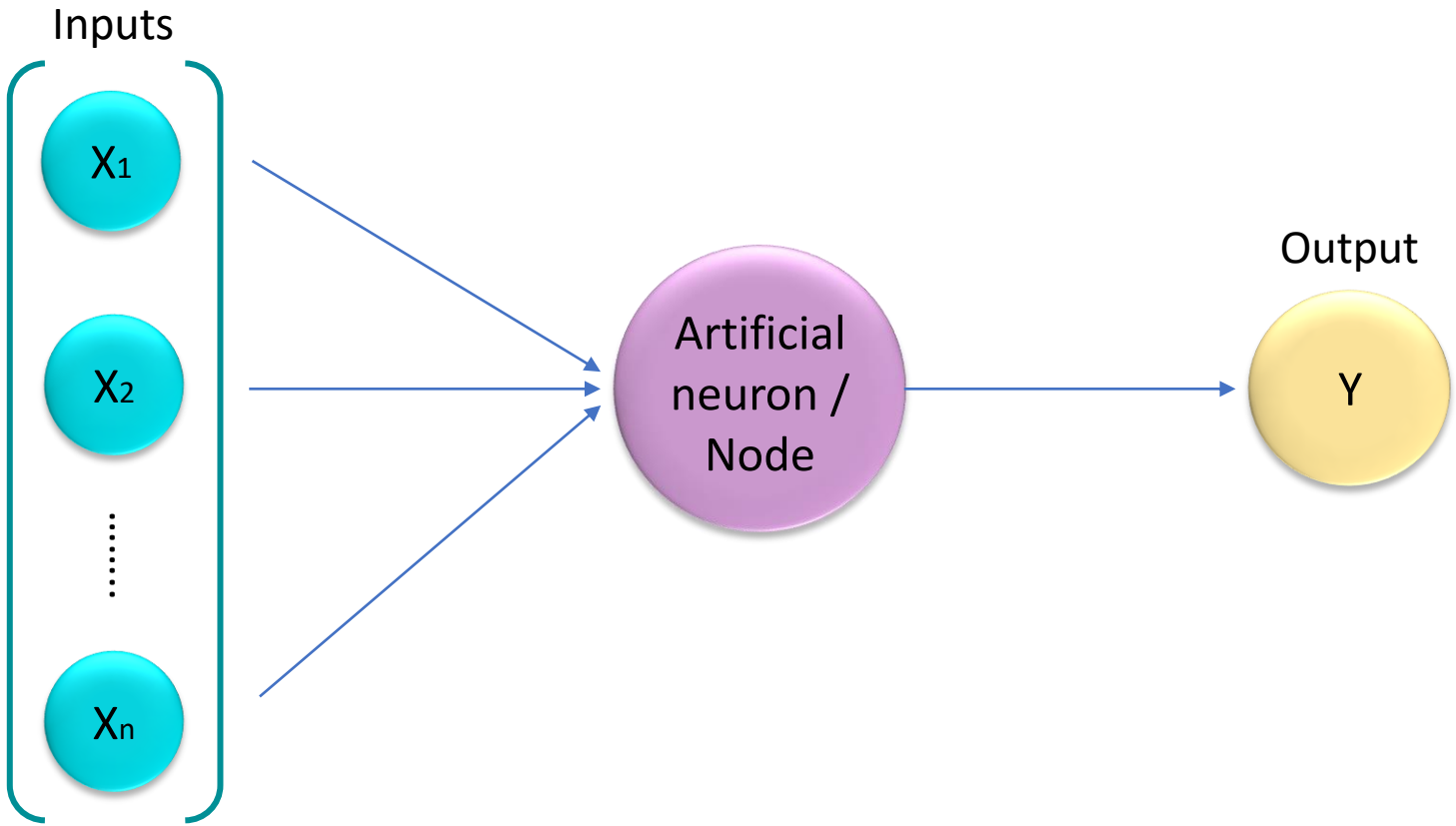
ANN Layers : Inputs

The inputs: Independent variables for a single observation

Numeric input features :

Inputs contain numerical values

→ area, weight, distance, etc.



ANN Layers : Inputs

The inputs: Independent variables for a single observation

Example :

If our *observation* is a *car* :

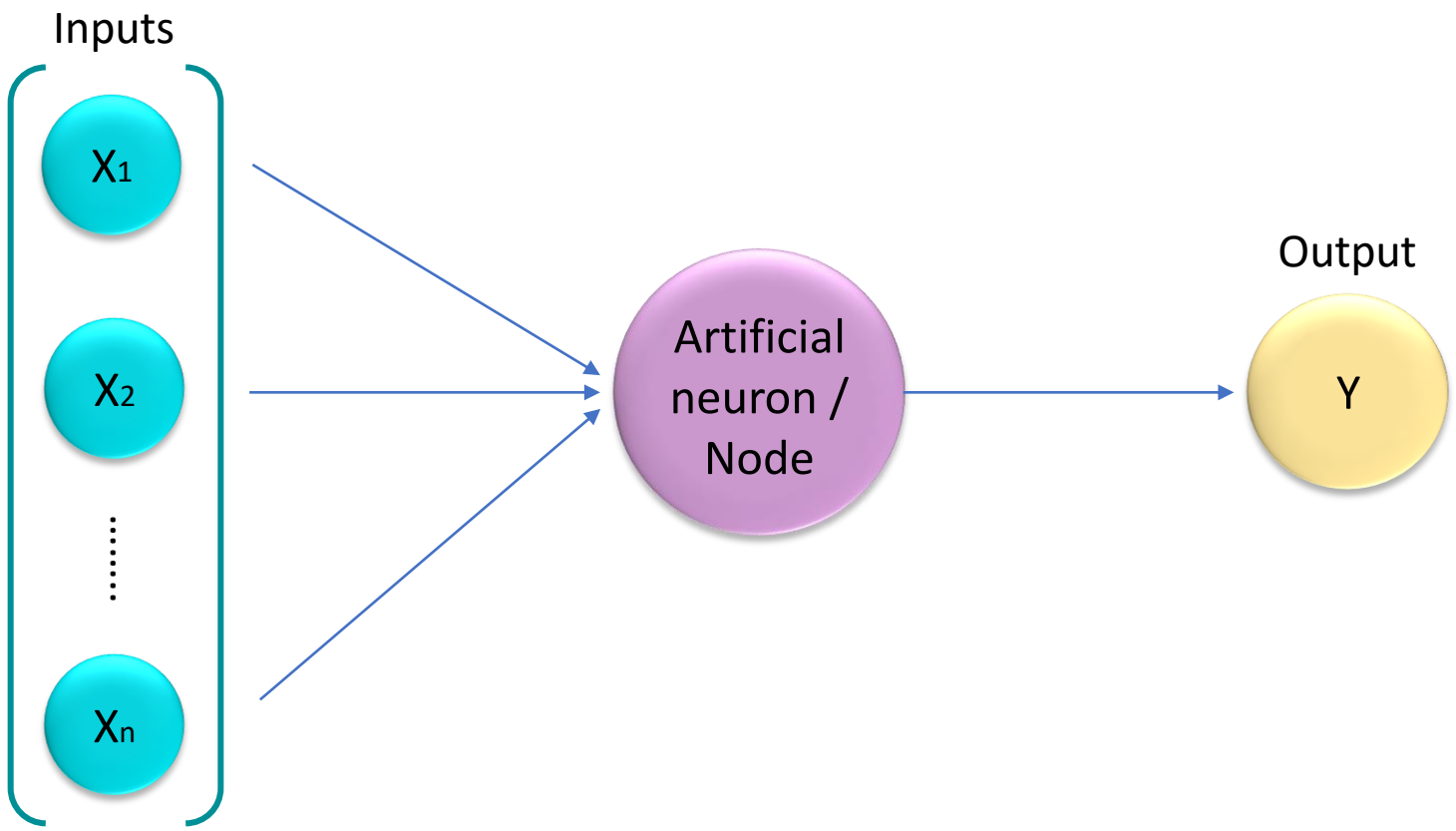
X1 : brand

X2 : manufacturing year

X3 : color

X4 : automatic/mechanical

⋮

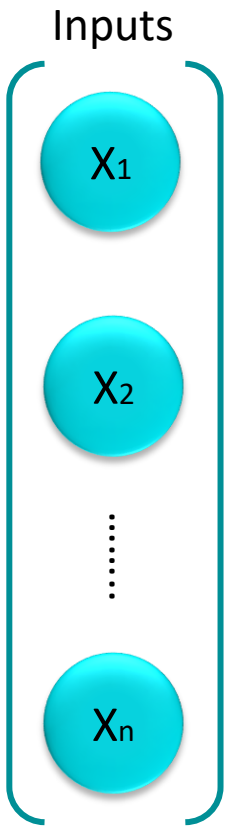


ANN Layers : Inputs

The inputs:

