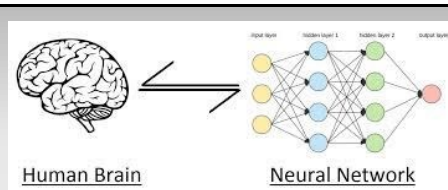

Artificial Neural Network and Deep Learning Lecture 1

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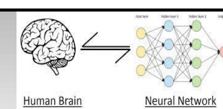
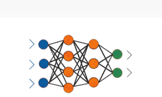
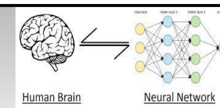
Thanks for Prof. Dr. Hala Mousher Ebied for her main credits in the course content preparation
Thanks for Dr. Ghada Hamed for her credits in the course content



Agenda

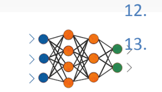
- ❑ Course Outlines
- ❑ Overview of Neural Networks
- ❑ Biological and Artificial Neuron Model
- ❑ Definition of Neural Networks
- ❑ Applications of Neural Networks
- ❑ Artificial Neuron Structures

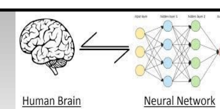




Course Outlines

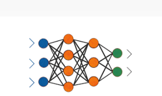
1. Introduction to NNs
2. Main characteristics of Neural Networks
3. Resenblatt's perceptron Single Layer Network
4. Least Mean Square algorithm for Single Layer Network
5. Multilayer Perceptron (MLP) Network
6. Optimization of Back-Propagation Algorithm
7. Deep Learning
8. Convolutional Neural Networks (CNNs)
9. Regularization and CNNs
10. YOLO for Object Detection
11. Fully CNNs and U-Net for Image Segmentation, Generative Models
12. Recurrent Neural Networks (RNNs) and Transformers
13. Graph Neural Networks

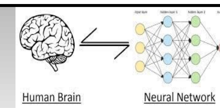




Textbooks

- Neural Networks and Deep Learning, Charu C. Aggarwal, Springer, 2023
- Haykin. Neural Networks and Learning Machines, 3ed., Prentice Hall (Pearson), 2009.
- Deep Learning, Ian Goodfellow, Yoshua Bengio, and Aaron Courville, MIT Press, Cambridge, 2016



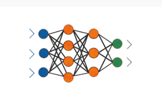


Course Assessment

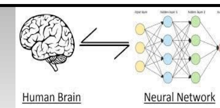
Assessment
- Homework, Quizzes, Computer Assignments, and Project (35 Points)
- Midterm Exam (15 Points)
- Final Exam (50 Points)

Assessment (Old Bylaw)
- Homework, Quizzes, Computer Assignments, and Project (25 Points)
- Midterm Exam (10 Points)
- Final Exam (65 Points)

Programming and homework assignments
- **Late answers are NOT accepted!**



Lecture 1:
Introduction to ANNs



Lecture Objectives

After studying this lecture, the student will be able to:

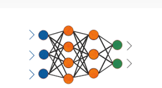
– Define the Neural Networks.

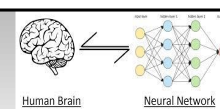
– Explain how the biological neuron works.

– Summarize the difference between the Biological and the Artificial Neuron.

– Explain the mathematical representation of the artificial neuron unit.

– Summarize the properties and capabilities of Neural Networks.





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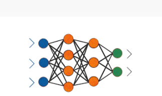
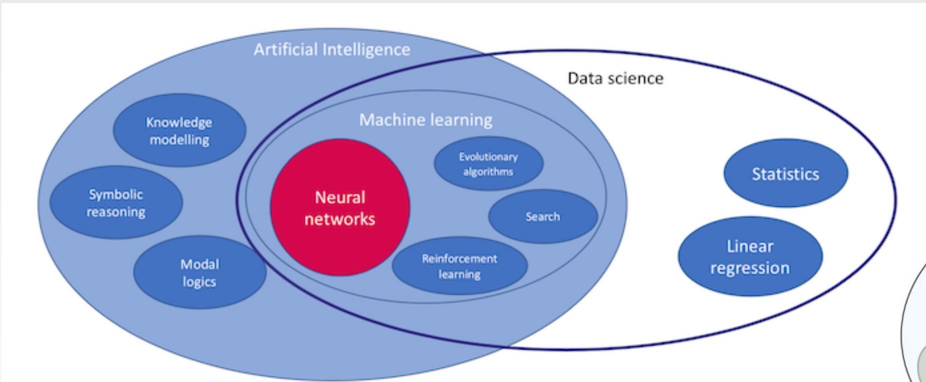
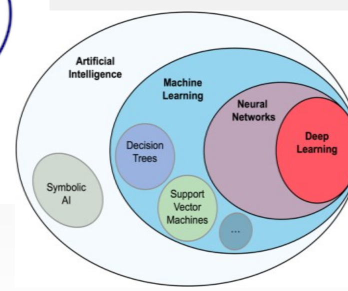


