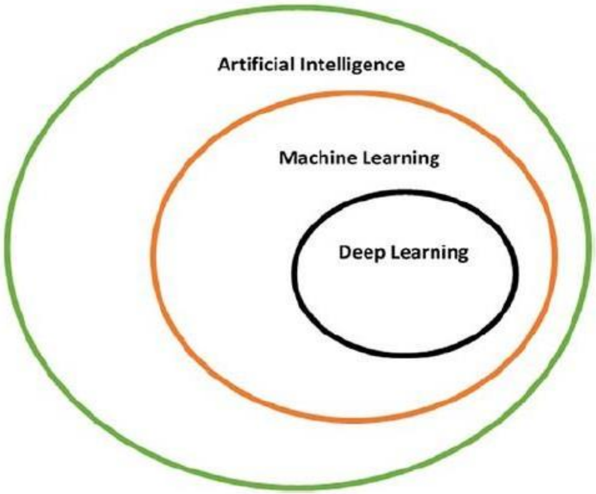
Deep Learning

What is Deep Learning (DL)?

- An extended field of ML that draws its roots from NN – proven to be highly useful in text, image & speech processing
- Collection of algorithms implemented have similarities with neurons in human brain
- Deep Learning is a subfield of ML, which is a subfield of AI
- Majority of DL algorithms are based on the concept of ANN
  - *Deep* refers to the depth (i.e., hidden layers)
  - *Learning* refers to learning through ANN
- Can be supervised, semi-supervised & unsupervised



What is Deep Learning (DL)?

- Deep learning is a branch of machine learning which is based on artificial neural networks. It is capable of learning complex patterns and relationships within data.
- In deep learning, we don’t need to explicitly program everything.
- It has become increasingly popular in recent years due to the advances in processing power and the availability of large datasets. Because it is based on artificial neural networks (ANNs) also known as deep neural networks (DNNs).
- These neural networks are inspired by the structure and function of the human brain’s biological neurons, and they are designed to learn from large amounts of data.

- Deep learning is the branch of machine learning which is based on artificial neural network architecture. An artificial neural network or ANN uses layers of interconnected nodes called neurons that work together to process and learn from the input data.
- In a fully connected Deep neural network, there is an input layer and one or more hidden layers connected one after the other. Each neuron receives input from the previous layer neurons or the input layer.
- The output of one neuron becomes the input to other neurons in the next layer of the network, and this process continues until the final layer produces the output of the network. The layers of the neural network transform the input data through a series of nonlinear transformations, allowing the network to learn complex representations of the input data.

Why Deep Learning?

- ML algorithms are shallow models, i.e., designed to use linear classifiers on a given feature set
- Finding the optimal output representation with a shallow model is not always possible
- Deep learning algorithms have enhanced the ability to classify, recognize, characterize & detect
- Able to learn by computing non-linear input-output mappings
- Provides a multi-layer approach to learn data representations
- Can handle large amounts of data & achieve high accuracy
- ***Example:*** *For image classification, linear classifiers are not good at detecting variations in position, orientation, or light*

Machine Learning	Deep Learning
Apply statistical algorithms to learn the hidden patterns and relationships in the dataset.	Uses artificial neural network architecture to learn the hidden patterns and relationships in the dataset.
Can work on the smaller amount of dataset	Requires the larger volume of dataset compared to machine learning
Better for the low-label task.	Better for complex task like image processing, natural language processing, etc.
Takes less time to train the model.	Takes more time to train the model.
Less complex and easy to interpret the result.	More complex, it works like the black box interpretations of the result are not easy.
It can work on the CPU or requires less computing power as compared to deep learning.	It requires a high-performance computer with GPU.
A model is created by relevant features which are manually extracted from images to detect an object in the image.	Relevant features are automatically extracted from images. It is an end-to-end learning process.