Data preparation :

To avoid false influence of the different input values and intervals on the trained model



1

Standardization :

1. Subtract the mean
2. Divide by the standard deviation

$Xi - mean \ / \ standard\_dev$

$==> Mean = 0 \ \& \ Variance = 1$

2

Normalization :

1. Subtract minimum value
2. Divide by the data range

$X_i - X_{min} \ / \ (X_{max} - X_{min})$

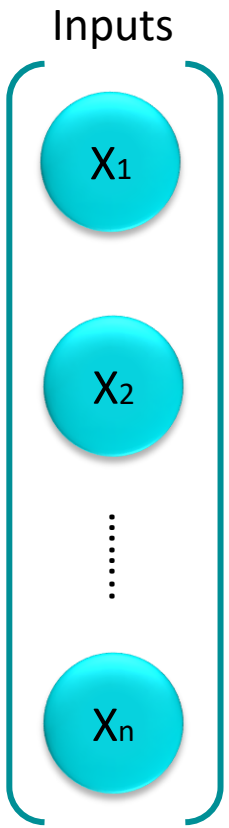
$==> 0 \leq X_{i\_new} \leq 1$

ANN Layers : Inputs

The inputs:

Data preparation :

To avoid false influence of the different input values and intervals on the trained model



1

Standardization :

Z-Score normalization

Mean = 0

Variance = 1

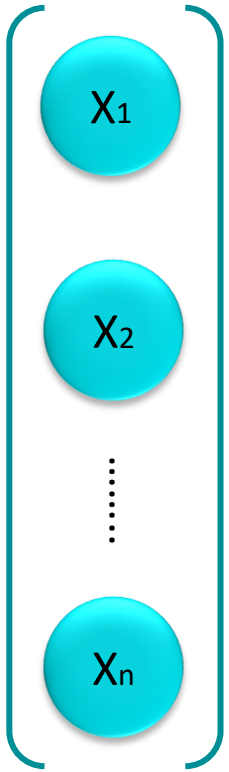
More robust to outliers (preserves them

Can be applied when the indepent variables follow normal (Gaussian) distributions with different means and standard deviations

ANN Layers : Inputs

The inputs:

Inputs



Data preparation :

To avoid false influence of the different input values and intervals on the trained model

2

Normalization :

Min-Max Scaling

1. Subtract minimum value
2. Divide by the data range

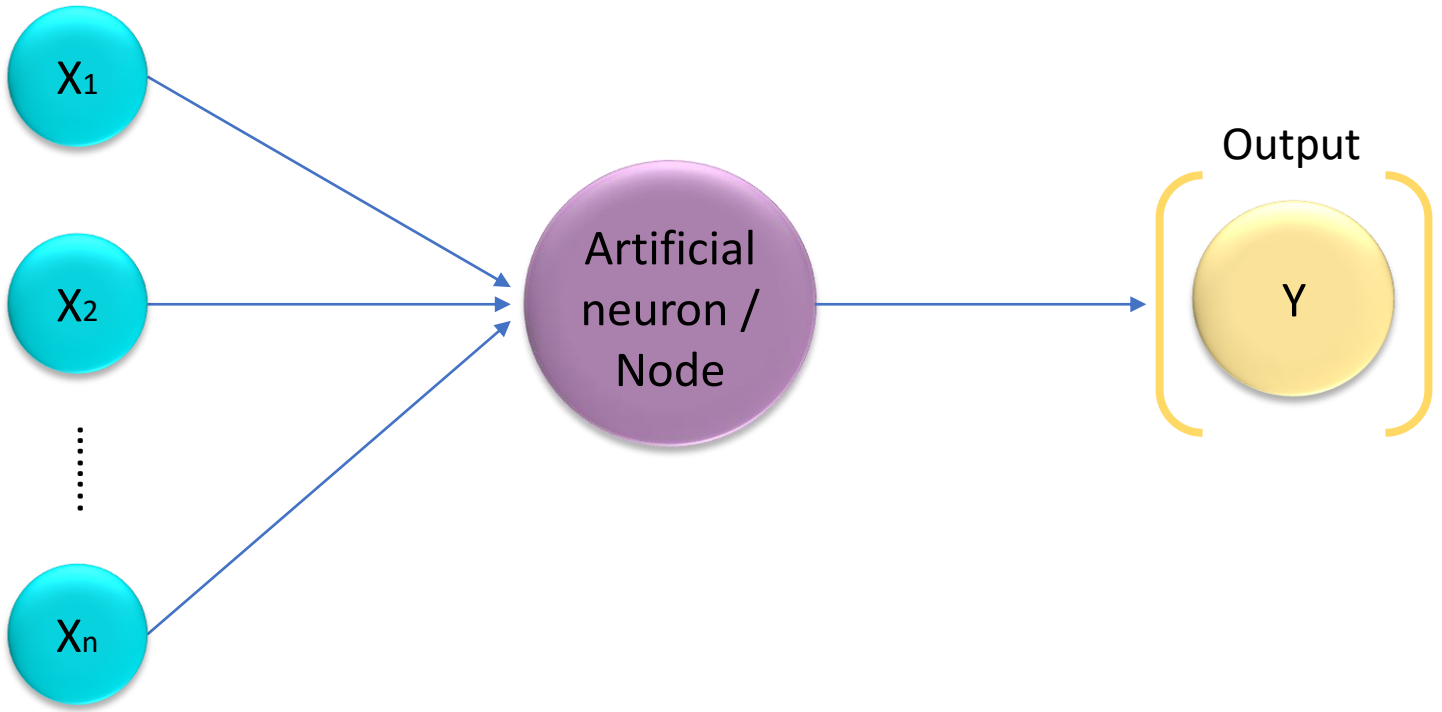
$$X_i - X_{min} \,/\, (X_{max} - X_{min})$$

$$==> 0 \leq X_{i\_new} \leq 1$$

Can be applied when the indepent variables vary in different scales and intervals

ANN Layers : Outputs

The output:



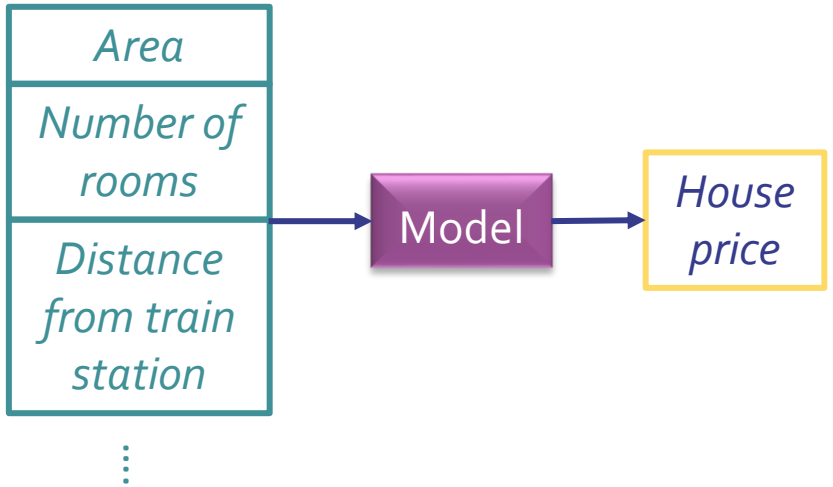
1. Continuous
2. Binary
3. Categorical

ANN Layers : Outputs

The output:

