Artificial Neural Network and Fuzzy Logic

Syllabus

UNIT-I Introduction to Artificial Neural Networks:

Elementary Neurophysiology, Models of a Neuron, Neural Networks viewed as directed graphs, Feedback, from neurons to ANN, Artificial Intelligence and Neural Networks; Network Architectures, Single-layered Feed forward Networks, Multi-layered Feed forward Networks, Recurrent Networks, Topologies.

UNIT-II Learning and Training :

Activation and Synaptic Dynamics, Hebbian, Memory based, Competitive, Error-Correction Learning, Credit Assignment Problem: Supervised and Unsupervised learning, Memory models, Stability and Convergence, Recall and Adaptation.

UNIT-III A Survey of Neural Network Models :

Single-layered Perceptron – least mean square algorithm, Multi-layered Perceptrons – Back propagation Algorithm, XOR – Problem, The generalized Delta rule, BPN Applications, Adalines and Madalines – Algorithm and applications.

Syllabus

UNIT-IV Applications :

Talking Network and Phonetic typewriter : Speech Generation and Speech recognition, Neocognitron – Character Recognition and Handwritten Digit recognition, Pattern Recognition Applications.

UNIT-V Neural Fuzzy Systems :

Introduction to Fuzzy sets, operations, relations, Examples of Fuzzy logic, Defuzzification, Fuzzy Associative memories, Fuzziness in neural networks and examples ,

Books

1. Artificial Neural Networks by B. Yagnanarayan, PHI
   - **(Cover Topologies part of unit 1 and All part of Unit 2)**
2. Neural Networks and Learning Machines by Simon Haykin, PHI.
   - **(Unit 1)**
3. Introduction to Neural Networks using MATLAB, S. N. Sivanandam, S. Sumathi, S. N. Deepa, TMH.
   - **(For Numeric of Unit 2, Unit 3 and Unit 4)**
4. Fuzzy Set and Fuzzy Logic, by George J. Klir and Bo Yuan, Prentice Hall.
   - **(Unit 5)**

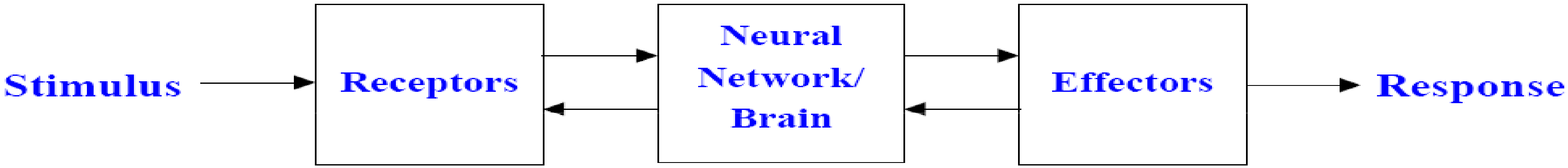
Introduction to Artificial Neural Networks

What are Neural Networks ?

- ***Neural Networks (NNs) are networks of neurons, for example, as found in*** real (i.e. biological) brains.
- ***Artificial Neurons are crude approximations of the neurons found in*** brains. They may be physical devices, or purely mathematical constructs.
- ***Artificial Neural Networks (ANNs) are networks of Artificial Neurons,*** and hence constitute crude approximations to parts of real brains. They may be physical devices, or simulated on conventional computers.
- From a practical point of view, an ANN is just a parallel computational system consisting of many simple processing elements connected together in a specific way in order to perform a particular task.
- One should never lose sight of how crude the approximations are, and how over-simplified our ANNs are compared to real brains.

The Nervous System

- The human nervous system can be broken down into three stages that may be represented in block diagram form as:



- The receptors collect information from the environment – e.g. photons on the retina.
- The effectors generate interactions with the environment – e.g. activate muscles.
- The flow of information/activation is represented by arrows – feed forward and feedback.
- Naturally, in this module we will be primarily concerned with the neural network in the middle.

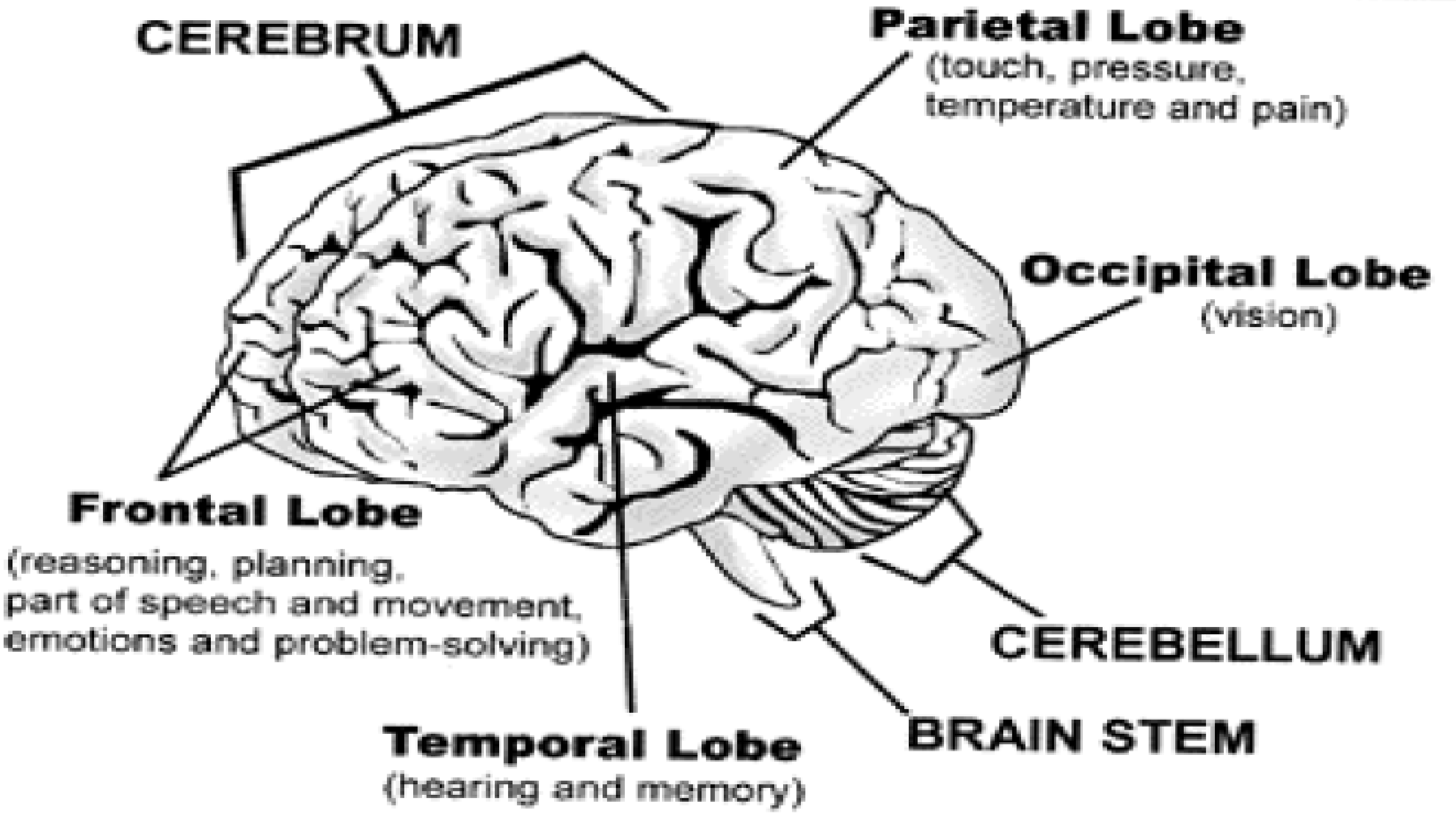
Levels of Brain Organization

- The brain contains both large scale and small scale anatomical structures and different functions take place at higher and lower levels.
- There is a hierarchy of interwoven levels of organization:

1. Molecules and Ions
2. Synapses
3. Neuronal microcircuits
4. Dendritic trees
5. **Neurons**
6. **Local circuits**
7. Inter-regional circuits
8. Central nervous system

- The ANNs we study in this module are crude approximations to levels 5 and 6.

Structure of a Human Brain



Slice Through a Real Brain

Basic Components of Biological Neurons

1. The majority of ***neurons encode their activations or outputs as a series of brief*** electrical pulses (i.e. spikes or action potentials).
2. The neuron's ***cell body (soma) processes the incoming activations and converts*** them into output activations.
3. The neuron's ***nucleus contains the genetic material in the form of DNA. This*** exists in most types of cells, not just neurons.
4. ***Dendrites are fibres which emanate from the cell body and provide the receptive*** zones that receive activation from other neurons.
5. ***Axons are fibres acting as transmission lines that send activation to other neurons.***
6. The junctions that allow signal transmission between the axons and dendrites are called ***synapses. The process of transmission is by diffusion of chemicals called neurotransmitters across the synaptic cleft.***