DL vs. Traditional Methods

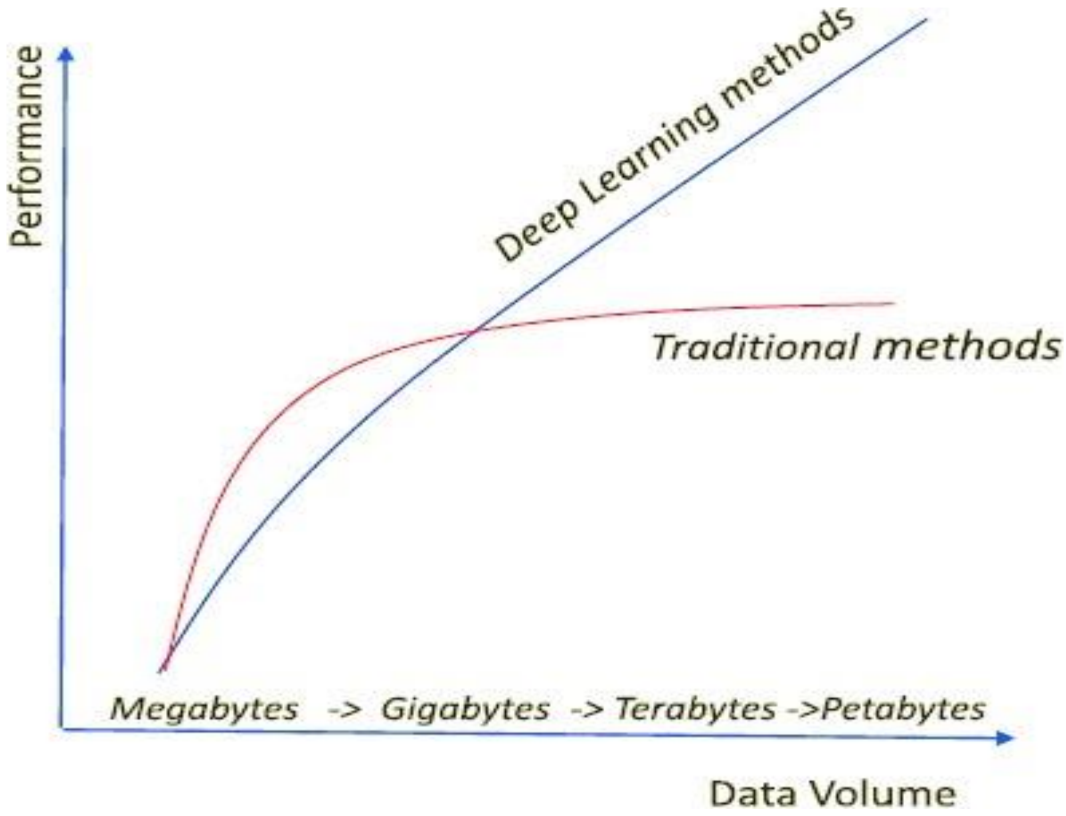
Advantages

- Outperforms ML models in several domains, e.g., computer vision
- More complex features can be learned with increase in hidden layers
- Works well with unstructured data

Disadvantages

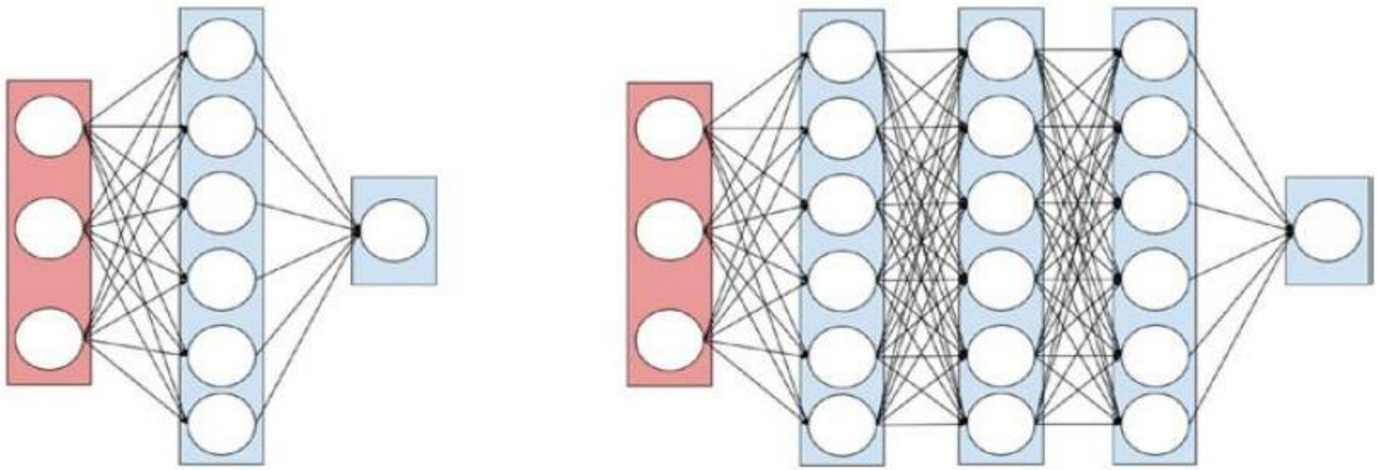
- Requires more data than traditional ML
- A black box – complex features produced may be difficult to understand
- Takes a lot of time to develop a Neural Network
- Can be computationally expensive – requires a lot of processing power

DL vs. Traditional Methods



Deep vs. Shallow Network

- *How many layers does a network need in order to qualify as deep?*
- **Shallow Networks** has 1 single layer
- **Deep Neural Network:** 2 or more hidden layers



Applications of Deep Learning

The main applications of deep learning can be divided into computer vision, natural language processing (NLP), and reinforcement learning.
In computer vision, Deep learning models can enable machines to identify and understand visual data. Some of the main applications of deep learning in computer vision include:

- **Object detection and recognition:** Deep learning model can be used to identify and locate objects within images and videos, making it possible for machines to perform tasks such as self-driving cars, surveillance, and robotics.
- **Image classification**: Deep learning models can be used to classify images into categories such as animals, plants, and buildings. This is used in applications such as medical imaging, quality control, and image retrieval.
- **Image segmentation:** Deep learning models can be used for image segmentation into different regions, making it possible to identify specific features within images.