Continuous

Value prediction

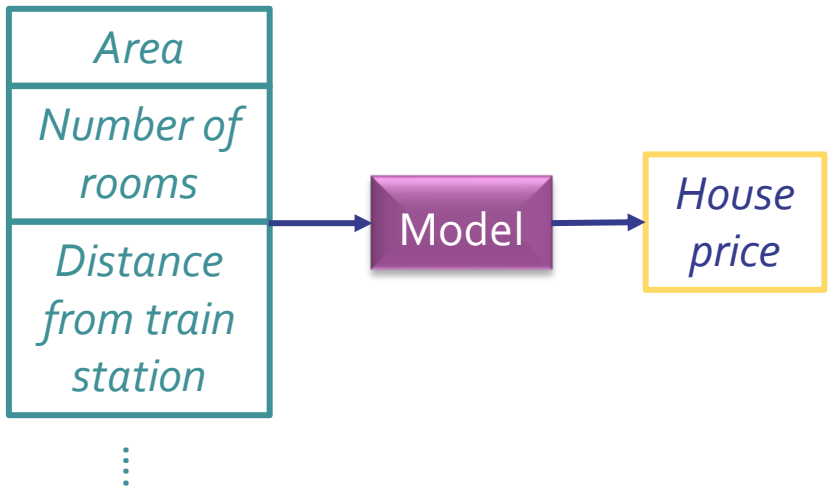


ANN Layers : Outputs

The output:

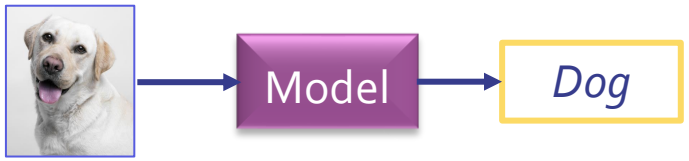
Continuous

Value prediction



Binary

Classification among 2 classes



(out of 2 possible classes (Dog & Cat)

ANN Layers : Outputs

The output:

Continuous

Value prediction

Area

Number of rooms

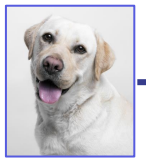
Distance from train station

⋮

Model → *House price*

Binary

Classification among 2 classes



Model → *Dog*

(out of 2 possible classes (Dog & Cat)

Categorical

Classification among several classes

Model → *Dog*

(out of more than 2 possible classes (Dog, Cat, Turtle, Elephant, Lion, etc.))

ANN Layers : Inputs & Outputs

Categorical Data Encoding : Most Machine Learning models do not accept text labels for inputs and outputs

➔ We have to encode those categorical labels to numerical values.

1. Ordinal Encoding : Every label is represented by an ordered number

Example : If we are classifying countries :

Country (Label)	Ordinal encoding
India	1
Japan	2
Madagascar	3
USA	4

ANN Layers : Inputs & Outputs

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1. Ordinal Encoding : Every label is represented by an ordered number

Example : If we are classifying countries :

Country (Label)	Ordinal encoding
India	1
Japan	2
Madagascar	3
USA	4

The system will probably establish false relations between these countries

➔ Example : It can consider India superior to Japan while there is no hierarchical relation between the countries !

ANN Layers : Inputs & Outputs

Categorical Data Encoding : Most Machine Learning models do not accept text labels for inputs and outputs

➔ We have to encode those categorical labels to numerical values.

2. One-Hot Encoding : Creates new binary variables based on the number of labels

→ N labels are represented by N bits, while only one bit = 1

Example : If we are classifying countries :

Country (Label)	One-Hot encoding
India	1 0 0
Japan	0 1 0
Madagascar	0 0 1

ANN Layers : Inputs & Outputs

Categorical Data Encoding : Most Machine Learning models do not accept text labels for inputs and outputs

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Example : If we are classifying countries :

Country (Label)	One-Hot encoding
India	1 0 0
Japan	0 1 0
Madagascar	0 0 1

If we have a large number of categories, the variable can grow to demand a considerable amount of memory storage

ANN Layers : Inputs & Outputs

Categorical Data Encoding :

So, which encoding should we use ?

Ordinal Encoding :

- When the labels are ordered (primary school, secondary school, university)
- The number of categories is very large

One-Hot Encoding :

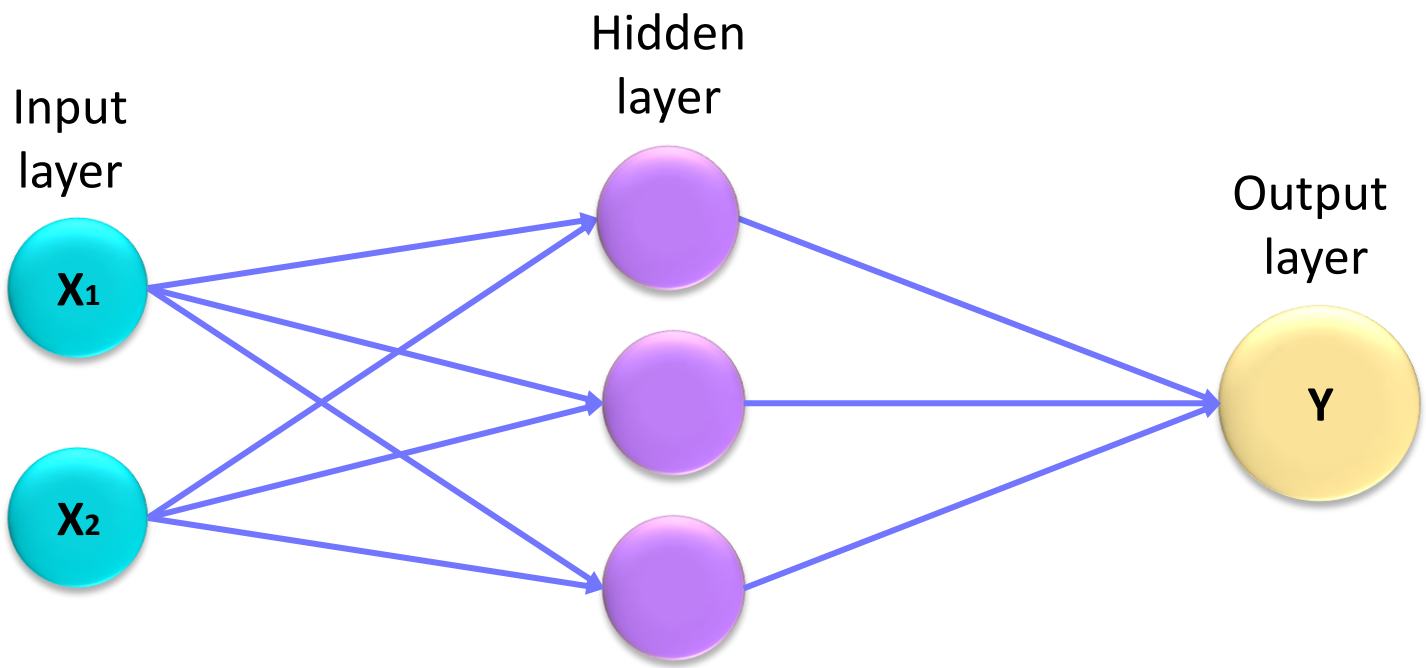
- When the labels are not ordered (countries, animals)
- The number of categories is not too large to cause memory problems

ANN Layers : Hidden Layers

The hidden layer is situated between inputs and outputs of a neural network

The hidden nodes have no direct connection with the output world

A collection of hidden nodes forms a « *hidden layer* ».