Where is NN?





What is a Neural Network?

- Neural Networks replicate the way humans learn, inspired by **how the neurons in our brains fire**, only **much simpler**.
- Researchers attempt to simulate Human brain by implementing artificial neural networks (ANN).
- The Human brain could give the correct response (**output**) for each **input** of its environment.

What is a Neural Network?, cont.

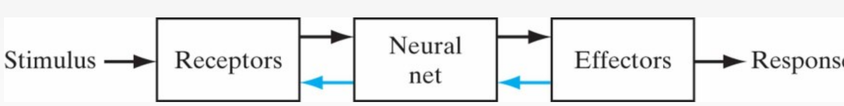
- The researchers considered the neural network as a **black box strategy**, which is **trainable**.

- The key aspect of black box approaches is developing relationships between input and output.
- The researchers tried to 'train' the neural black-box to 'learn' the correct response output for each of the training samples.

The Human Nervous System

The human nervous system may be viewed as a three-stage system:

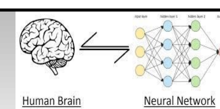
- The *brain*, represented by the neural (verve) net, is central to the system. It continually *receive* information, *perceives* it, and *makes* appropriate *decision*.
- The *receptors* convert stimuli from the human body or the external environment into electrical impulses that convey information to the brain.
- The *effectors* convert electrical impulses generated by the brain into discernible responses as system output.



Block diagram representation of nervous system.

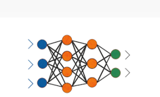
Human brain

- **The Human brain computes in different way from digital-computer:**
  - The brain is a highly complex, nonlinear, and parallel computing.
  - It characterize by;
    - Robust and fault tolerant - because they are always able to respond and small changes in input do not normally cause a change in output.
    - Flexible – can adjust to new environment by learning
    - Can deal with probabilistic, noisy or inconsistent information
    - Is small, compact and requires little power than the digital computer.



Human brain, cont.

- The brain is slower than the digital-computer in the mathematic computation, however, The brain is many times faster than the digital-computer in:
  - vision, pattern recognition, perception, motor control
- Human uses 1% calculation, 99% *understanding*
  - based on patterns, drawing information from experience
- Machine opposite: 99% calculation, 1% understanding
  - though this understanding is growing



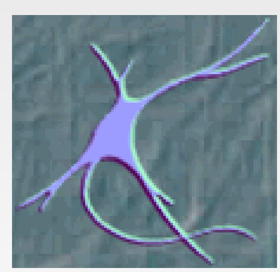
How does the Human brain do the task required from it?

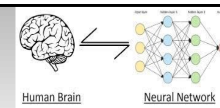
At birth, a brain has great structure and the ability to build or build up its own rules by "experience".

- Experience is build up over time, dramatic development within 2 years after birth and continues to develop afterward.

Basic element in a biological brain

- A neuron is the basic element in a biological brain
- There are approximately 100,000,000,000 neurons in a human brain
- One neuron is connectedly with approximately 10,000 other neurons
- Each of these neurons is relatively simple in design.

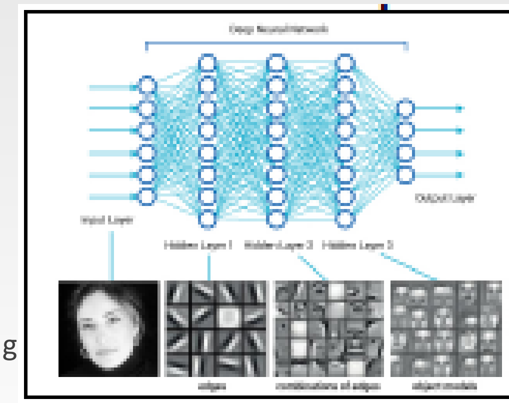


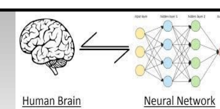


How does the computer simulate the Human?