Schematic Diagram of a Biological Neuron

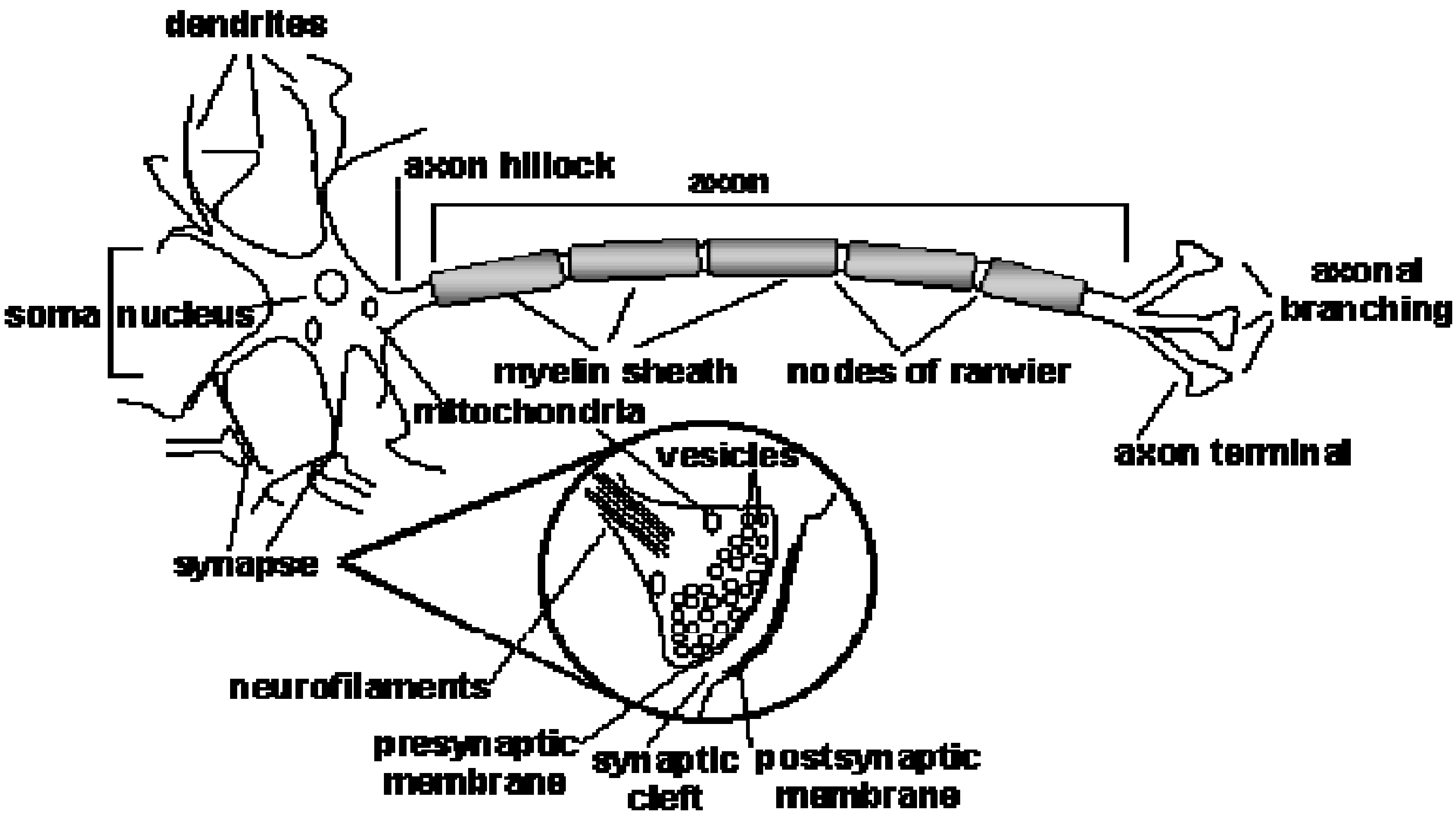
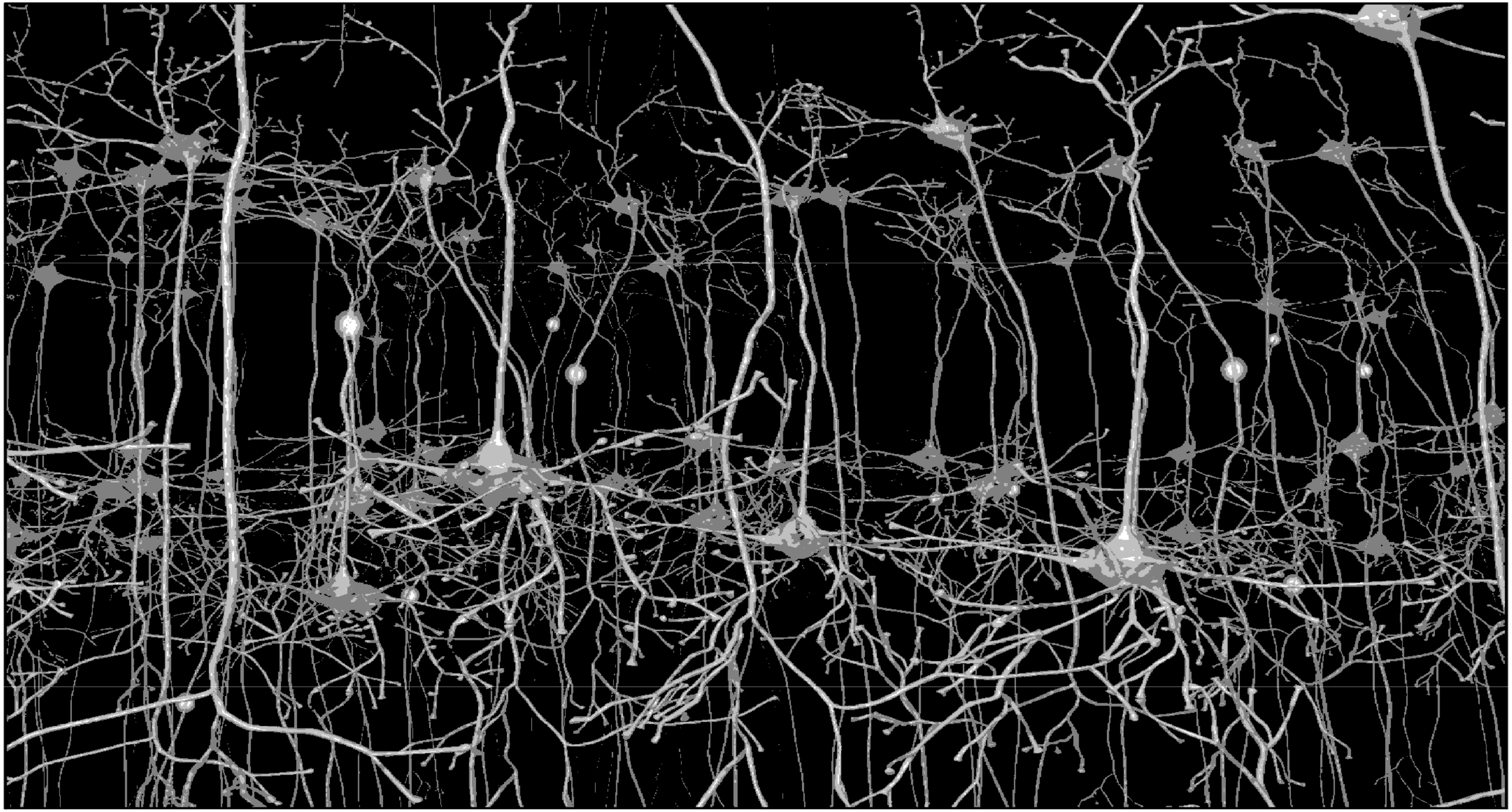


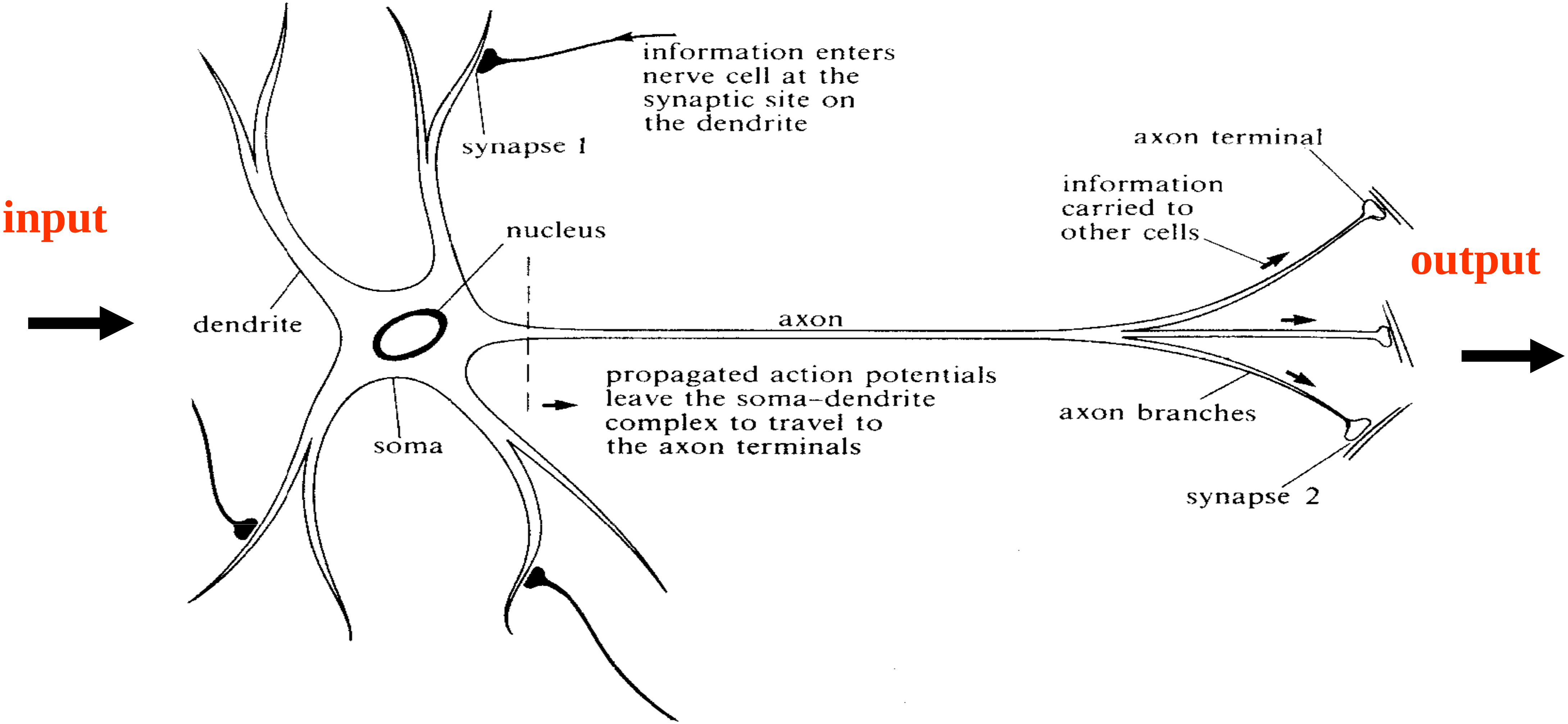
Image of Biological Neurons



DIGITAL STUDIO SA

CG image of the vertical organization of neurons in the primary visual cortex (V1).
Smooth stellate and spiny stellate cells relay visual information coming out from the retina to pyramidal cells, themselves doing a first basic computation of visual motion perception.
version of July 2000

How do we go from real neurons to artificial ones?



Brains versus Computers : Some numbers

1. There are approximately 10 billion neurons in the human cortex, compared with 10 of thousands of processors in the most powerful parallel computers.
2. Each biological neuron is connected to several thousands of other neurons, similar to the connectivity in powerful parallel computers.
3. Lack of processing units can be compensated by speed. The typical operating speeds of biological neurons is measured in milliseconds (10-3 s), while a silicon chip can operate in nanoseconds (10-9 s).
4. The human brain is extremely energy efficient, using approximately 10-16 joules per operation per second, whereas the best computers today use around 10-6 joules per operation per second.
5. Brains have been evolving for tens of millions of years, computers have been evolving for tens of decades.