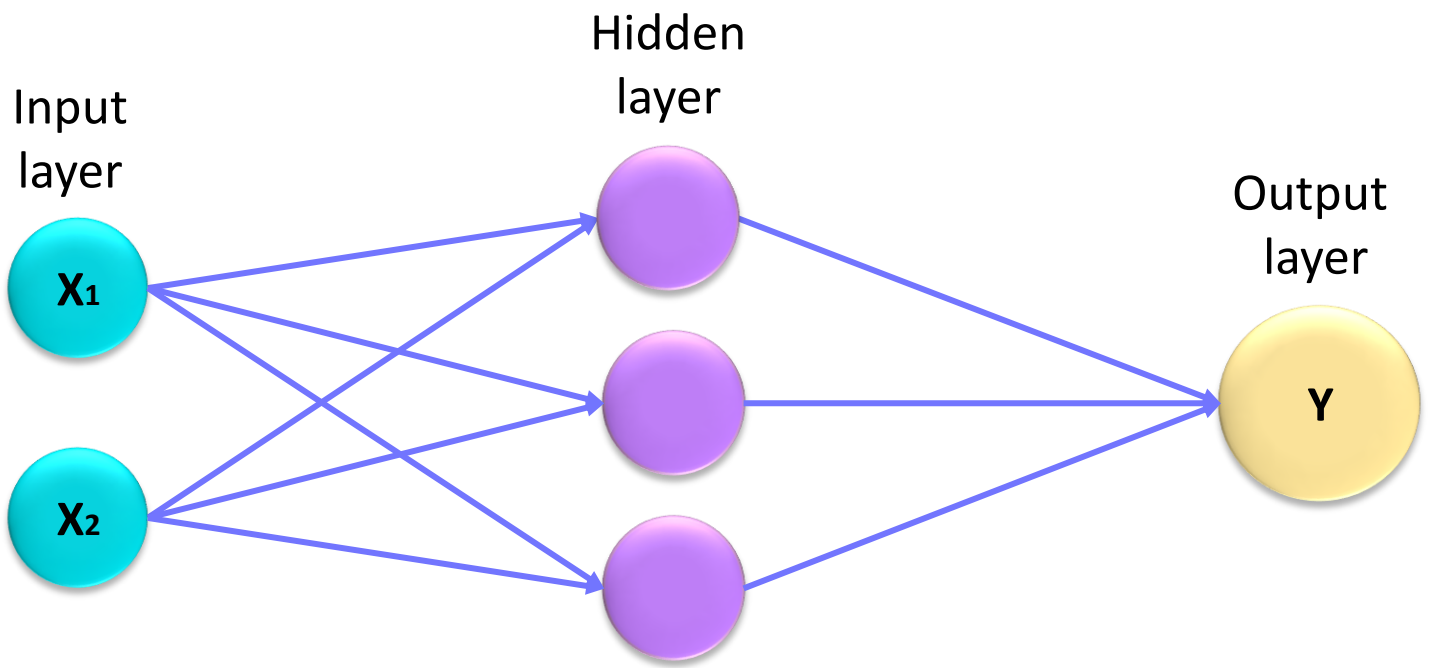
ANN Layers : Hidden Layers

The hidden layer is situated between inputs and outputs of a neural network

The output of one neuron is the input of another

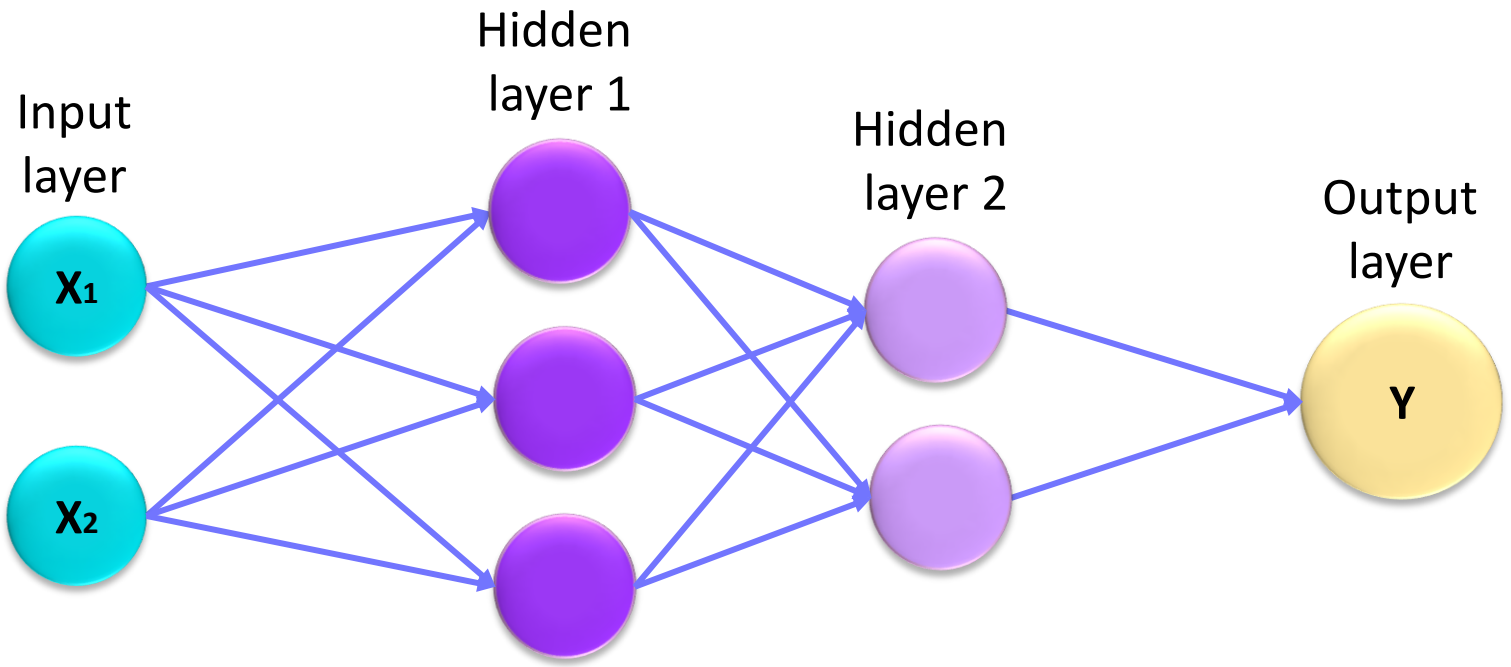
The hidden nodes have no direct connection with the output world

A collection of hidden nodes forms a « *hidden layer* ».