Allow computers to learn from experience like humans
- By gathering knowledge from experience (examples or training set)

Understand the world as hierarchy of concepts
- Build the computer in hierarchical way like the brain
  - Biological neurons = nodes
  - Neurons connected to each others
- Thereby learn complicated concepts by building them out of simpler ones





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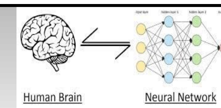
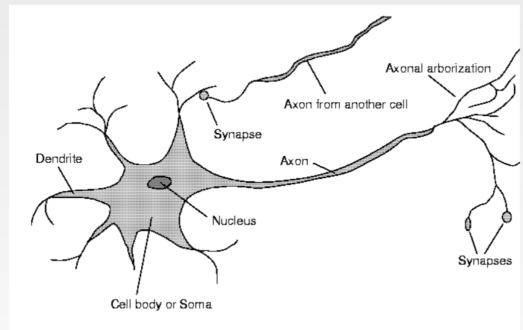


Biological Neuron Structure

The biological neuron is composed of four major parts:

- A neuron contains a cell body for signal processing,
- many dendrites to receive signals (Inputs receives through dendrite)
- an axon for outputting the result; and
- a synapse between the axon and each dendrite



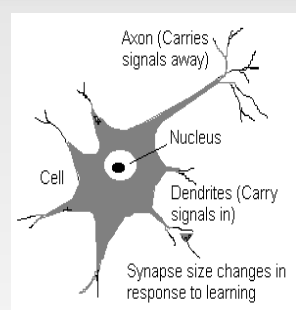
How does a bio-neuron work?

Synaptic activity

Electrical Signals (impulses) come into the dendrites through the synapses.

Electrical signal causes a change in **synaptic potential** and the release of **transmitter chemicals.**

Chemicals can have an excitatory effect on the receiving neuron (making it more likely to fire) or an inhibitory effect (making it less likely to fire).

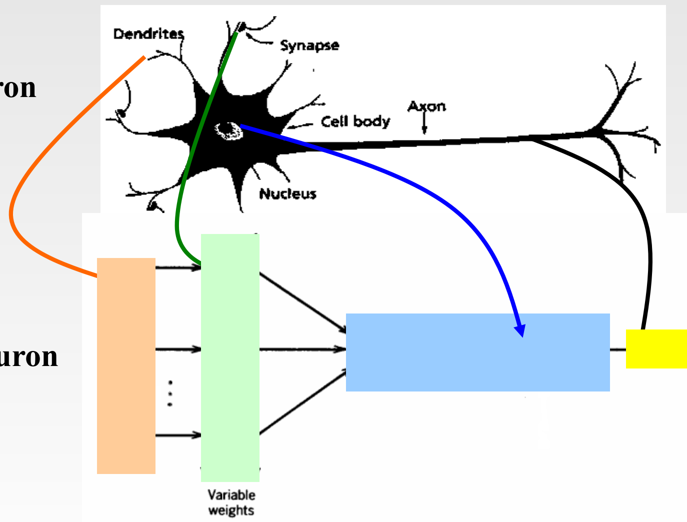


- Total inhibitory and excitatory from all dendrites connections to a particular neuron are summed up in the cell body.
- When the sum is larger than a **threshold**, the neuron **fires**, and sends out an impulse signal to other neurons through the axon

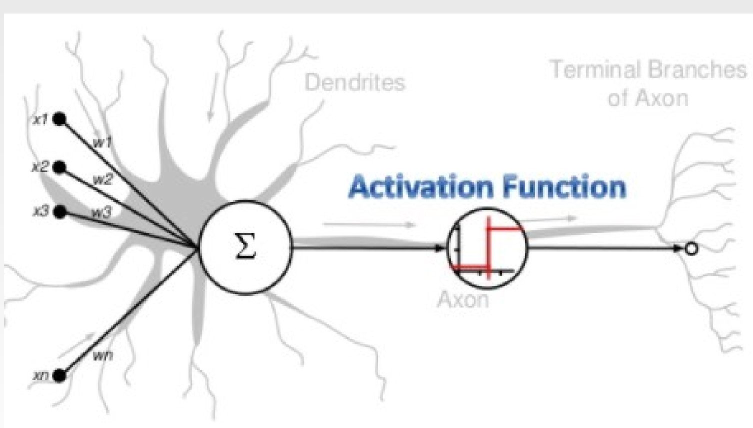
Translate from Biological Neuron to Artificial Neuron