Von Neumann Computer Versus Biological Neural System

	Von Neumann Computer	Biological Neural System
Processor	Complex	Simple
	High Speed	Low Speed
	One or a few	A large number
Memory	Separate from processor	Integrated into
	Non-content addressable	Content addressable
Computing	Centralized	Decentralized
	Sequential	Parallel
	Stored program	Self learning
Reliability	Very vulnerable	Robust
Expertise	Numerical and symbolic	Perceptual problems
Operative environment	Well defined and constrained	Poorly defined and unconstrained

Comparison between Neural Networks, Expert Systems & Conventional Programming

Parameters	Artificial Neural Networks	Expert Systems	Conventional Programming Techniques
Process	Learning	Inference	Algorithm
Input Data	Pattern	Knowledge	Numerical
Algorithm	Statistical	Heuristic	Programming
Computation	Numerical	Symbolic or Logic	Arithmetic or Logic
Data Processing	Parallel	Serial	Serial
Output Results	Inductive	Deductive	Computed

Artificial Neural Networks

- Artificial Neural Networks are nonlinear information (signal) processing devices, which are built from interconnected elementary devices called neurons.
- An Artificial Neural Networks is an information processing paradigm that is inspired by the way biological nervous systems such as the brain.
- The key element of this paradigm is the novel structure of the information processing system.
- It is composed of a large number of highly interconnected processing elements (neurons) working in union to solve specific problems.

Characterization / Basic Building Block of Artificial Neuron Networks

- Architecture (connection between neurons)
- Training or Learning (Determining weights on the connections)
- Activation Function

Artificial Neural Network Architecture

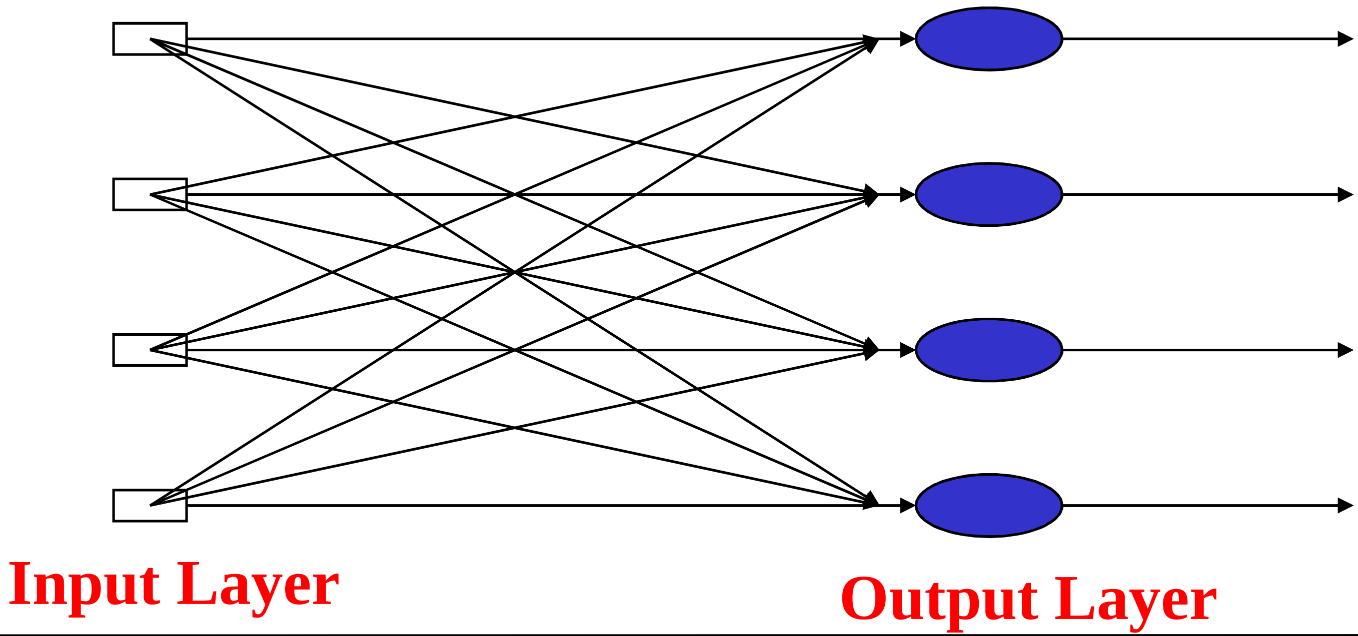
- The arrangement of neurons into layers and the pattern of connection within and in-between layer are generally called as the architecture of the net.
- The neurons within a layer are found to be fully interconnected or not interconnected.
- The number of layers in the net can be defined to be the number of layers of weighted interconnected links between the particular slabs of the neurons.

Type of Network Architecture

- Feed Forward
  - Input Single Layer Feed forward
  - Input Multi Layer Feed forward
- Recurrent Net
- Competitive Net

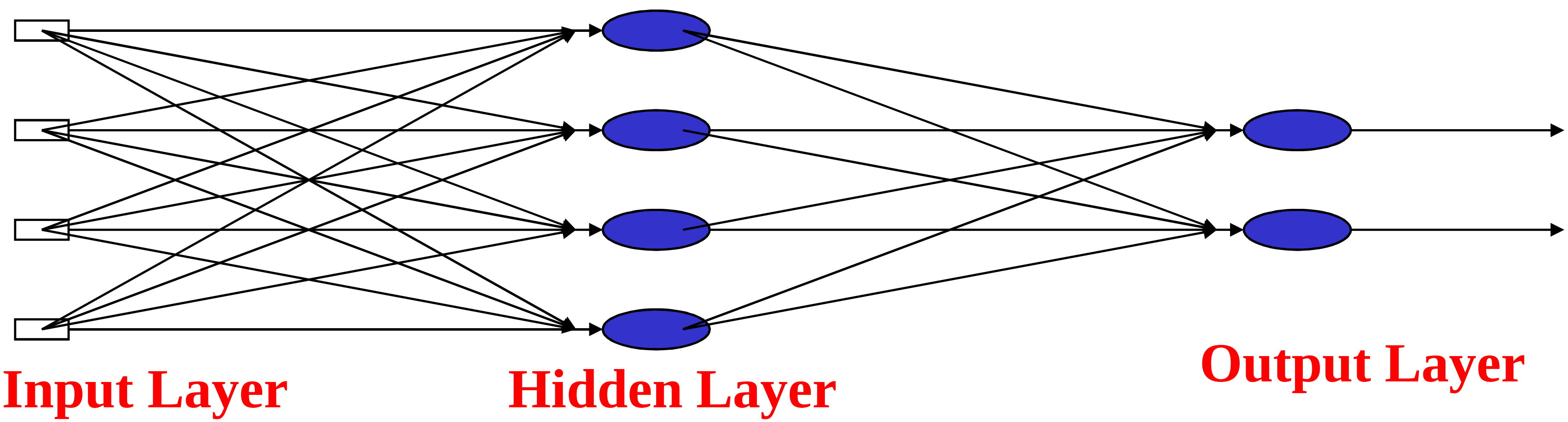
Single Layer Feed forward Networks

- It has only one layer of weighted interconnections. The inputs may be connected fully to the output units.
- In the single layer net the weights from one output unit do not influence the weights for other output units.



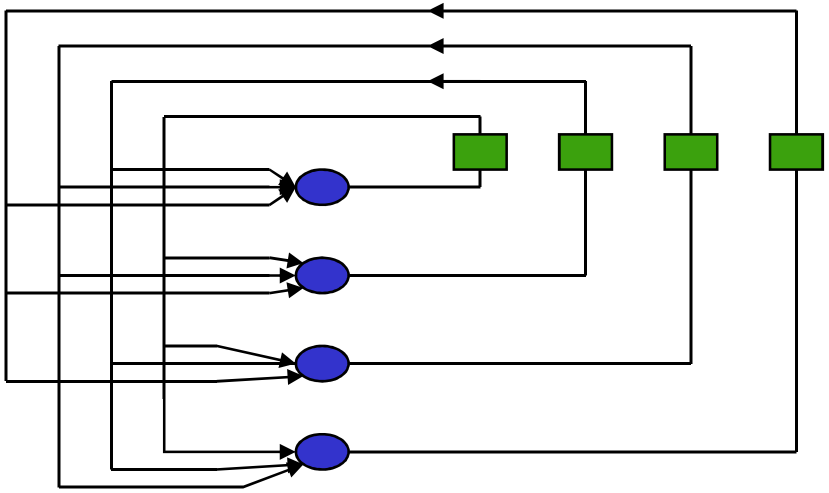
Multi Layer Feed Forward

- The net where the signals flow from the input units to the output units in forward direction.
- The multi-layer net pose one of more layers of nodes between the input and output units.
- The advantage of multi layer feed forward over single layer feed forward net is the sense that, it can be used to solve more complicated problems

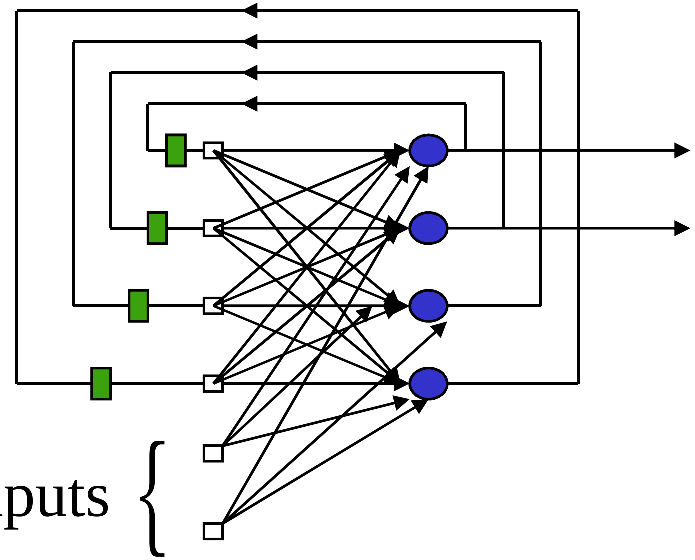


Recurrent Net

- All unit are connected to all other unit and every unit is both an input and an output.
- Typically, a set of patterns is instantiated on all of the units, one at a time. As each pattern is instantiated the weights are modified.