ANN Layers : Hidden Layers

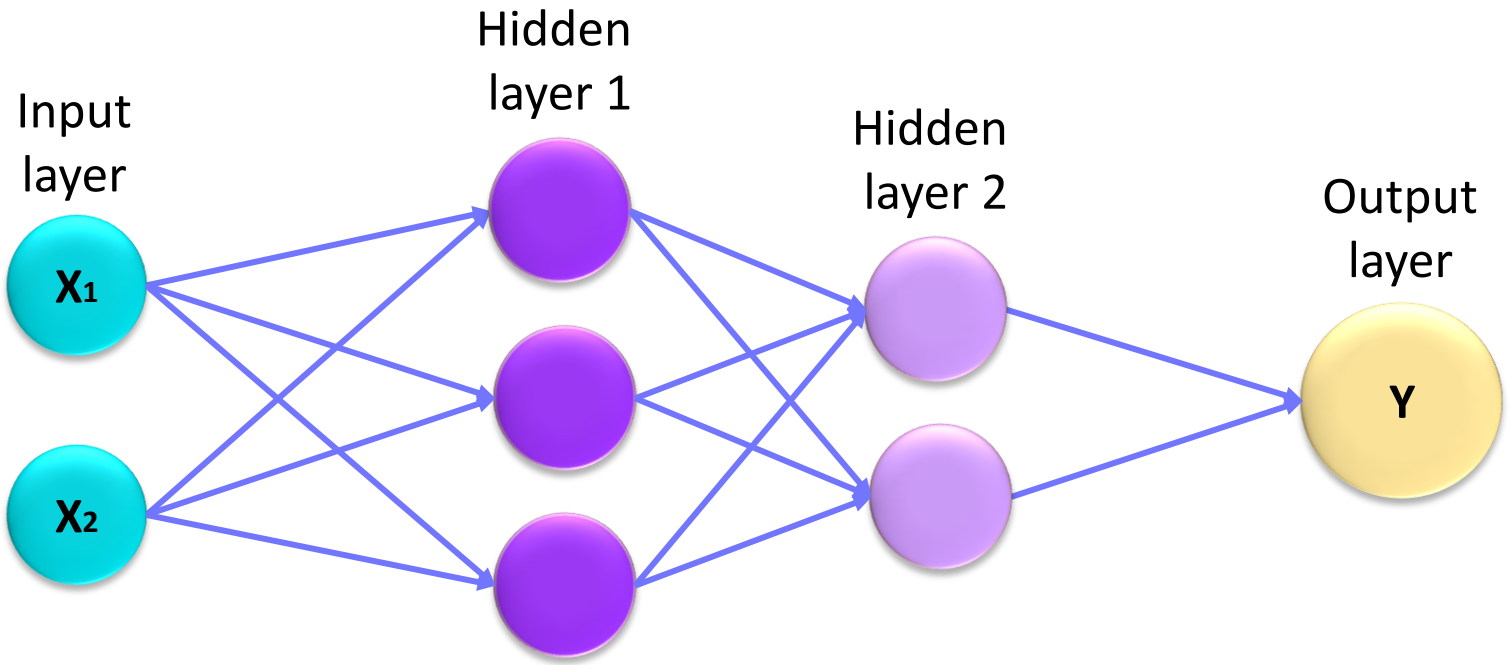
There usually are multiple hidden layers in a neural network



ANNs can have zero or multiple hidden layers

ANN Layers : Hidden Layers

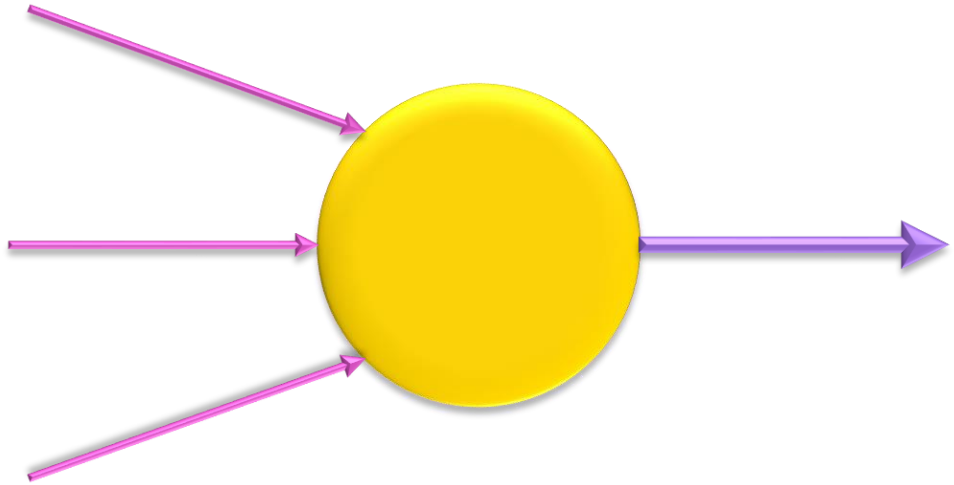
There usually are multiple hidden layers in a neural network



Traditional neural networks typically have fully-connected hidden layers

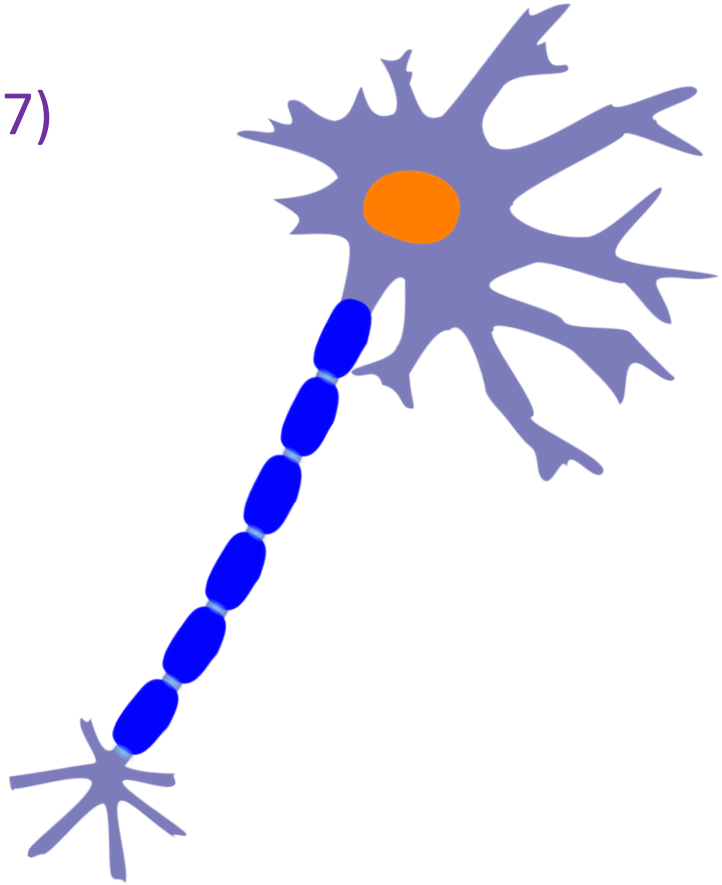
Fully-connected layer : every neuron is connected to all the neurons in the previous and the next layers

The Perceptron



The Perceptron

- The Perceptron model is proposed by Frank Rosenblatt (1957)



Single Layer Perceptron

Multi Layer Perceptron

- Modeled after the essential unit of the human brain – the neuron

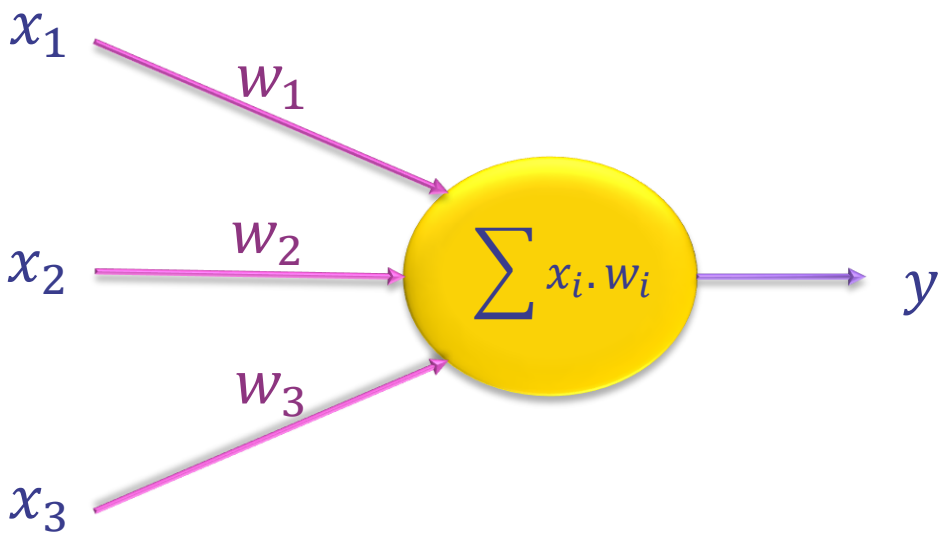
The Perceptron

1 Single Layer Perceptron

- SLP is the simplest type of ANN
- contains **no hidden layers**
- can only classify linearly separable classes (a straight line to separate classes)
- can only perform binary classification (2 classes)