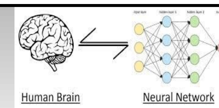
A physical neuron

An artificial neuron



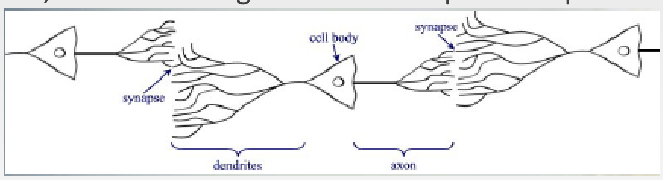
Translate from Biological Neuron to Artificial Neuron



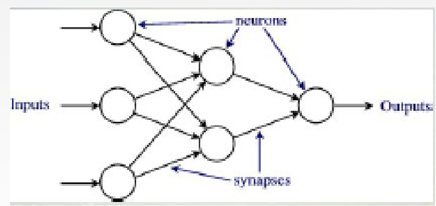


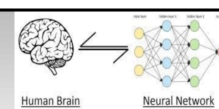
Network of Neurons

The human brain composed of many “neurons” that co-operate to perform the desired objective, which means give desired output to a specific input.



- We can consider the Neural Networks as a network of many simple processors “node or units”.
- This called forward propagation.
- Summation at each node can be occurred in parallel using parallel programming(They are independent) .





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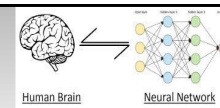
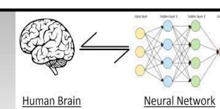


What is a Neural Network?

- A Neural Networks is a <u>method of computing</u>, based on the interaction of multiple connected processing elements.
- Its <u>computational model</u> inspired from neurological model of the brain.
- It is a machine that is designed to model the way in which the brain performs a practical task.
  - It is usually implemented by using <u>electronic components</u> or is <u>simulated in software</u>.



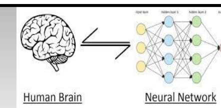
What is a Neural Network?, cont.

It is a <u>massively parallel distributed processor (Formal Definition in the Book)</u>

- Made up of <u>simple processing units (neurons)</u>
- The simple processing units has a natural propensity for <u>storing experience knowledge</u> and making it available for use.

It resembles the brain in two respects:

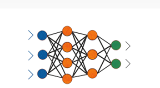
- Knowledge is acquired from environment through learning process.
- Interneuron connection strengths, known as <u>synaptic weights</u>, are used to store the acquired knowledge

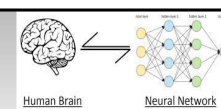


Computing power of Neural Networks

Its derives its computing power through:

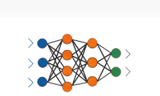
- Its massively **parallel** **distributed** **structure**.
- Its ability to **learn** and therefore **generalize**.
  - **Learning**: the function of which is to modify synaptic weights in an orderly fashion to obtain a desired objective.
  - **Generalization**: refers to the ability of neural network to produce outputs for inputs not encountered during training (learning).

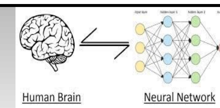




Properties and Capabilities of Neural Networks

1. Nonlinearity. An artificial neuron can be linear or nonlinear. A neural network, made up of an interconnection of nonlinear neurons, is itself nonlinear.
2. Input-Output Mapping
   - It is built by learning from examples in order to minimize the difference between the desired response and the actual response.
3. Adaptively
   - NNs have a built-in capability to adapted their synaptic weights to changes in the surrounding environment, i.e. it can be easily retrained to deal with minor changes in the operating environment.
   - In non-stationary environment, a NN can be designed to change its synaptic weights in real-time.





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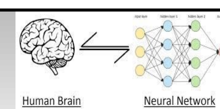


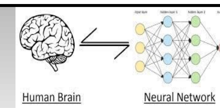
Problems Commonly Solved With Neural Networks

There are many different problems that can be solved with a neural network.