Applications of Deep Learning

In NLP, the Deep learning model can enable machines to understand and generate human language. Some of the main applications of deep learning in NLP include:

- Automatic Text Generation – Deep learning model can learn the corpus of text and new text like summaries, essays can be automatically generated using these trained models.
- **Language translation**: Deep learning models can translate text from one language to another, making it possible to communicate with people from different linguistic backgrounds.
- **Sentiment analysis**: Deep learning models can analyze the sentiment of a piece of text, making it possible to determine whether the text is positive, negative, or neutral. This is used in applications such as customer service, social media monitoring, and political analysis.
- **Speech recognition**: Deep learning models can recognize and transcribe spoken words, making it possible to perform tasks such as speech-to-text conversion, voice search, and voice-controlled devices.

Applications of Deep Learning

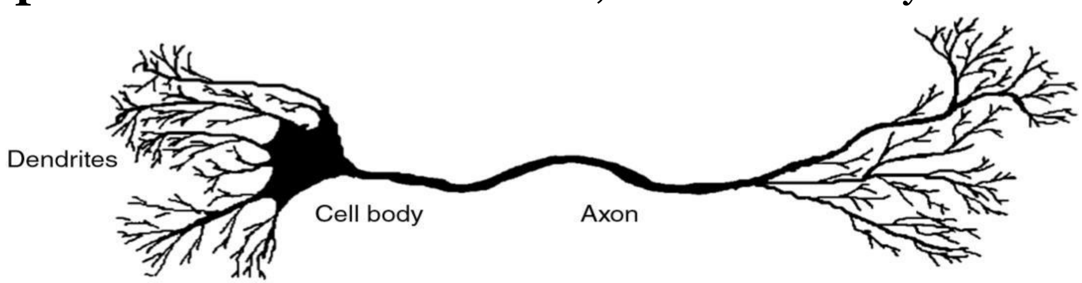
In reinforcement learning, deep learning works as training agents to take action in an environment to maximize a reward. Some of the main applications of deep learning in reinforcement learning include:

- **Game playing:** Deep reinforcement learning models have been able to beat human experts at games such as Go, Chess, and Atari.
- **Robotics:** Deep reinforcement learning models can be used to train robots to perform complex tasks such as grasping objects, navigation, and manipulation.
- **Control systems:** Deep reinforcement learning models can be used to control complex systems such as power grids, traffic management, and supply chain optimization.