The Perceptron

1 Single Layer Perceptron

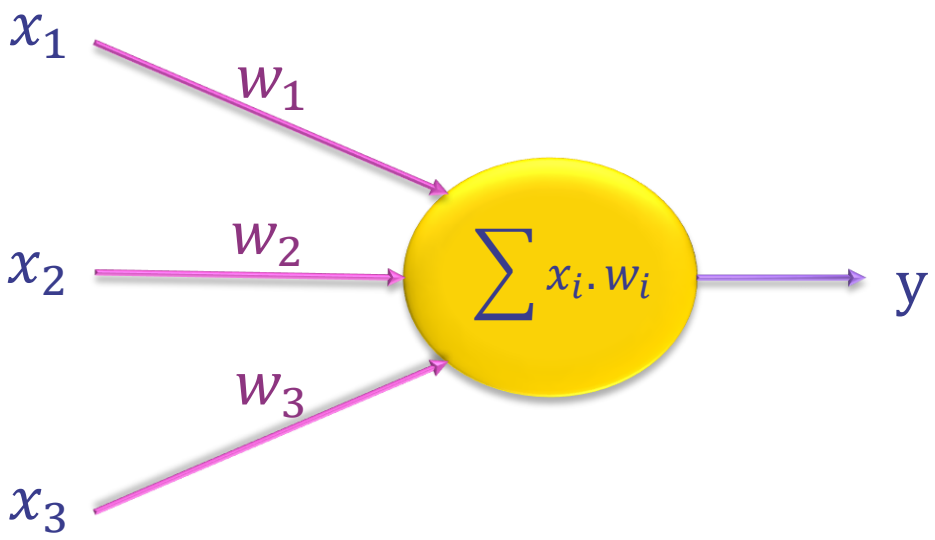


$$y = \begin{cases} 1 \; if \sum x_i . w_i \; > \; \theta \; (predetermined) \\ 0 \quad otherwise \end{cases}$$

The Perceptron

1

Single Layer Perceptron



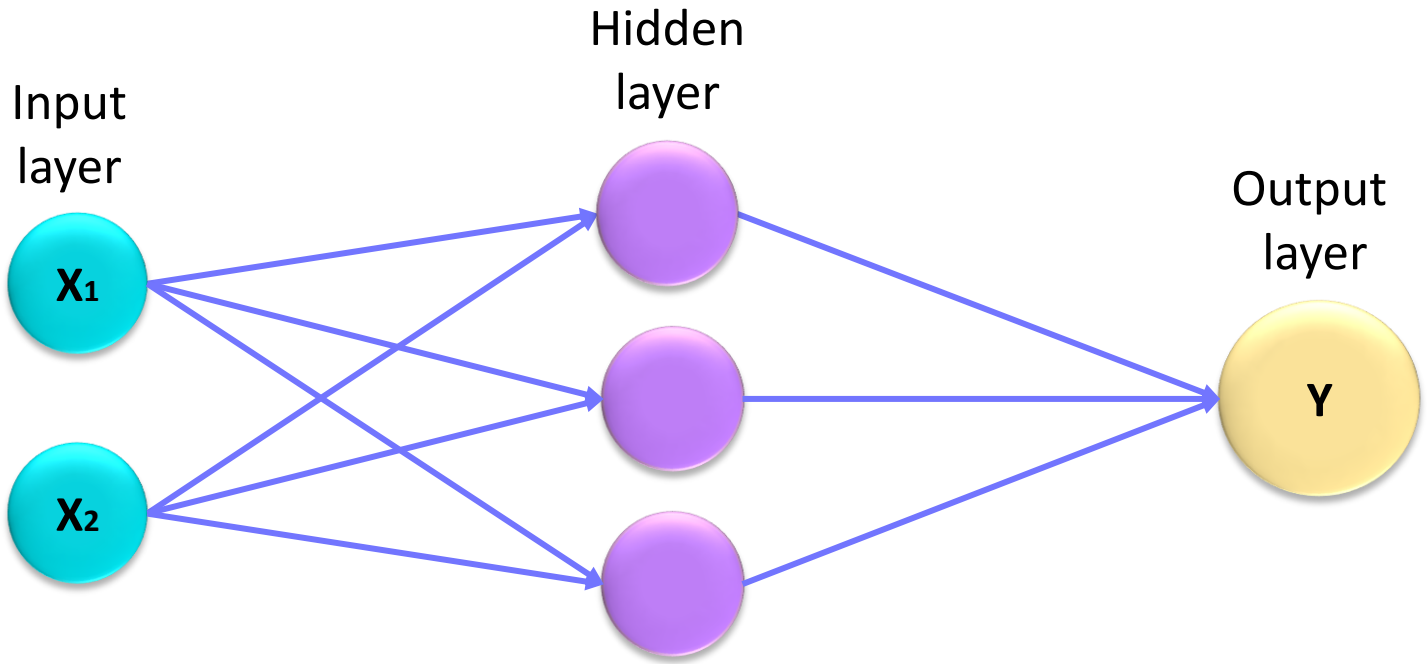
$$y = \begin{cases} 1 \; if \sum x_i . w_i \; > \; \theta \; (predetermined) \\ 0 \quad otherwise \end{cases}$$

- Has no hidden layers
- Each input has a corresponding weight to designate how important it is
- The output *y* provides a decision (one of two classes)

The Perceptron

2

Multi Layer Perceptron

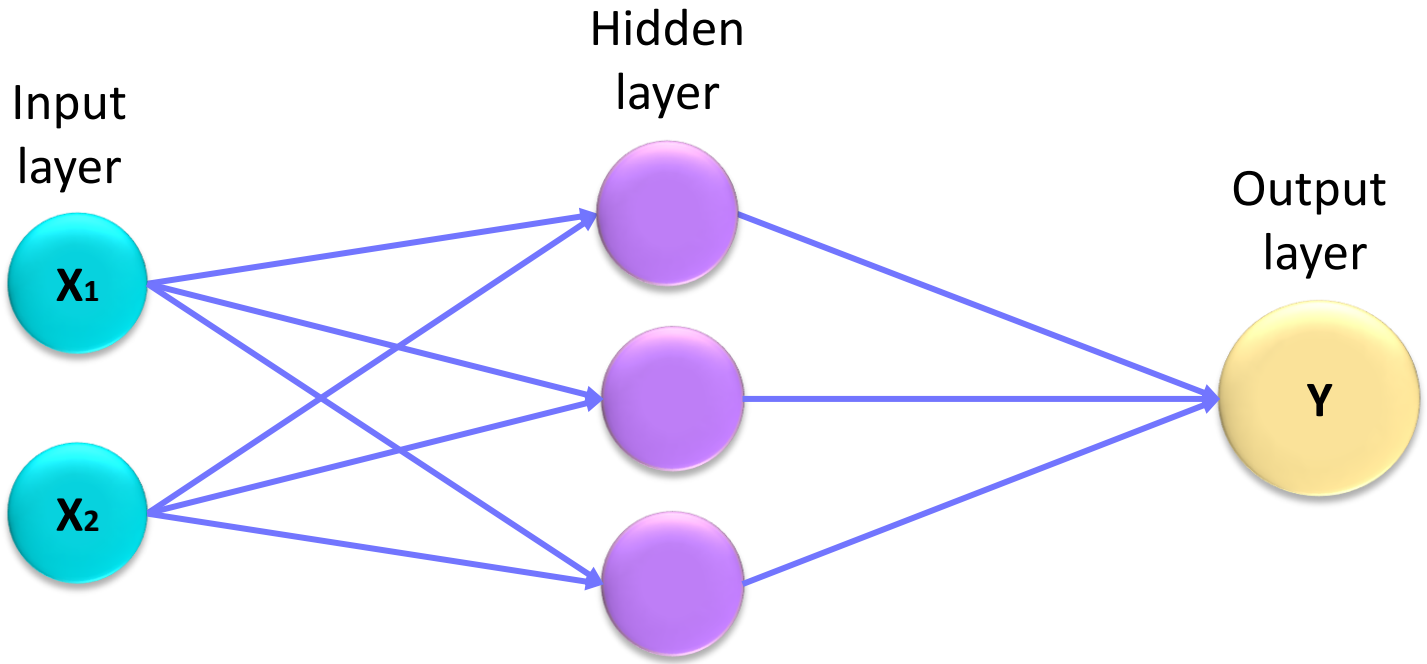


- Has **one or more** hidden layers
- Perceptrons team up with each other to solve complex problems
- Each layer can have multiple perceptrons, and there can be multiple layers