However, neural networks are commonly used to address particular types of problems. The following types of problem are frequently solved with neural networks:

- Regression - Approximate an unknown function
- Classification
- Pattern recognition
- Prediction
- Optimization
- Clustering

These problems will be discussed briefly.

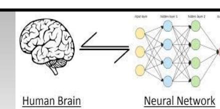


Regression (1l3)

- Computer program required to Predict a numerical value given some input.
- Ex.: for every house price, I know the area of this house.

House price	100,000	130,000	200,000	500,000	1,000,000
Area (m2)	80	90	100	150	200

- Then someone asked me that there is a house with specific area what is its price?
- If we are following rule-based methods or search methods, then the algorithm will fail because the new price.
- As a result, we need house-fitting or interpolation to get the value of the house price.
- The output of this problem will be continuous variable.
- Face detection problem can be categorized below regression?



Regression (2/3)

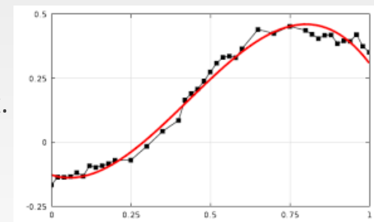
- Another Ex.: the job salaries and these job salaries are a very large database that tells us the domain of every job.

Job Salary	10X	20X	30X	35X	50X
Domain	X	Y	X	Z	Z
Location	CAI	NY	PAR	NY	CAI
Grade	B	A	A	B	A

- If anybody searches for a new job, even if this job is not existed in our DB, the system can predict the output by using the regression.
- In all cases, the output is a continuous variable.
- If we looked at the problem mathematics, we will find that there are a lot of names; **House-fitting**, **regression**, in general it is a **function approximation.**

Regression (3/3) - Function approximation

- So, the system need to learn a function that maps input x to output y.
- This function could be a curve on which we apply fitting on a data we have.
- The curve could be linear or non-linear
- As a result, that curve is expected to have errors,
- In the opposite figure, y doesn`t equal some function of x.



$$y_i = \varphi(x_i) + E$$

- y equal function of x and the ϕ of x plus some error.
- Estimation error: measure the distance between this example and the curve on which we applied the fitting.

Classification or Recognition (1/2)

Here the output variable turned from continuous variable into a discrete variable.

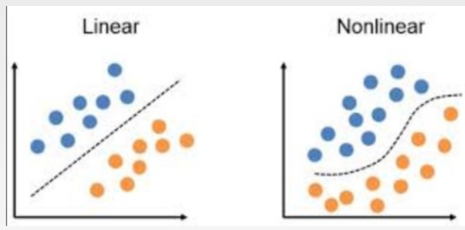
Instead of predicting the house price, we need to predict the house category: instead of returning numbers for prices, we will use low category, economical category, high category, or premium end or high end.

The difference is that the problem is converted from function approximation to classification problem.

We still trying to estimate the function but in this case we are trying to get something called **Decision Boundary** instead of curve.

Classification or Recognition (2/2)

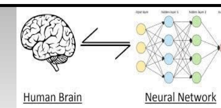
- The Decision Boundary means to get a **break** between two classes.



- In case of the binary classification, the break will separate two classes where there are any example of class 1 existed in class 2 region.
- One of the classification names is discrimination, or discriminative function.

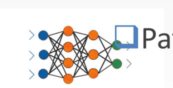
Classification

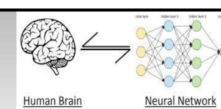
- Classification is the process of classifying input into groups.
- For example, an insurance company may
  - Want to classify insurance applications into different risk categories,
  - Or an online organization may want its email system to classify incoming mail into groups.
- Often, the neural network is trained by presenting it with a sample group of data and instructions as to which group each data element belongs.
- This allows the neural network to learn the characteristics that may indicate group membership.



Pattern Recognition

- ❑Pattern recognition is one of the most common uses for neural networks.
- ❑Pattern recognition is a form of classification.
- ❑Pattern recognition is simply the ability to recognize a pattern. The pattern must be recognized even when it is distorted.
- ❑In general, pattern recognition is the problem to classify given patterns into several classes
  - ❑Character recognition
  - ❑Speech recognition
  - ❑Face detection/recognition
- ❑Pattern recognition is the basis for creating machines that can learn and think.