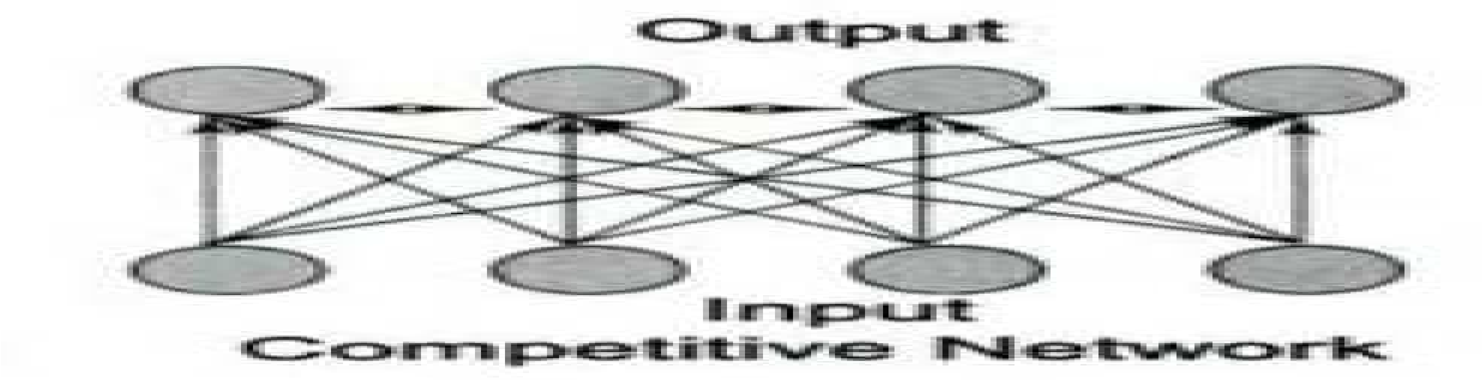
Recurrent network without hidden units



Recurrent network with hidden units

Competitive Net

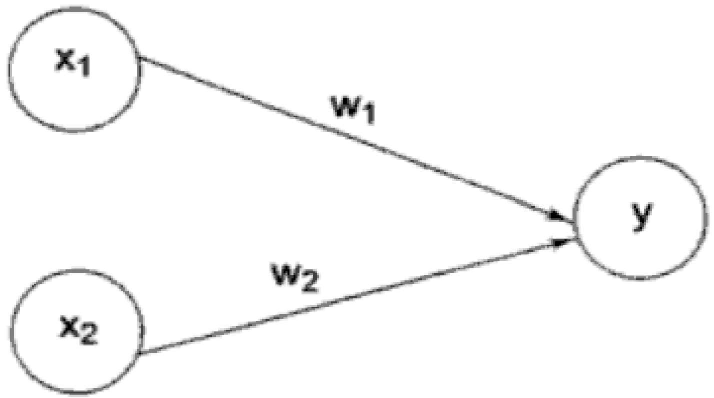
- The competitive net is similar to a single layered feed forward network except that there are connections, usually between negative between output nodes.
- Because of these connections the output nodes tend to compete to represent the current input pattern.
- Sometime the output layer is completely connected and some times the connections are restricted to units that are close to each other (in some neighborhood).



Weights

- Weight is an information used by the neural net to solve a problem.

- x_1 = Activation of neuron 1 (input signal)
- x_2 = Activation of neuron 2 (input signal).
- y = output neuron
- w_1= Weight connecting neuron 1 to output
- w_2 = Weight connecting neuron 2 to output



- Based on all these parameters, the net input 'net' is calculated. The Net is the summation of the products of the weights and the input signals
- $Net = x_1w_1 + x_2 w_2$
- Or $$Net = \sum_i x_i w_i$$

Setting the Weights

- The method of setting the value for the weights enables the process of learning or training.
- The process of modifying the weights in the connections between network layers with the objective of achieving the expected output is called training a network.
- The internal process that takes place when a network is trained is called learning.
- There are three types of training
  - Supervised Training
  - Unsupervised Training
  - Reinforcement Training

Supervised Training

- Supervised training is the process of providing the network with a series of sample inputs and comparing the output with the expected responses.
- The training continues until the network is able to provide the expected response.
- For this purpose a sequence of training input vectors there may exist target output vectors.
- The weights may then be adjusted according to learning algorithm.
- Some of the supervised training algorithms
  - Hebb net
  - Pattern association memory net
  - Back propagation net
  - Counter propagation net

Unsupervised Training

- In a neural net, if for the training input vectors, the target output is not known, the training method adopted is called as unsupervised training.
- The net may modify the weight so that most similar input vector is assigned to same output unit.
- Some of the unsupervised training algorithms
  - Binary Adaptive Resonance Theory (ART1)
  - Analog Adaptive Resonance Theory (ART2)
  - Discrete Hopfield
  - Continuous Hopfield
  - Kohonen Self Organizing Map (SOM)
  - Competitive Learning

Reinforcement Training

- In this method, a teacher is also assumed to be present, but the right answer is not presented to the network.
- The network is only presented with an indication of whether the output answer is right or wrong.
- The network must then use this information to improve its performance.
- Some of the reinforcement training algorithms
  - Markov decision process
  - Markov chain

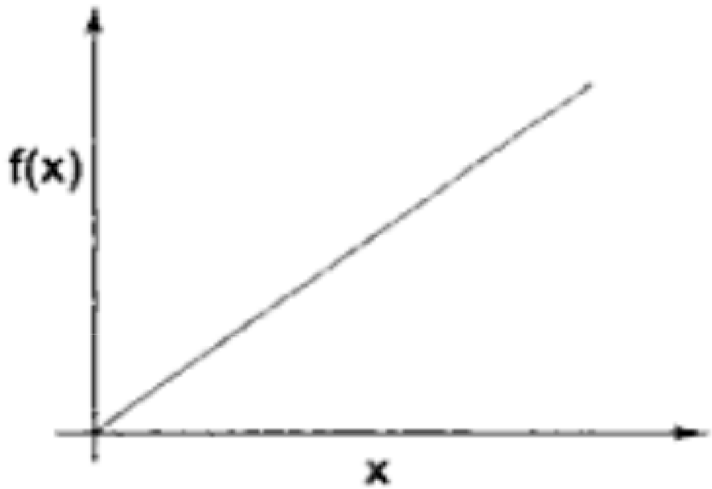
Activation Function

- The activation function is used to calculate the output response of a neuron.
- The sum of the weighted input signal is applied with an activation to obtain the response.
- Some activation functions are:
  - Identity function
  - Binary step function
  - Sigmoidal Functions (Binary and Bipolar)

Activation Function…

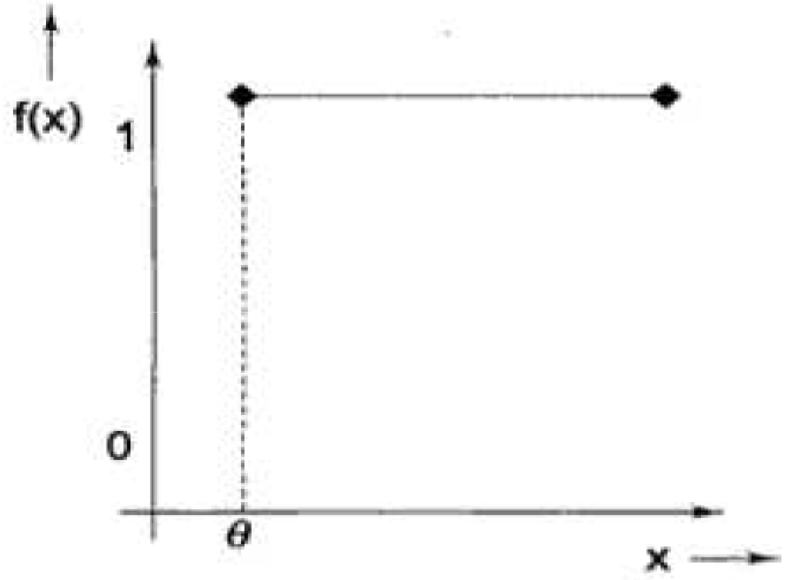
- **Identity Function**
  - The function is given by,

    F(x) = x; for all x



- **Binary Step Function**
  - The function is given by

$$f(x) = \begin{cases} 1; & \text{if} \quad f(x) \geq \theta \\ 0; & \text{if} \quad f(x) < \theta \end{cases}$$



Activation Function…

- Sigmoidal Functions
  - These functions are usually S-shaped curve.
  - These are used in multilayer nets like back propagation network, radial basis function network etc.
  - There are two main types of Sigmoidal fuctions:
    - Binary Sigmoidal Function
    - Bipolar Sigmoidal Function

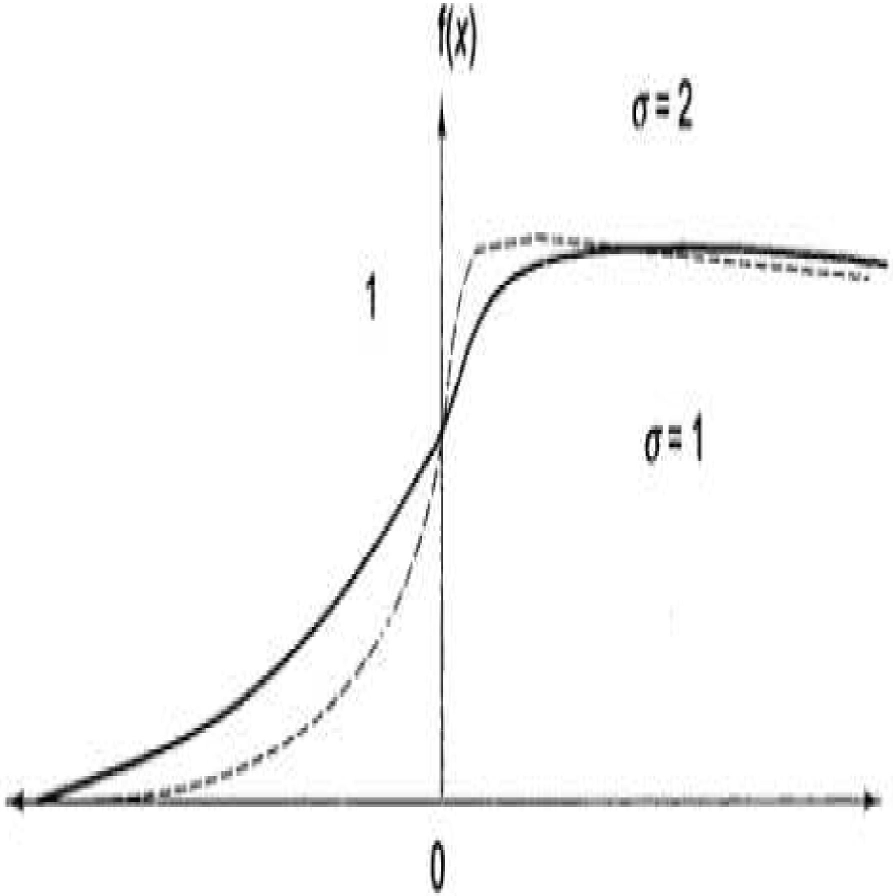
Binary Sigmoidal Function

- This is called logistic function
- It ranges between 0 to 1.
- This function can be represented as

$$f(x) = \frac{1}{1 + \exp(-\sigma x)}$$

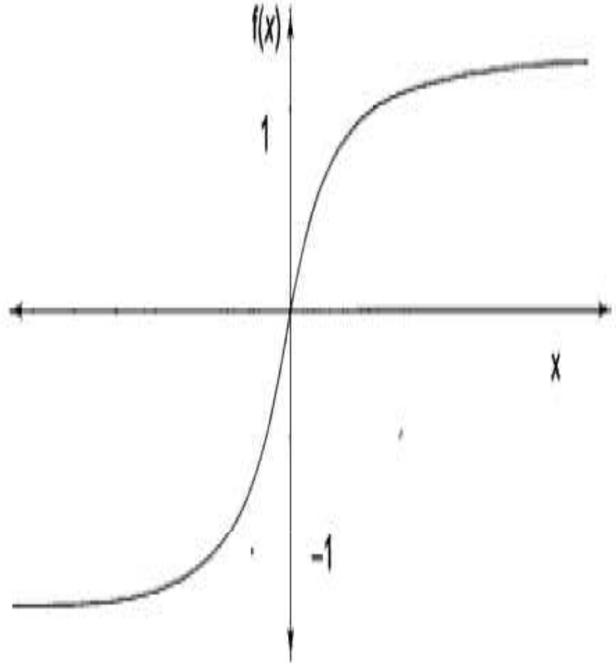
- Where σ is called the steepness parameters. If f(x) is differentiated we ge