The Perceptron

2

Multi Layer Perceptron

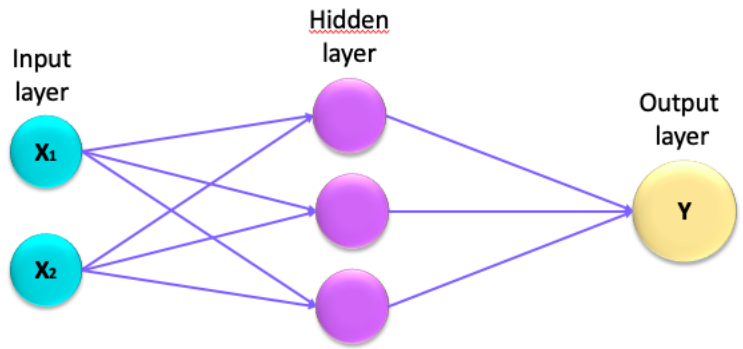


MLP is a class of feedforward ANNs

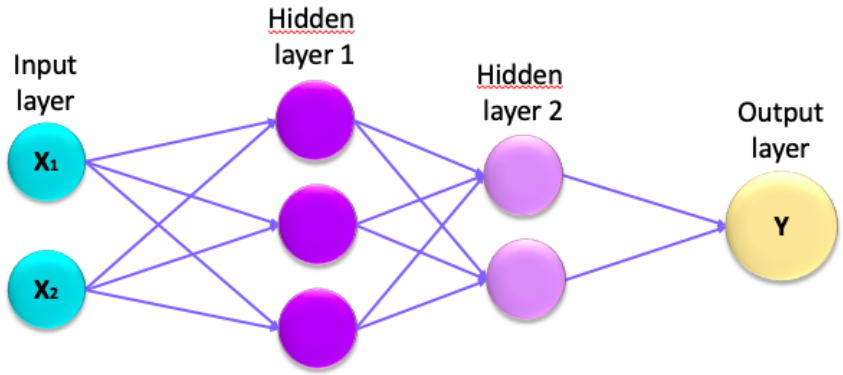
- Has one or more hidden layers
- Perceptrons team up with each other to solve complex problems (even non-linearly seperated ones)
- Each layer can have multiple perceptrons, and there can be multiple layers

The Perceptron

2 Multi Layer Perceptron



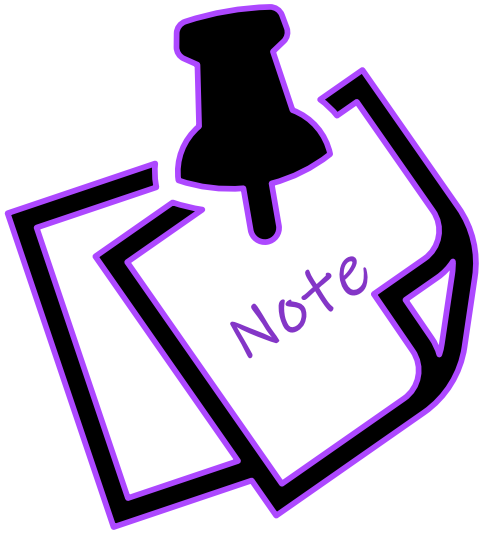
An ANN with one hidden layer is called a **shallow** or **non-deep neural network**



An ANN with more than one hidden layer is called **deep neural network**

The Perceptron

2 Multi Layer Perceptron



Difference between MLP and Neural Network :

MLP :

- Uses a step function for decision
- The decision is binary

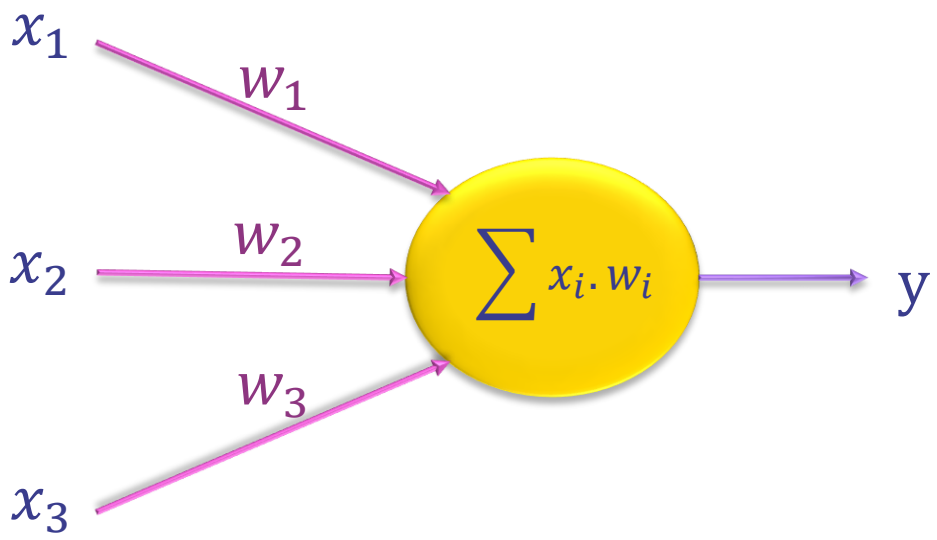
Neural Networks :

- Evolved from MLP
- Other activation functions can be used
- Outputs are real values, probability-based or classes