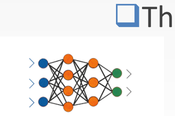


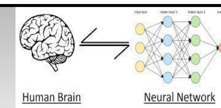
Application: Face detection

- ❑Face detection is an example of pattern classification or pattern recognition

Face detection (“face” or “non-face”)

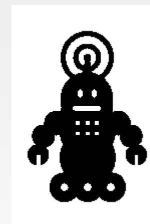
- ❑Face detection is to search for a face in a given image
- ❑The image can be a still picture taken by a digital camera, or moving pictures captured by a video camera
- ❑This problem is important for many security related systems, internet based media search, etc.
- ❑The problem is highly non-linear.

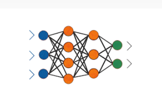


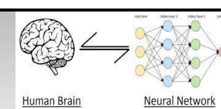


Application: Automatic driving

- ❑Automatic driving is a special case of pattern recognition
- ❑Examples: car-driving, Control of mobile robots
  - ❑The inputs of the neural network may be contains a video image and some distance information
  - ❑The outputs corresponds directly to handle directions
- ❑The problem is to find the parameters of the neural network controller from given observations
- ❑A car can be considered as a special mobile robot







Prediction

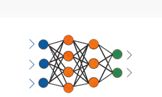
Prediction = estimating the future value(s) in a time series

Given a time-based series of input data, a neural network will predict future values.

The accuracy of the guess will be dependent upon many factors, such as the quantity and relevancy of the input data.

For example, neural networks are commonly applied to problems involving predicting movements in financial markets.

Example: Given stock values observed in the past few days, guess if we should buy or sell today



Optimization

Optimization can be applied to many different problems for which an optimal solution is sought.

The neural network may not always find the optimal solution; rather, it seeks to find an acceptable solution.

Perhaps one of the most well-known optimization problems is the traveling salesman problem (TSP).

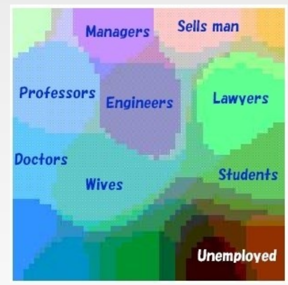
Clustering

- It is the process of grouping the data into classes (clusters) so that the data objects (examples) are:
  - similar to one another within the same cluster
  - dissimilar to the objects in other clusters
- no predefined classes
- The purpose is to extract rules or relations between data, and using these knowledge to gain profit.
- Data visualization is an important way to see the relation between data points in a high-dimensional space. (Image Segmentation)
- Self-organized feature map is a kind of neural network for this purpose

Clustering, Application

An example

- All users can be categorized into several groups according to their occupations (Professors, Engineers, Wives, Students, Sells man, Managers, Lawyers, Doctors, Unemployed)
- The data can be visualized by mapping them to a 2-D space
- From this map, we can see if a person is a payable user or not



Clustering Applications

Other examples: image segmentation (Satellite images)

= find homogeneous regions in the image (facilitate the analysis of the image)

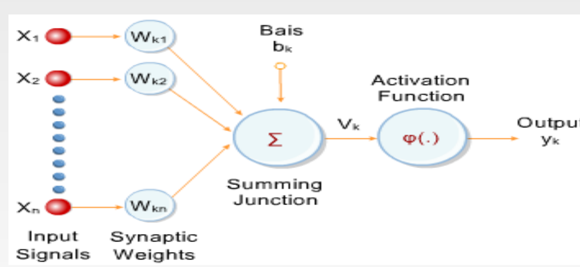
Agenda

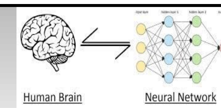
- Course Outlines
- Overview of Neural Networks
- Biological and Artificial Neuron Model
- Definition of Neural Networks
- Applications of Neural Networks
- **Artificial Neuron Structures**

Artificial Neuron

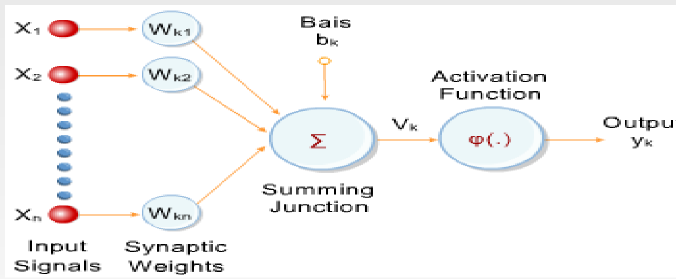
- Neuron is the basis information processing unit.
- **Three-basic elements of the neural model:**

1. A set of synapses or connecting links
   - Characterized by **weight** or **strength**.
2. An adder
   - Summing the inputs signals weights by synapses.
   - is called a linear combiner.
3. An activation function
   - Also called **squashing function**
   - Squash limits the output to some finite values.