- $$f'(x) = \sigma f(x) [1 - f(x)].$$



Bipolar Sigmoidal Function

- The desired range here is between +1 and -1 .
- This function is related to the hyperbolic tangent function
- The bipolar sigmoidal function is b(x) = 2f(x) -1



$$b(x) = 2 \times \frac{1}{1 + \exp(-\sigma x)} - 1$$

$$= \frac{2 - 1 - \exp(-\sigma x)}{1 + \exp(-\sigma x)}$$

$$b(x) = \frac{1 - \exp(-\sigma x)}{1 + \exp(-\sigma x)}$$

On differentiating the function

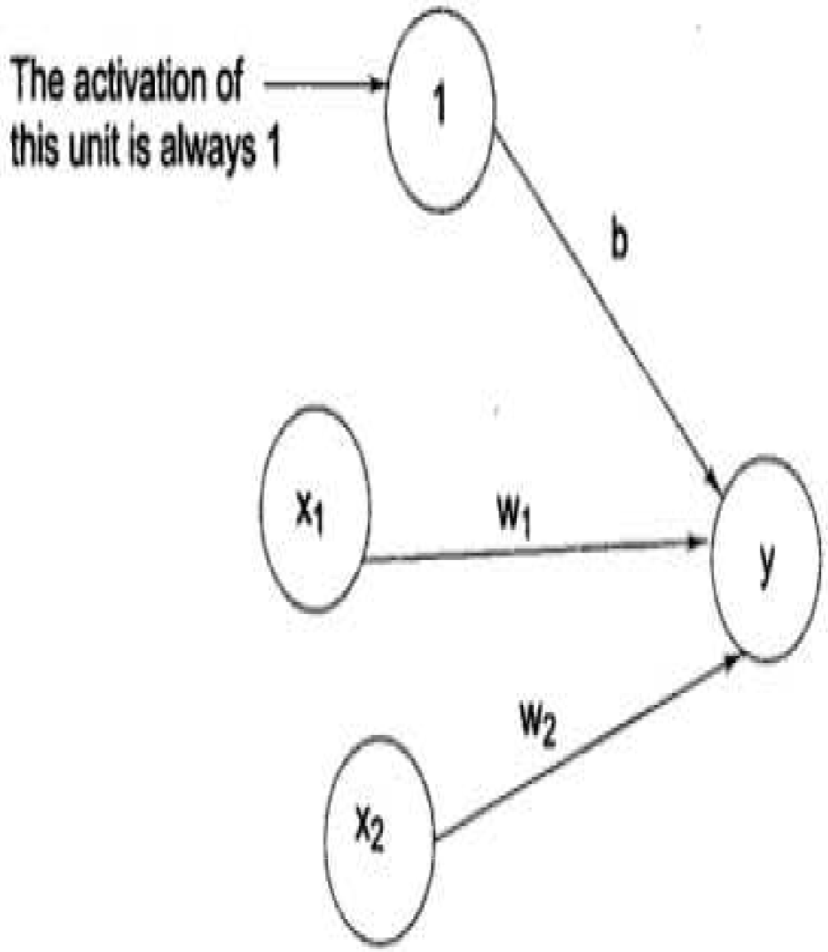
$$b'(x) = \frac{\sigma}{2}[\{1 + b(x)\}(1 - b(x))]$$

Bias

- Bias acts as a weight on connection from a unit whose activation is always 1.
- Increasing the bias increases the net input to the unit.
- The bias improves the performance of the neural network.
- Bias can be initialized either 0 or to any specified values based on neural net.
- If bias is present the net input is calculated as:

$$Net = b + \sum x_i w_i$$

Where b is bias



Threshold

- The threshold ‘θ’ is a factor which is used in calculating the activations of the given net.

$$\text{(i)}\quad y = f(\text{Net}) = \begin{cases} +1 & \text{if net } \geq \theta; \\ -1 & \text{if net } < \theta; \end{cases}$$

$$\text{(ii)}\quad y_j = f(\text{Net}) = \begin{cases} 1 & \text{if } y_{inj} > \theta_j \\ y_j & \text{if } y_{inj} = \theta_j \\ -1 & \text{if } y_{inj} < \theta_j \end{cases}$$ used for a bidirectional associative memory net

Neural network as directed Graph

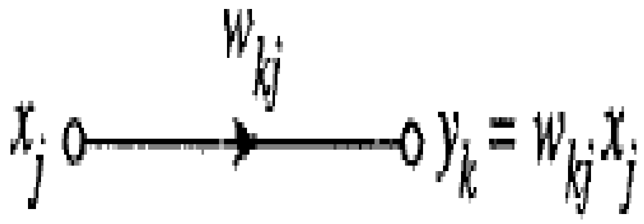
- The block diagram provides a functional description of the various elements that constitute the model of an artificial neuron.
- Block diagram can be simplify by the idea of signal flow graph
- A signal flow graph is a network of directed links (branches) that are interconnected at certain points called notes.
- node is associated with signal

Neural network as directed Graph…

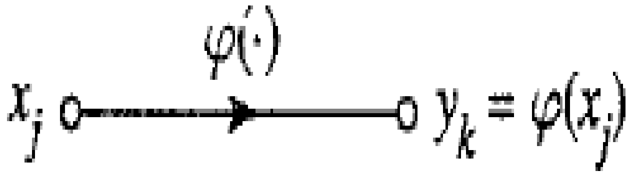
- Rule 1: A signal flows along a link only in the direction defined by the arrow on the link.

- Two different types of links may be distinguished:

  - Synaptic links, whose behavior is governed by a linear input -output relation. Specifically, the node signal x_i is multiplied by synaptic weight w_{kj} to produce the node signal y_k

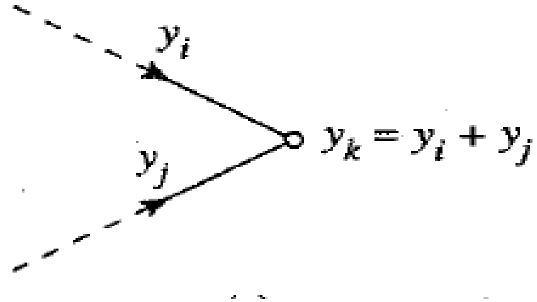


  - Activation links, whose behavior is governed in general by a nonlinear input-output relation.

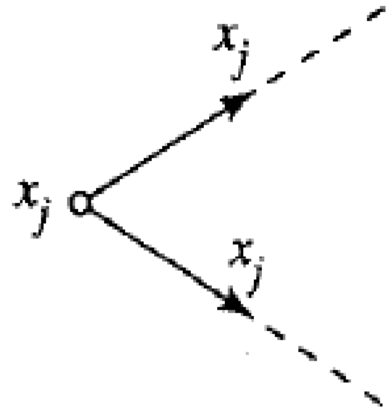


Neural Network as directed Graph…

Rule 2: A node signal equals the algebraic sum of all signals entering the pertinent node via the incoming links.



Rule 3. The signal at a node is transmitted to each outgoing link originating from that node, with the transmission being entirely independent of the transfer functions of the outgoing links.

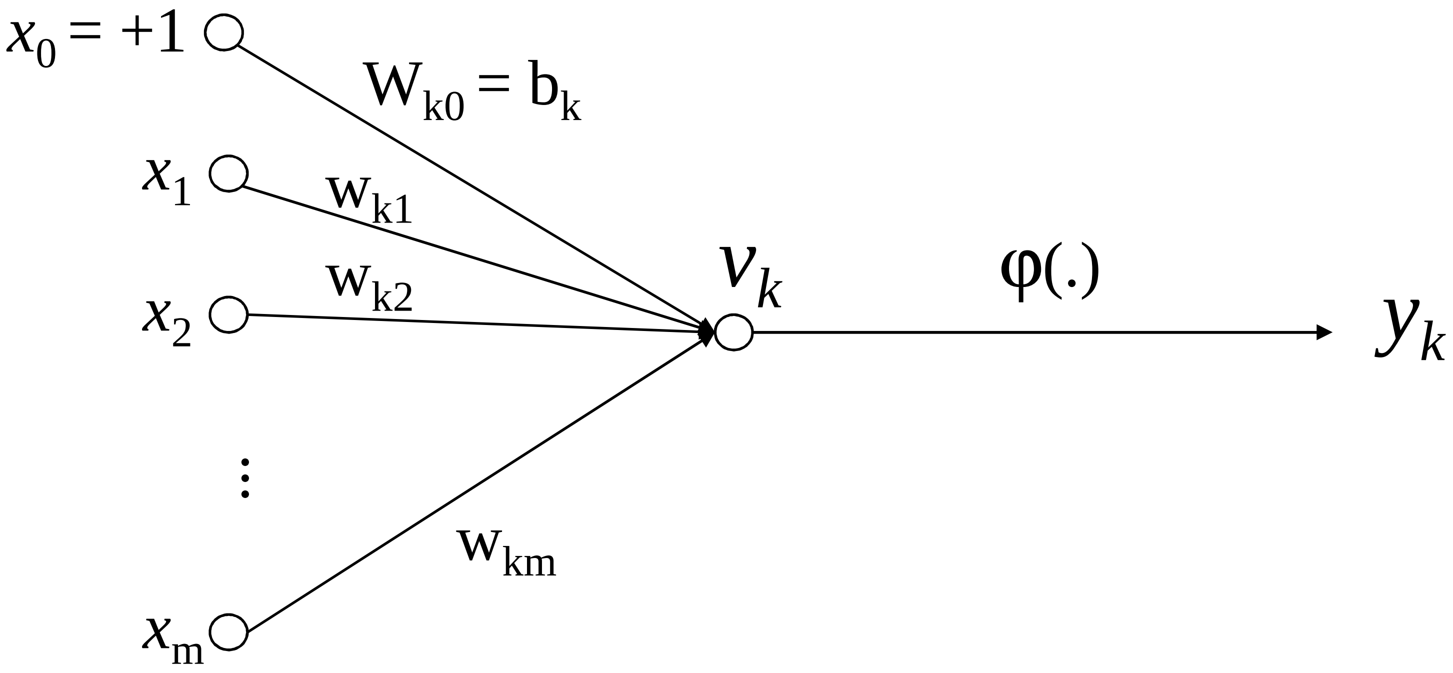


Properties

A neural network is a directed graph consisting of nodes with interconnecting synaptic and activation links, and is characterized by four properties:

1. *Each neuron is represented by a set of linear synaptic links, an externally applied bias, and a possibly nonlinear activation link. The bias is represented by a synaptic link connected to an input fixed at +1.*
2. *The synaptic links of a neuron weight their respective input signals.*
3. *The weighted sum of the input signals defines the induced local field of the neuron in question.*
4. *The activation link squashes the induced local field of the neuron to produce an output.*

Signal Flow Graph of a Neuron

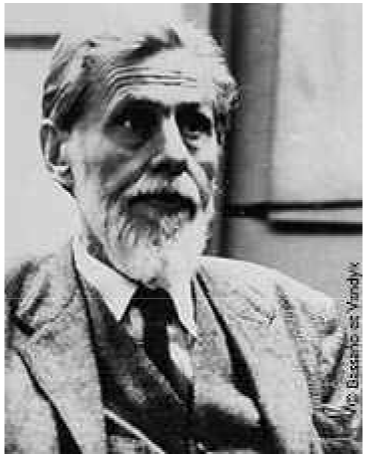


Architectural graph of a Neuron

- Partially complete directed graph describing layout
- Computation node : shaded
- source node : small square
- Three graphical representations
  - Block diagram - providing functional description of a NN
  - Signal flow graph - complete description of signal flow
  - architectural graph - network layout

McCulloch Pitts Neuron Model

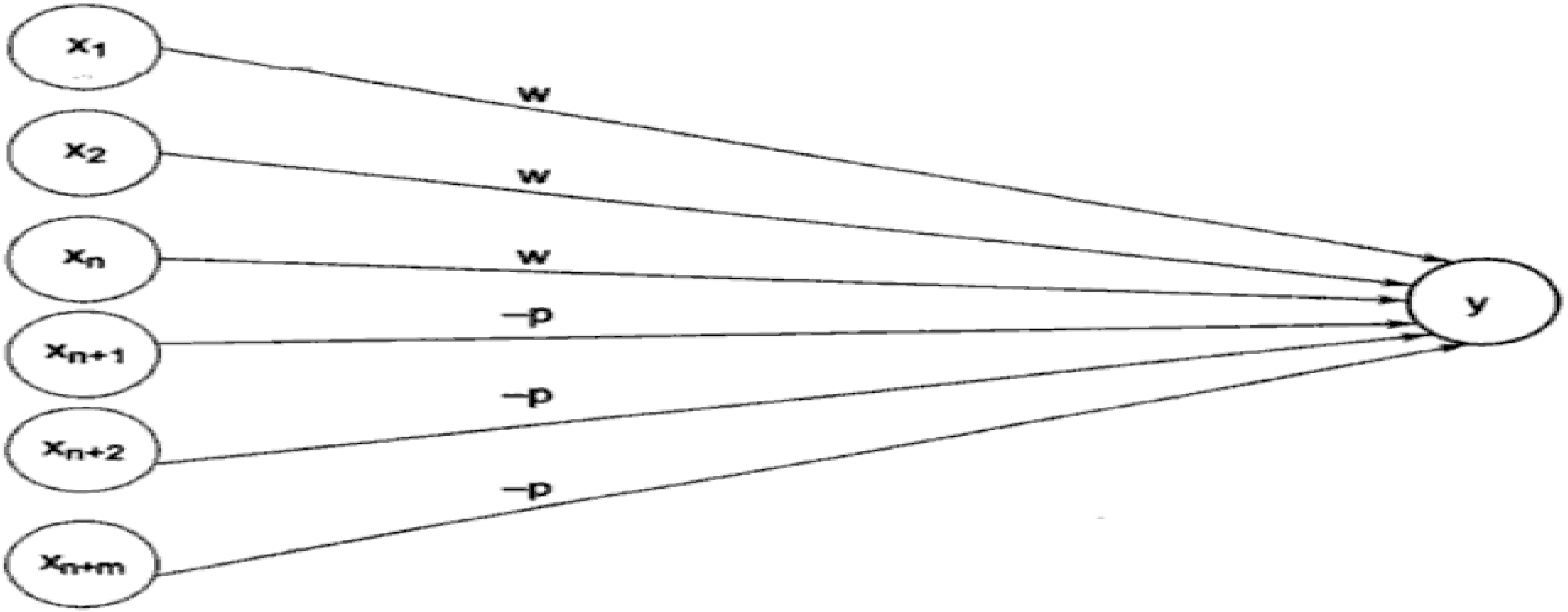
- It is first neural neuron model
- It was developed by Warren McCulloch and Walter Pitts in 1943.
- It allows binary 0 and 1 states only.
- These neurons are connected by direct weighted path.
- The connected path can be excitatory or inhibitory.
- Excitatory connections have positive weights.
- Inhibitory connections have negative weights.
- The neuron is associated with the threshold values.



Warren McCulloch

Walter Pitts

Architecture of McCulloch Pitts Model



- 'Y' is the McCulloch Pitts neuron, it can receive signal from any number of other neurons.
- The connection weight from x_1, x_2, …x_n are excitatory.
- The connection weight from x_{n+1}…x_{n+m} are inhibitory

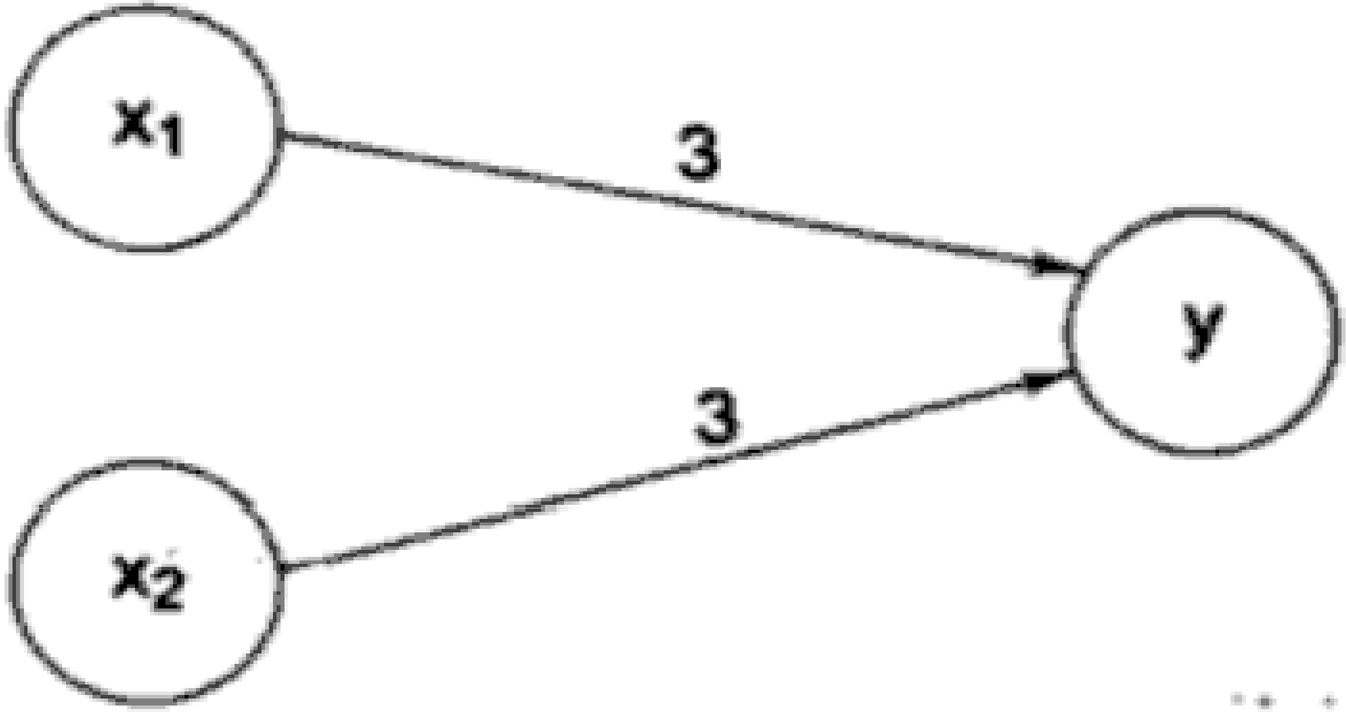
McCulloch Pitts Activation Function

- The McCulloch Pitts neuron Y has the activation function

$$f(y_{in}) = \begin{cases} 1 & \text{if } y_{-in} \geq \theta \\ 0 & \text{if } y_{-in} < \theta \end{cases}$$

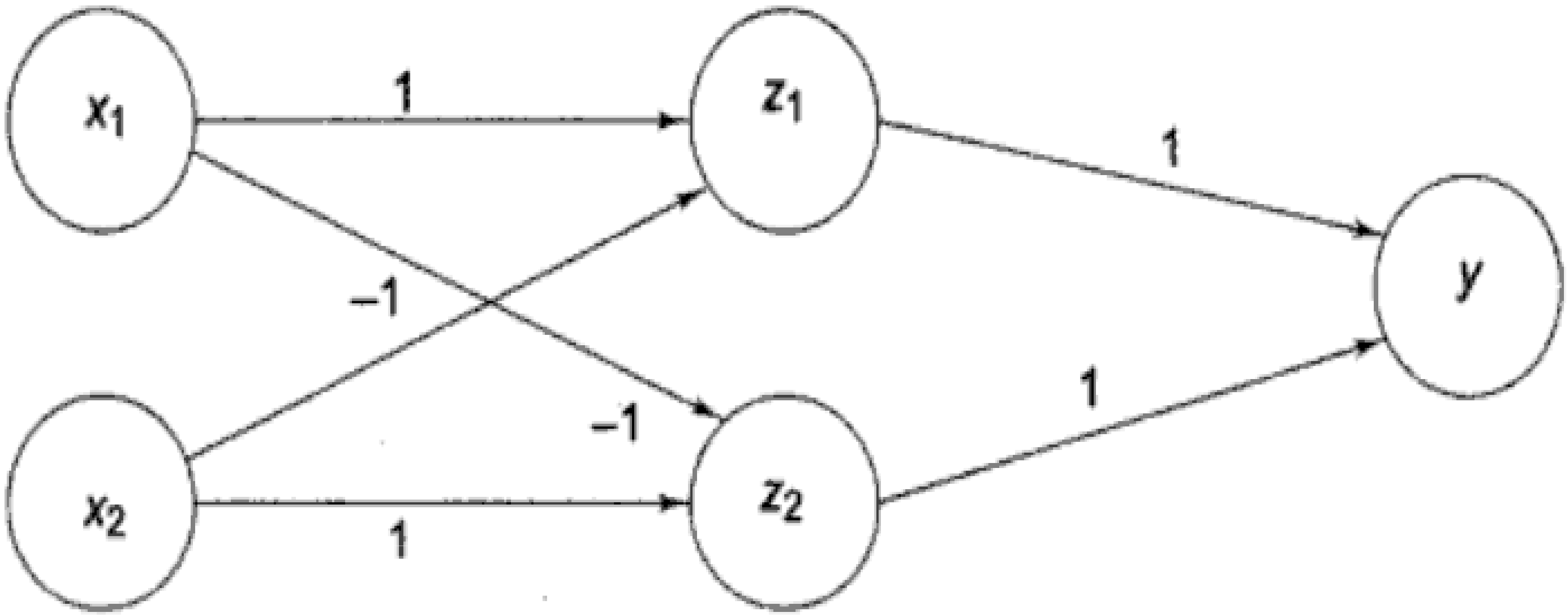
Problem

- Realize the OR function using McCulloch Pitts neuron.