Weights & Biases

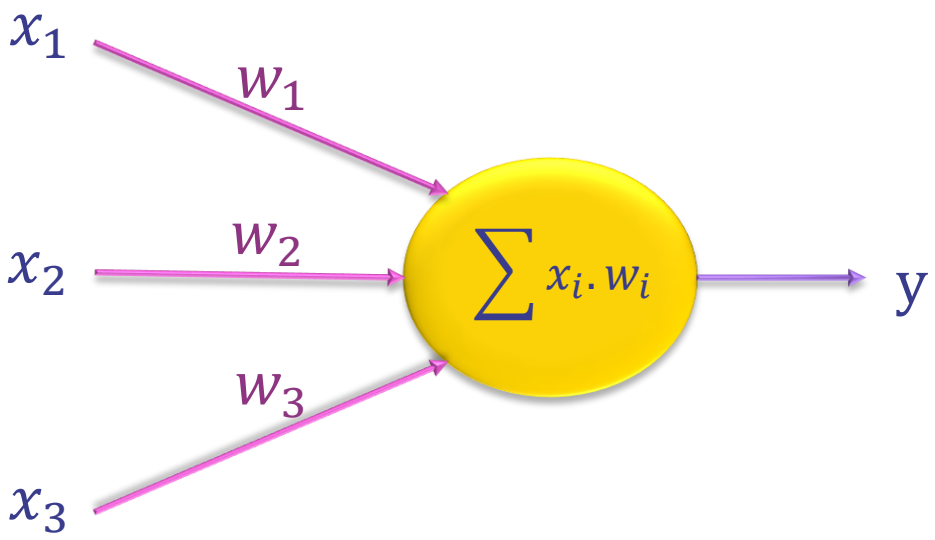
Weights and Biases

1 Weights



Weights and Biases

1 Weights

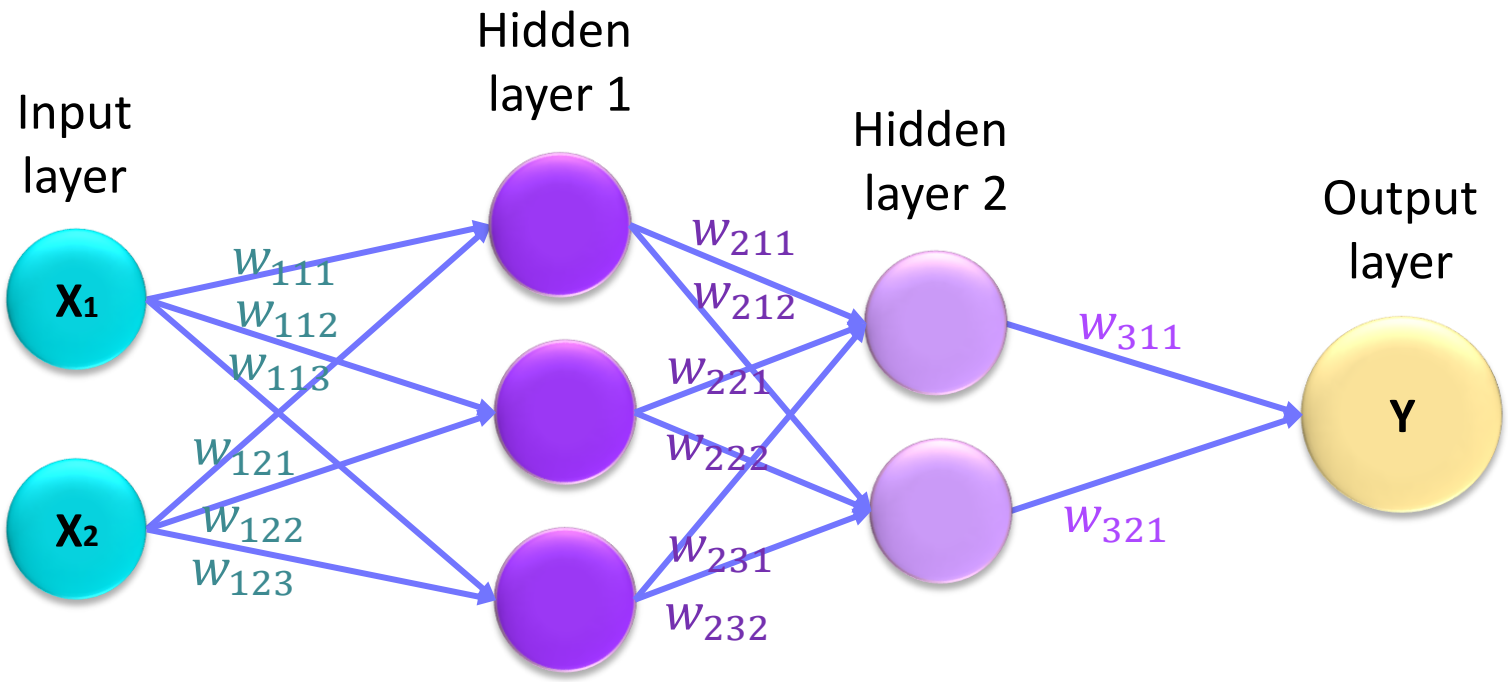


Weights determine the relative importance of every feature in the classification decision.

$$y = \sum x_i . w_i$$

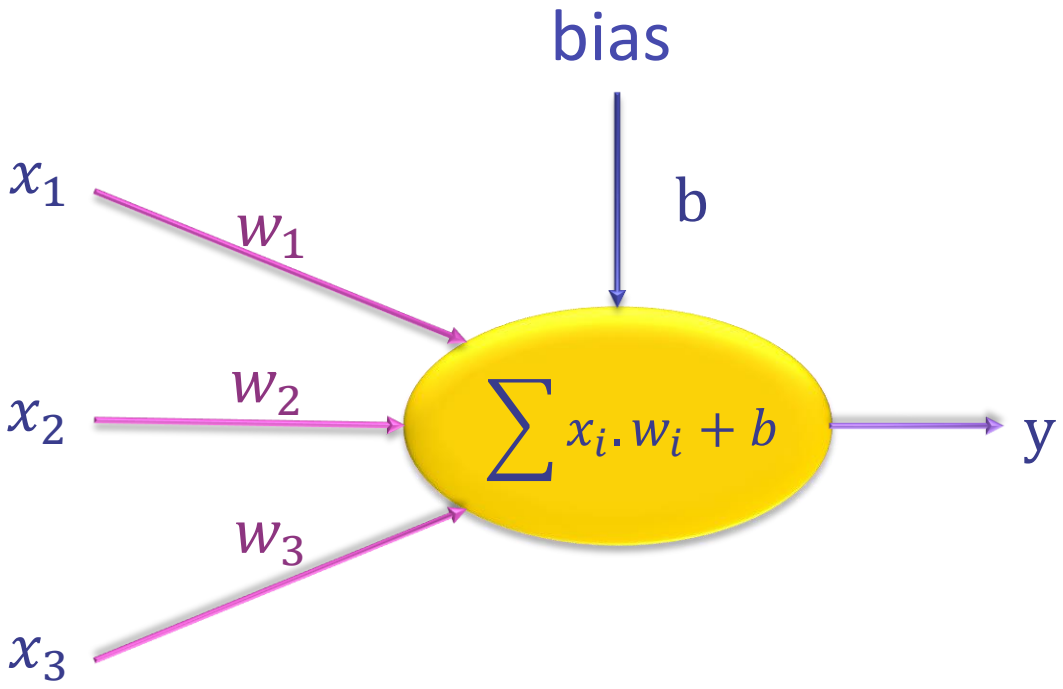
Weights and Biases

1 Weights



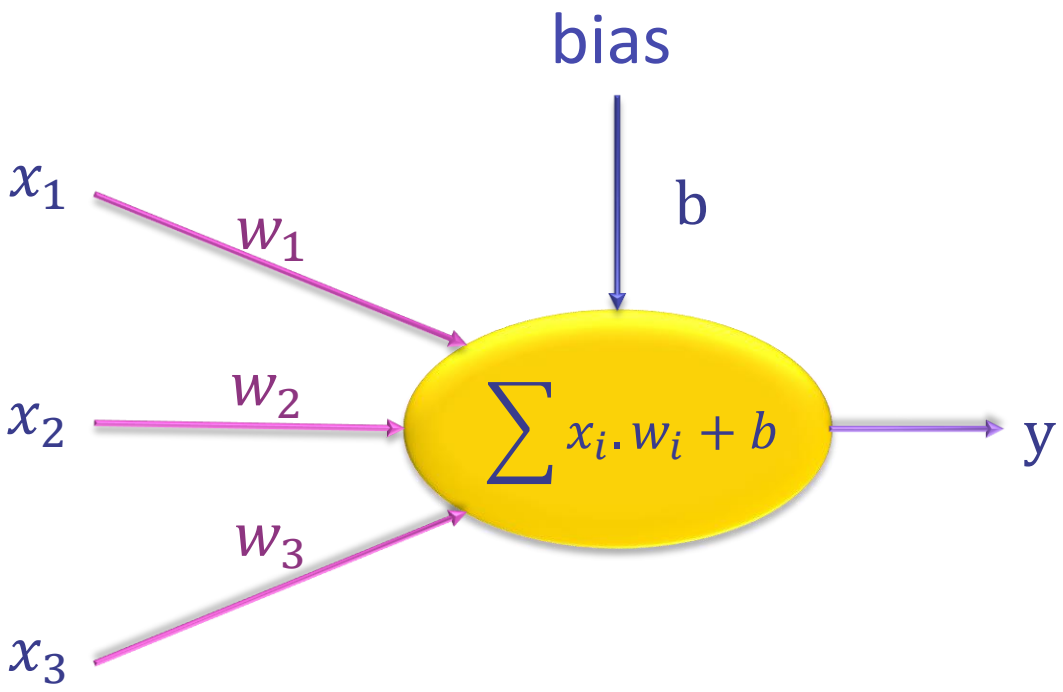
Weights and Biases

2 Biases



Weights and Biases

2 Biases



A bias b :

- is a constant that helps the model fit the given data best.
- behaves as the intercept of a linear equation.

$$y = \sum x_i . w_i + b$$

Weights and Biases

2 Biases

$$y = \sum x_i . w_i + b$$