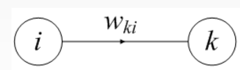


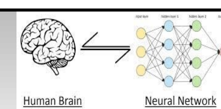


Mathematical terms of Nonlinear Neuron Model



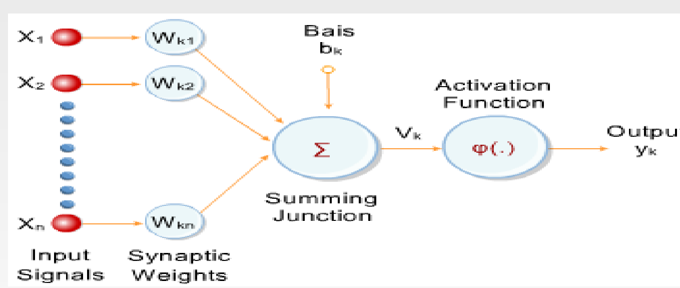
- Each input has an associated **weight** *w*
- The neuron model of the figure in this screen includes: input signals ($x_1, x_2, \ldots, x_n$); and synaptic weights ($w_{k1}, w_{k2}, \ldots, w_{kn}$).
  - Note that $\mathbf{w}_{ki}$ refers to the weight from unit ***i*** to unit ***k***





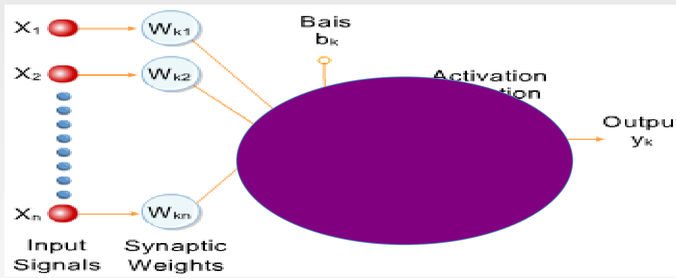
Mathematical terms of Nonlinear Neuron Model

- The weighted sum of all the inputs coming into neuron k:
  - The weighted sum u_k is called the **net input** to unit ***k***,
  - The adder of summing the input signals is <u>linear process.</u>



$$u_k = \sum_{j=1}^{n} w_{kj} x_j$$

Mathematical terms of Nonlinear Neuron Model



- Add the **bias b_k** : $v_k = u_k + b_k$
- The output signal is:

$$y_k = \varphi(u_k + b_k)$$

Where the function φ is the **activation function**.

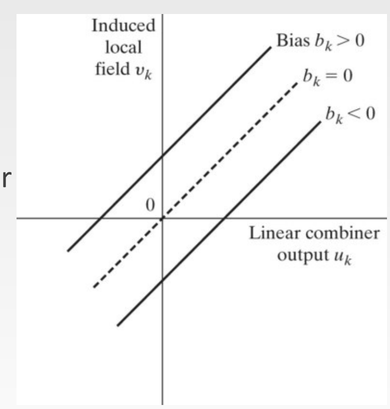
Effect of adding a Bias

- The use of bias b_k has the effect of applying an *affine transformation* to the output u_k.

$$v_k = u_k + b_k$$

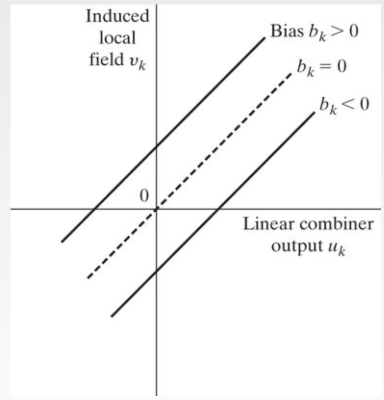
- Depending on weather the bias b_k is positive or negative, the relation between
  - the activation potential v_k of neuron *k*, and
  - the linear combiner output u_k

  is modified as in the next figure.