Problem

- Realize the Exclusive –OR function using McCulloch Pitts neuron.

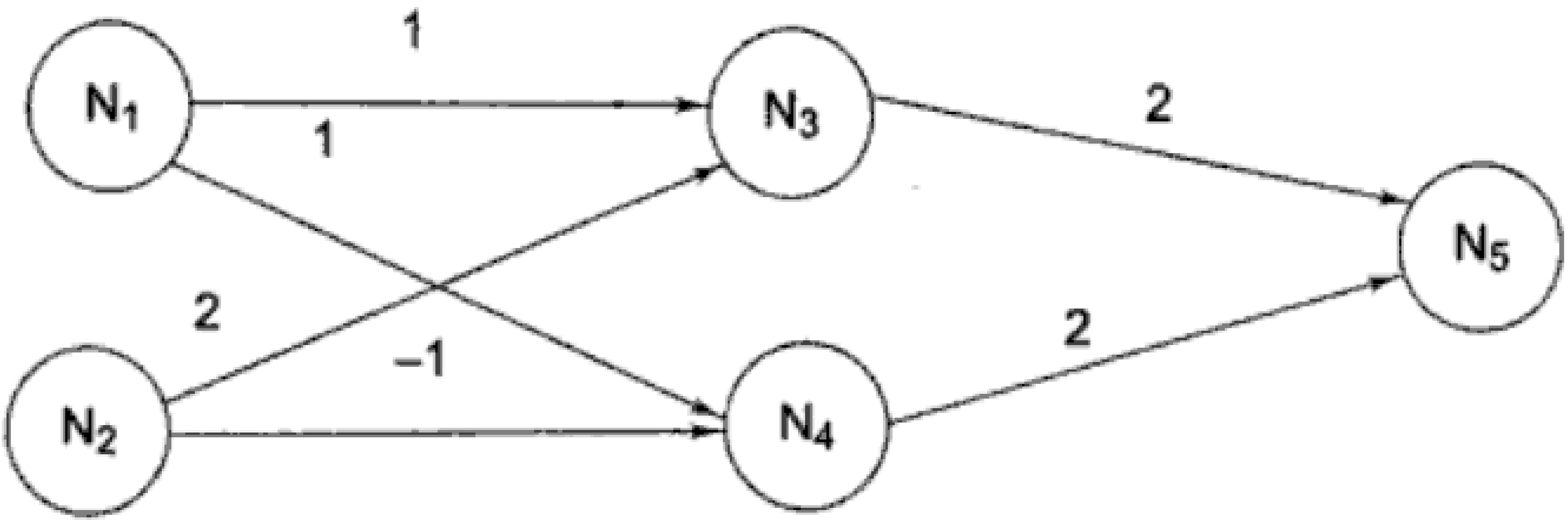


Problem

- Consider the neural network of McCulloch-Pitts neuron shown in figure. Each neuron (other than the input neurons N_1 and N_2) has threshold of 2.

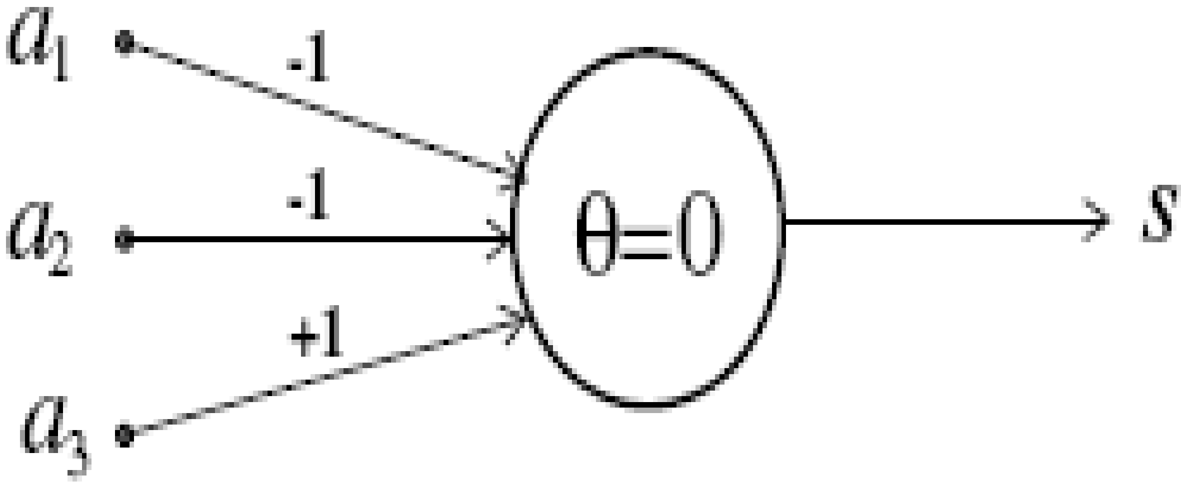
a. Define the response of neuron N_5 at time t in terms of the activation of the input neurons, N_1 and N_2 at the appropriate time.

b. Show that the activation of each neuron that results from an signal of $N_1 = 1$, $N_2 = 0$ at t=0.



Problem

- Explain the logic functions (using truth tables) performed by the following networks with MP neurons given below.



Solution

- Using the logic function,
- $f(x) = 1, x>\theta$

  $= 0 , x<= \theta$
- where $x = \sum w_i a_i$, the truth table is obtained by giving all possible combinations of a1; a2; a3. The results are shown in the following table.

a1	a2	a3	s
0	0	0	0
0	0	1	1
0	1	0	0
0	1	1	0
1	0	0	0
1	0	1	0
1	1	0	0
1	1	1	0

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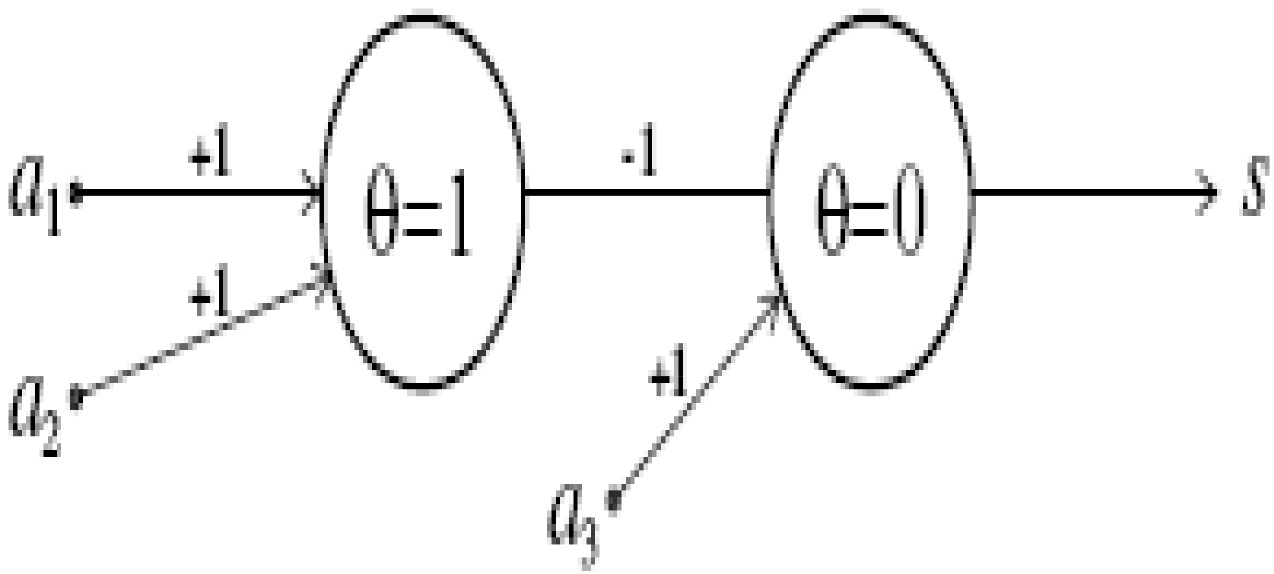

Solution

a1	a2	a3	s
0	0	0	0
0	0	1	1
0	1	0	0
0	1	1	1
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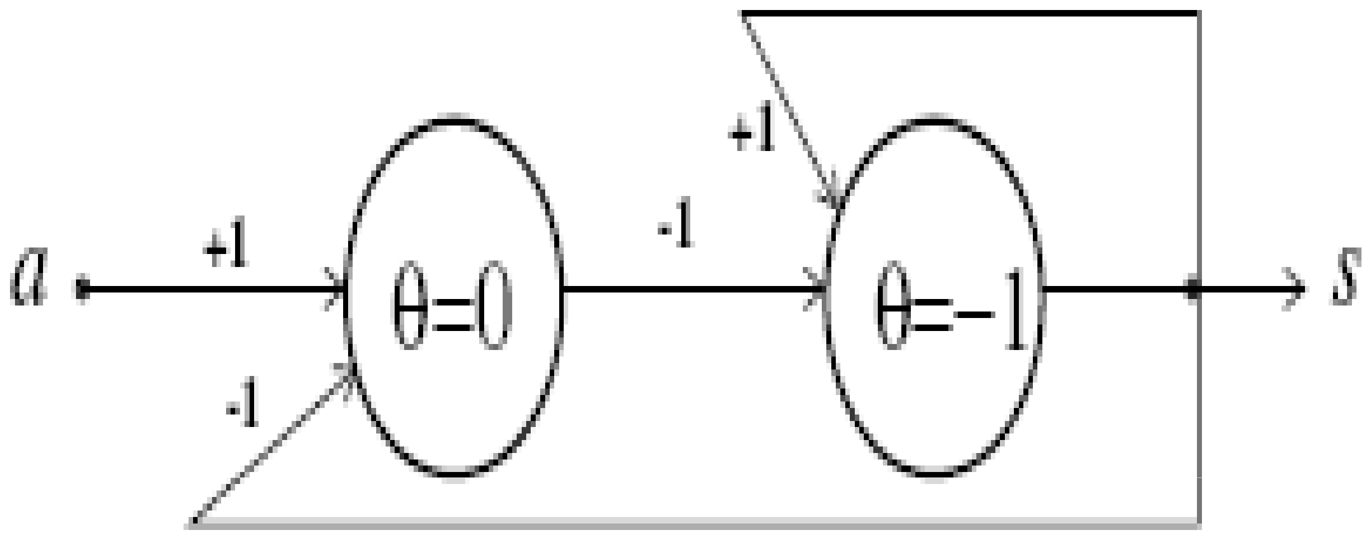