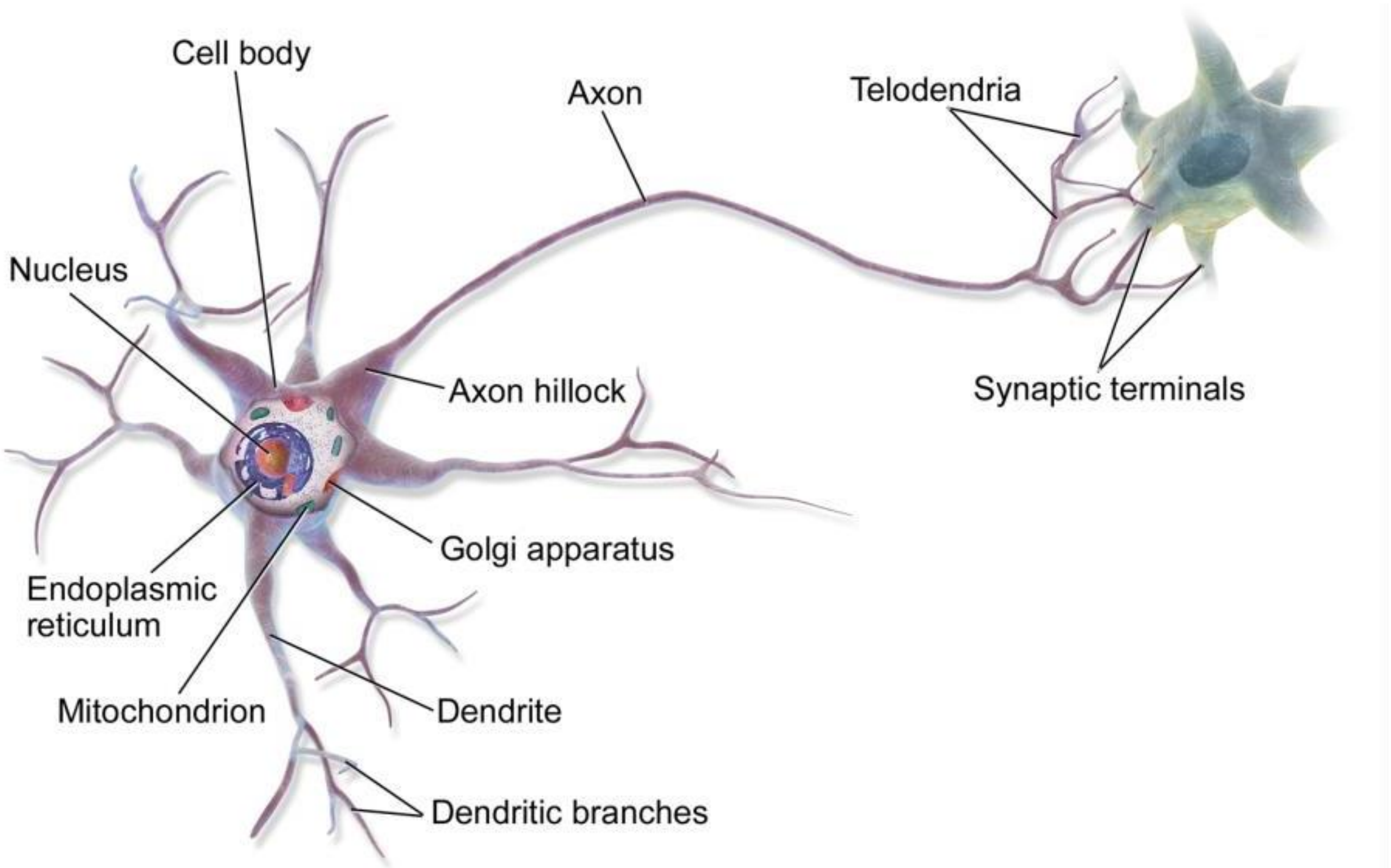
Neural Networks

Neural Networks

- A system inspired by biological neural networks to perform different tasks on a large amount of dataset
- The network composed of *biological or artificial neurons (nodes)*
- The nodes are interconnected such that it works like a human brain
- A neuron consists of 4 major parts:
  - **Soma:** Cell body, i.e., processing unit
  - **Dendrites**: Used by neuron to gather inputs from other neurons
  - **Axon:** Used for sending the output of the neuron to other neurons.
  - **Synapse:** At the end of each branch, converts activity from the axon.