Effect of adding a Bias, cont.

- Note that as a result of this affine transformation, the graph of v_k versus u_k no longer passes through the origin.
- The **bias** helps convergence of the weights to an acceptable solution. It works as a threshold.
- **Bias** or **threshold**: if the effective input is larger than the bias, the neuron outputs a one, otherwise, it outputs a zero.



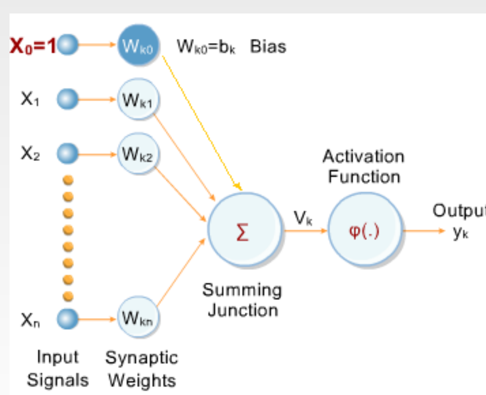
Bias as extra input

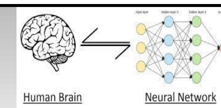
In this figure, the effect of the bias is accounted for by doing two things:

1. A Bias unit can be thought of as a unit which always has an input value of 1, x_0=+1.
2. A bias value is exactly equivalent to a weight w_{k0} on an extra input line x_0.

- So we may formulate v_k as follows:

$$v_k = \sum_{j=0}^{n} w_{kj} x_j$$





Vector-matrix formulation of single-unit

A single linear unit has a model of the form:

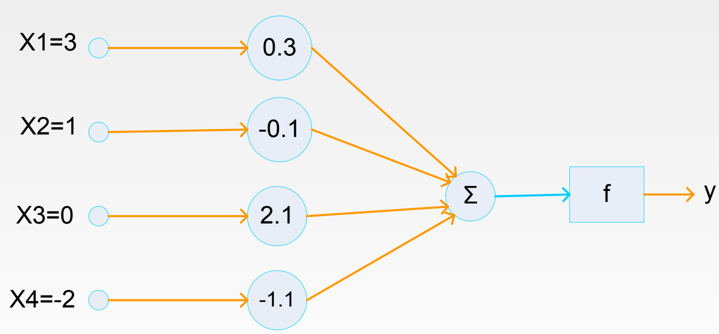
$$v_k = net_k = \sum_{j=0}^{n} w_{kj} x_j$$

$$= w_{k0}x_0 + w_{k1}x_1 + w_{k2}x_2 + \ldots + w_{kn}x_n \quad = \begin{bmatrix} w_{k0} & w_{k1} & \ldots & w_{kn} \end{bmatrix} \begin{bmatrix} x_0 \\ x_1 \\ . \\ . \\ . \\ x_n \end{bmatrix}$$

$$= W^T X \qquad where \quad W = \begin{bmatrix} w_{k0} \\ w_{k1} \\ . \\ . \\ . \\ w_{kn} \end{bmatrix} \quad and \quad X = \begin{bmatrix} x_0 \\ x_1 \\ . \\ . \\ . \\ x_n \end{bmatrix}$$

Example

- The inputs (3, 1, 0, -2) are presented to single neuron, its weight is (0.3, -0.1, 2.1, -1.1).
- i. What is the net input to the transfer function?
- ii. What is the neuron output?



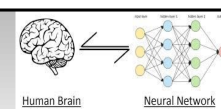
Example

- Solution:

i- *The net input is given by summed weighted inputs:*

$$
\begin{aligned}
u_k &= net_k = W^T X \\
&= \begin{bmatrix} 0.3 & -0.1 & 2.1 & -1.1 \end{bmatrix} \begin{bmatrix} 3 \\ 1 \\ 0 \\ -2 \end{bmatrix} \\
&= 3(0.3) + 1(\text{-}0.1) + 0(2.1) + \text{-}2(\text{-}1.1) \\
&= 0.9 + (\text{-}0.1) + 2.2 \\
&= 3
\end{aligned}
$$

ii- The output cannot be determined because the transfer function is not specified. which function should be used as an activation function?



Thank you!

Next Lecture:

- Types of activation functions