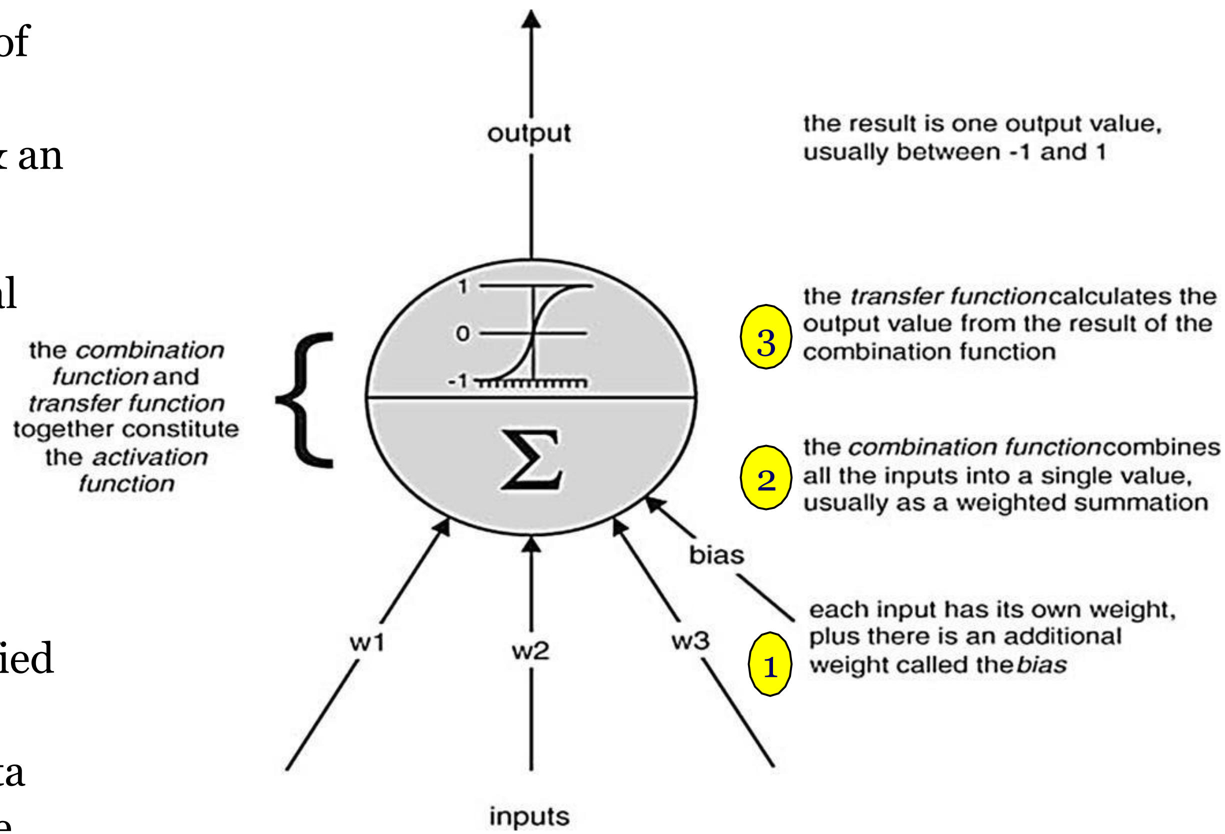


Biological Neuron



ANN – A Closer Look

- ANNs are comprised of an input layer, one or more hidden layers, & an output layer
- Each node, or artificial neuron, connects to another & has an associated weight & threshold.
- When the output of a node is above a specified threshold, the node is activated, sending data to the next layer of the network



Building Blocks of ANN

1. **Activation Functions**
   - Extra force or effort applied over the input to obtain an exact output
   - Consists of the combination function and the transfer function

$$activation\ function(x_1w_1 + x_2w_2 + \cdots + x_nw_n + bias)$$

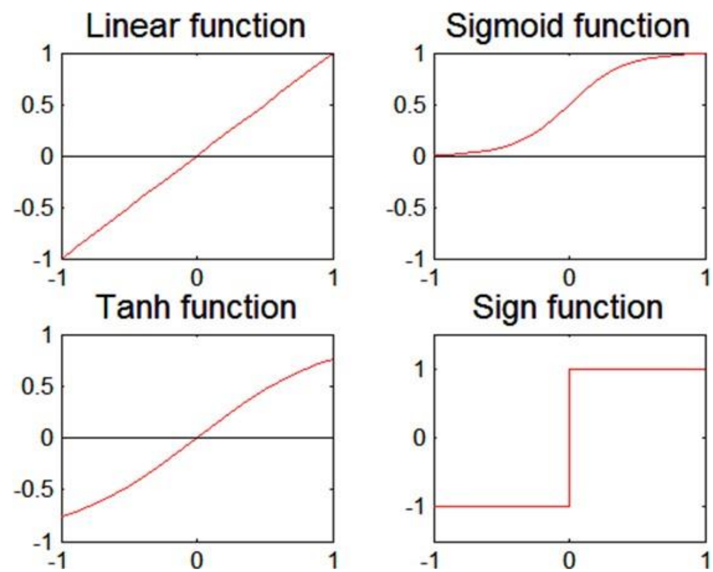
2. **Network Topology (or Architecture):**
   - The arrangement of a network, with its nodes & connecting lines
3. **Adjustments of Weights or Learning Algorithm:**
   - Method for modifying the weights of connections between the neurons of a specified network.
   - Weights help determine the importance of any given variable - large weights contribute more significantly to the output

1. Types of Activation Function (*f*)

- **Linear:** Derives a linear combination of weighted inputs. Output can take any value between -∞ to ∞

$$Y = f\left(\sum_i w_i X_i\right)$$

- **Non-linear:** mostly used
  - ***Sigmoid or Logit:*** scales down output between 0 & 1 by applying a log function
  - ***Softmax function:*** generalization of sigmoid function. Well-suited for multi-class classification problems
  - ***Tanh:*** range from (-1 to 1)
  - ***ReLu (Rectified linear unit):*** Keeps the activation guarded at 0.



Purpose of an activation function is to transform the input signal into an output signal

2. Network Topology

- The neural network architecture is categorized based on:

I. **Construction:**
   - Single layer: No hidden layer
   - Multi-layer: Has one or more hidden layers

II. **Connections:**
   - *Feed-forward neural networks:* Connections between nodes does not form a cycle
   - *Recurrent Neural Networks:* Certain pathways are cycled

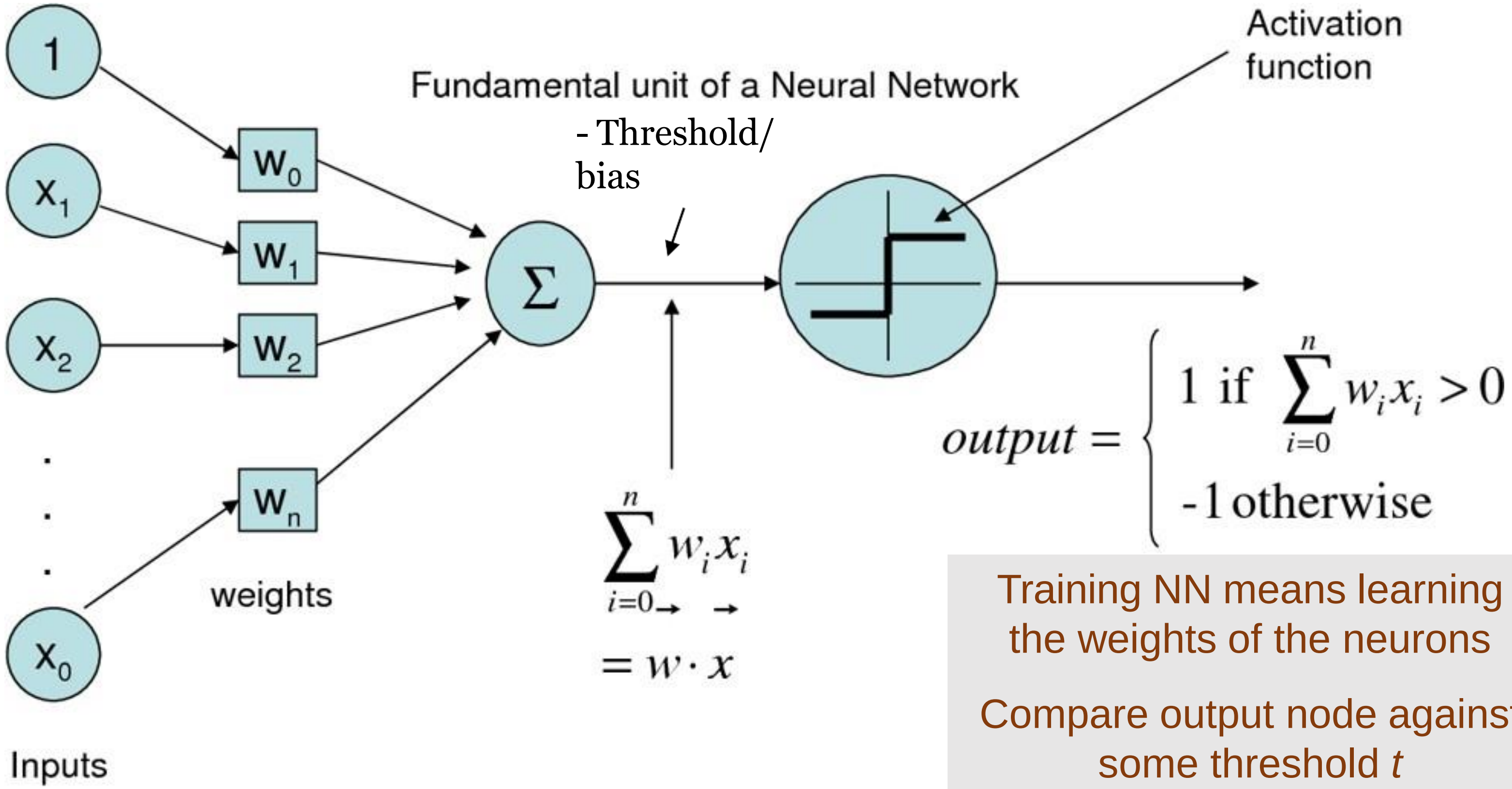
Perceptron

- The perceptron is the basic unit of the Neural Network
- Consists of a ***single neuron*** with an arbitrary number of inputs along with ***adjustable weights***

- A perceptron takes in multiple inputs
- Applies a linear combination, which is **> *or* <** some threshold value ***t***
- Produces binary output of ***1 or 0*** respectively depending on threshold

- **Goal:** Correctly classify data into one of 2 classes - C1 & C2
  - For the perceptron to function properly it is necessary that the 2 classes C1 & C2 are linearly separable

Schematic Representation of a Perceptron

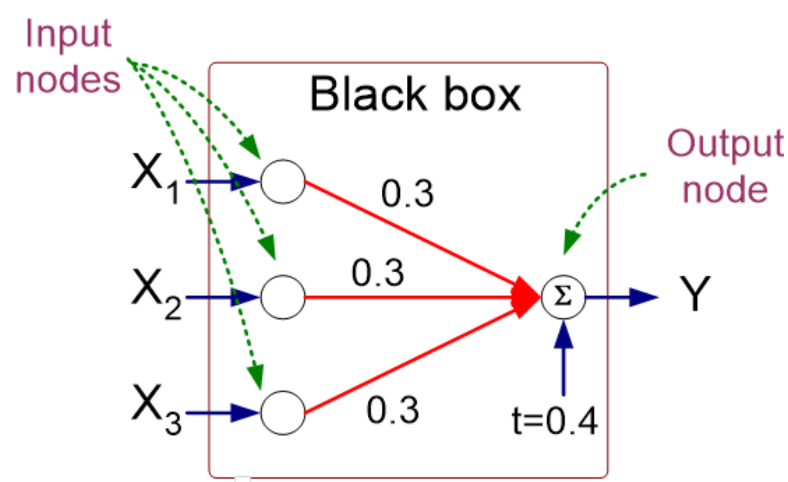


Training NN means learning the weights of the neurons

Compare output node against some threshold *t*

Single-Layer Perceptron

- Contains only input & output nodes
- Activation function: $f = sign(w \cdot x)$
- Applying model is straightforward



- **Example:**

$$Y = sign(0.3X_1 + 0.3X_2 + 0.3X_3 - 0.4)$$

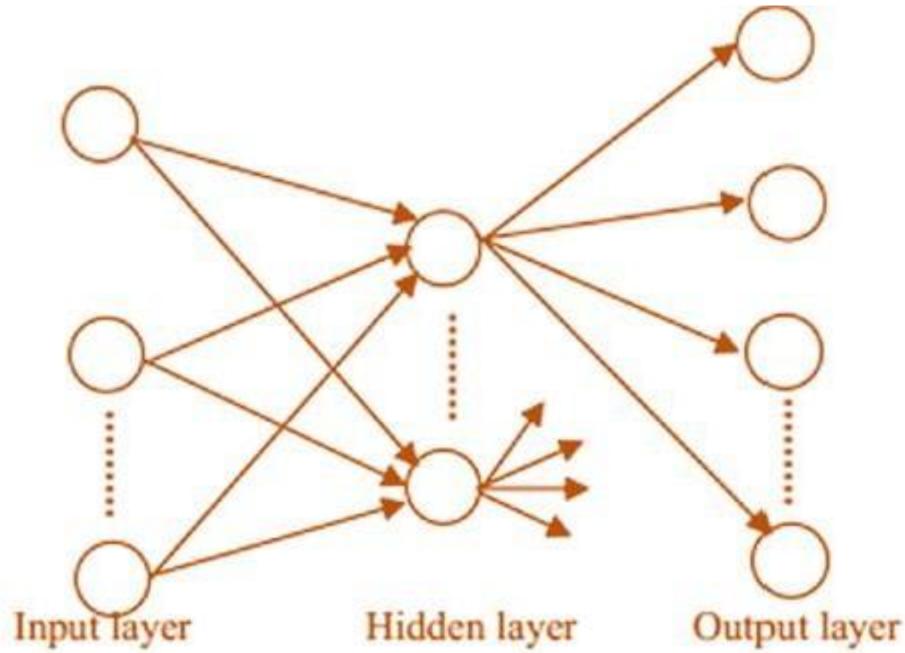
$$\text{where } sign(x) = \begin{cases} 1 & \text{if } x \geq 0 \\ -1 & \text{if } x < 0 \end{cases}$$

If $X_1 = 1$, $X_2 = 0$, $X_3 = 1$ => y = sign(0.2) = 1

Multilayer perceptron models (MLPs), succeed single-layer perceptron models (SLPs)

Feed-Forward Neural Network

- Simplest form of Neural Network
- Data movement is in one direction - from the input layer to output layer
- Restricts any kind of loops
- Output from one layer serves as input to the next layer

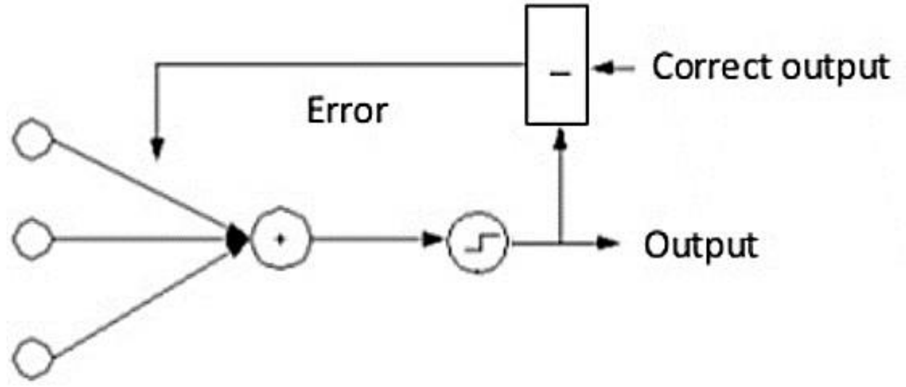


3. Weight Adjustment or Learning

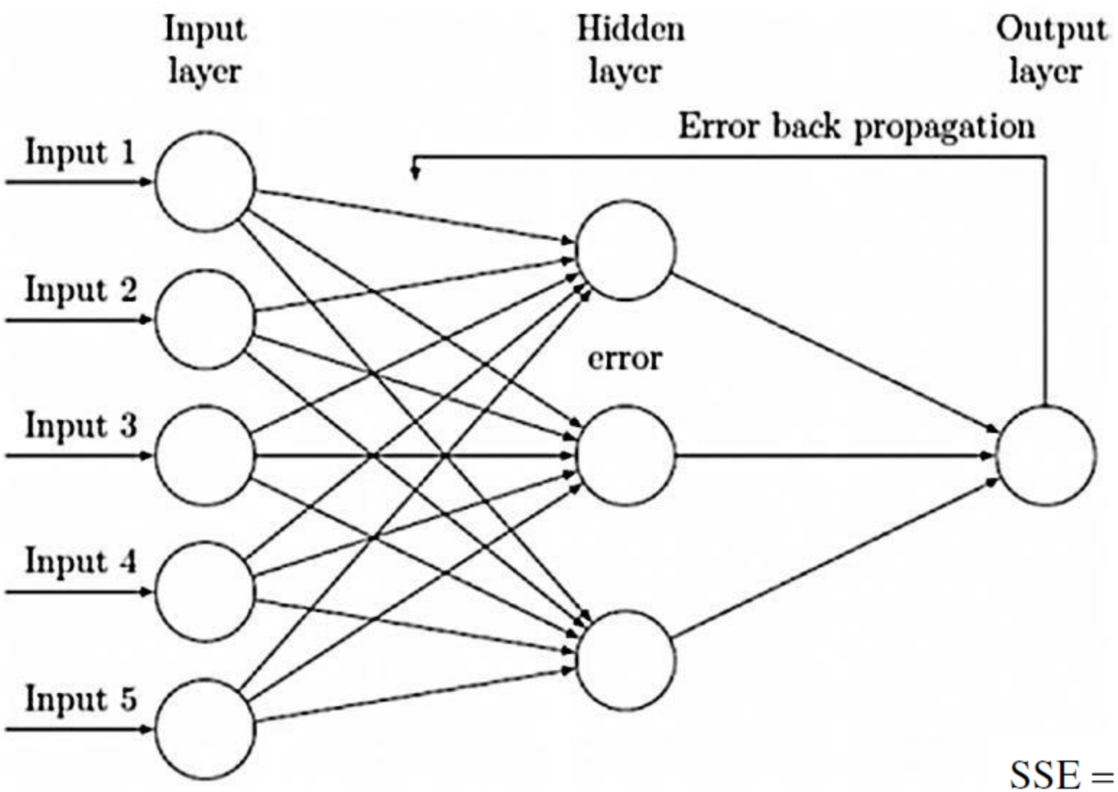
- Means calibrating weights by repeating 2 key steps - Forward Propagation & Backpropagation
- **Steps:**
  - **Initialization:** Initial weights are applied to all the neurons.
  - **Forward propagation:** Inputs from a *training set* are passed through the Neural Network & an output is computed.
  - **Error or Loss Function:** Given the current model weights (“how far off” is the model from the correct result)
  - **Backpropagation:** Change the weights for the neurons to bring the error function to a minimum.
  - **Weight update:** Change weights to optimal values according to the results of the backpropagation algorithm.
  - **Iterate until convergence.**

Backpropagation

- Backpropagation is a **Neural Network** learning algorithm
- Performs a highly efficient search for the optimal weight values, using the *gradient descent technique*
- During the learning phase, the **network learns by adjusting the weights** of the neurons so that the result is closer to the known true result



Backpropagation



Weights are modified to **minimize loss function (the mean squared error)** between the network's prediction & the actual target value

$$\text{SSE} = \sum_{\text{records}} \sum_{\text{output nodes}} (\text{actual} - \text{output})^2$$

Neural Networks as a Classifier

- Used to solve many problems in various fields:
  - Classifying prospect customers
  - Detecting frauds in credit card transactions
  - Predicting stock prices
  - Estimating houses prices
  - Identifying clusters (segments) of customers
- ***Benefits:***
  - Quite robust for noisy, complicated, or nonlinear data
- ***Drawbacks:***
  - Relatively opaque to human interpretation, unlike decision trees
  - Requires a # of parameters, e.g., network topology, # of nodes
  - Long training time

Application Areas

- **Computer vision & image generation:** e.g., diagnose diseases by leveraging medical imaging solutions
- **NLP** (Speech recognition, machine translation)
- **E-commerce:**
  - Scanning image of product to find product in the store or suggest similar alternatives
  - Forecasting product demand more accurately according to buying habits analysis & future trend predictions
- **Sales & Marketing:** Advertising – user-targeted ads, Recommender systems
- **Customer Success**:
  - Chatbots offering immediate & personalized customer service
  - Churn prevention