Solution

a	s(t − 1)	s(t)
0	0	1
0	1	1
1	0	0
1	1	1

Problem

- (a) Design networks using M-P neurons to realize the following logic functions using ± 1 for the weights

$$s(a_1, a_2, a_3) = a_1 a_3 + a_2 a_3 + \bar{a}_1 \bar{a}_3$$

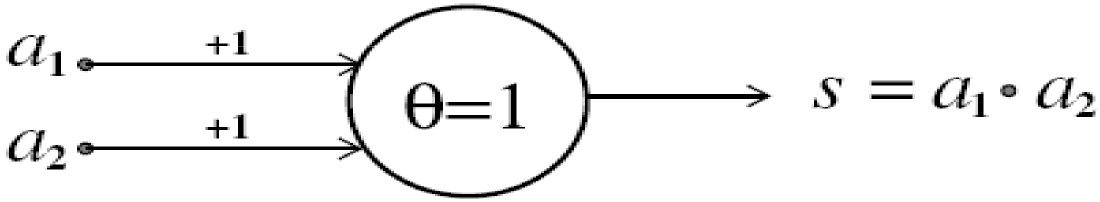
(b) Design networks using M-P neurons to realize the following logic functions using ± 1 for the weights

$$s(a_1, a_2, a_3) = a_1 a_2 a_3$$

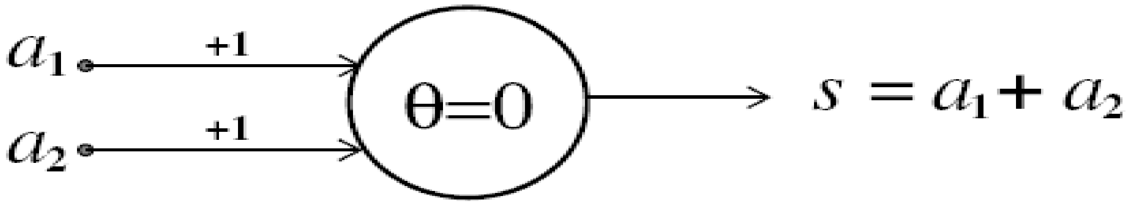
Solution

- Using the following basic logic networks

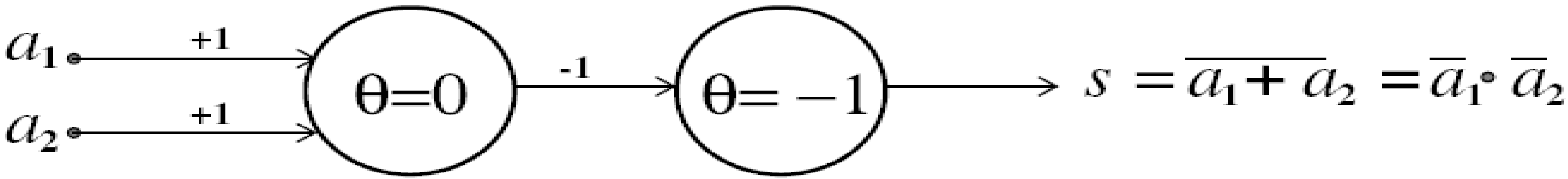
and



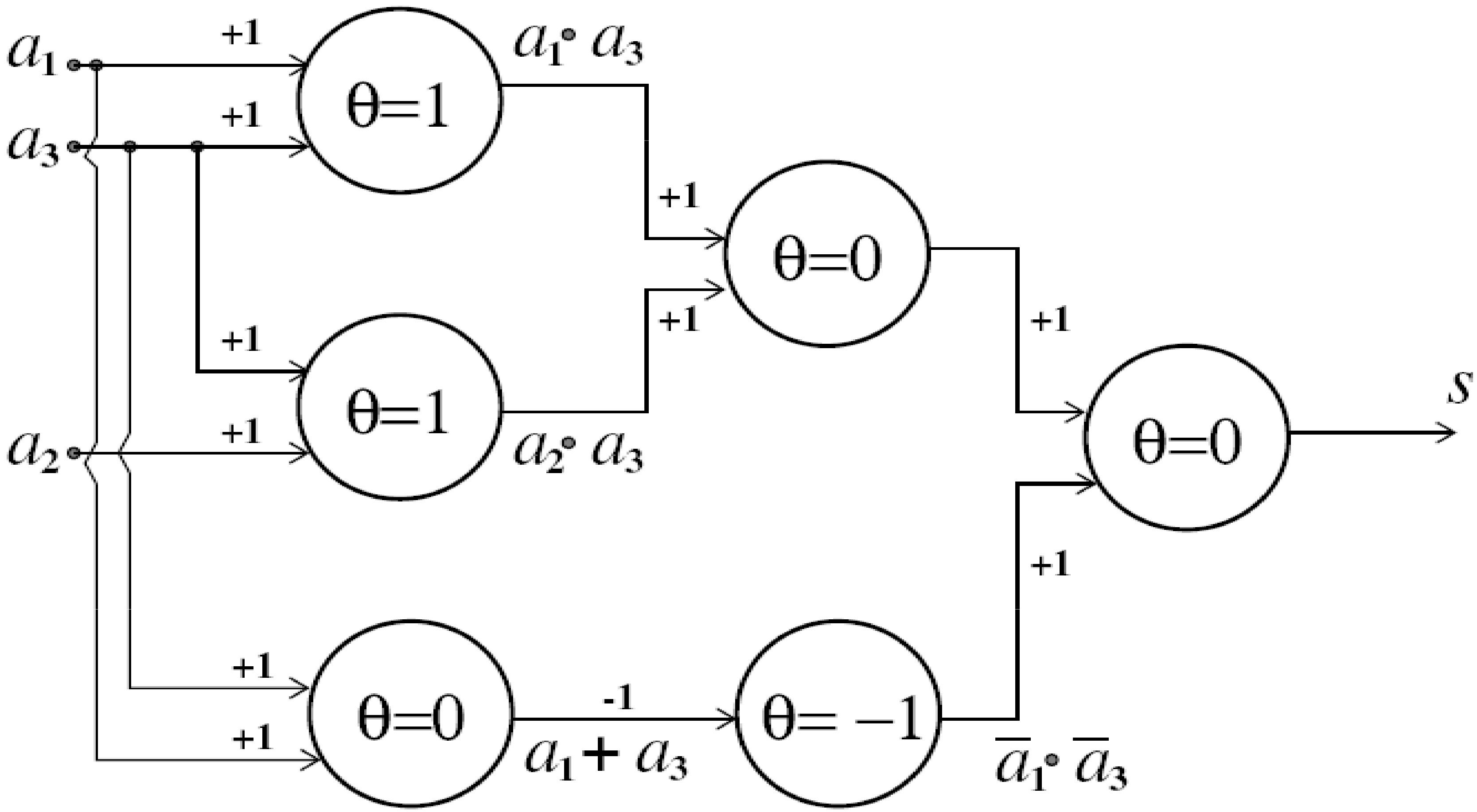
or



nor

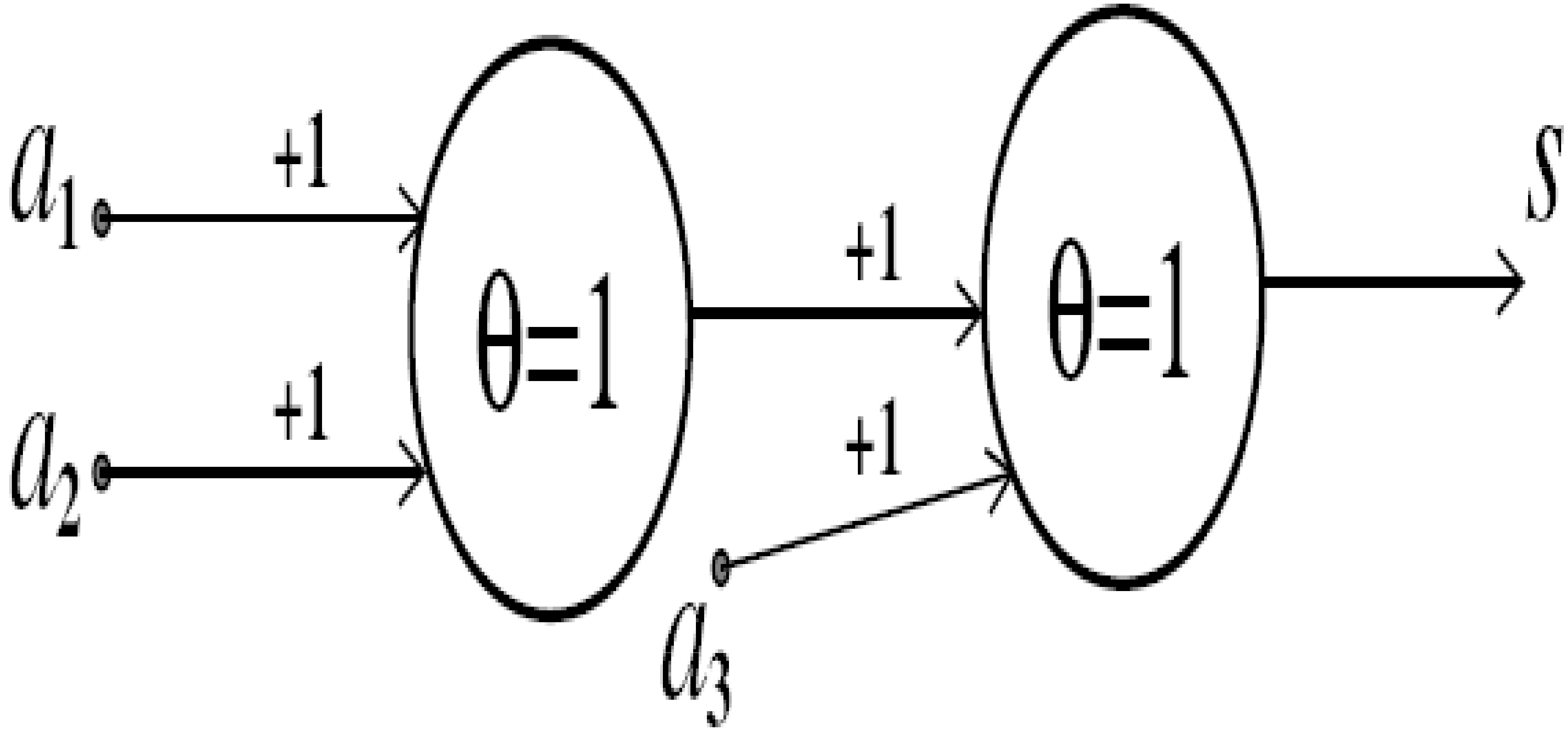


Solution (a)



a_1
a_3
a_2
+1
+1
+1
+1
+1
+1
θ=1
θ=1
θ=0
$a_1 \cdot a_3$
$a_2 \cdot a_3$
+1
+1
θ=0
-1
$a_1 + a_3$
θ= −1
$\overline{a_1} \cdot \overline{a_3}$
+1
+1
θ=0
s

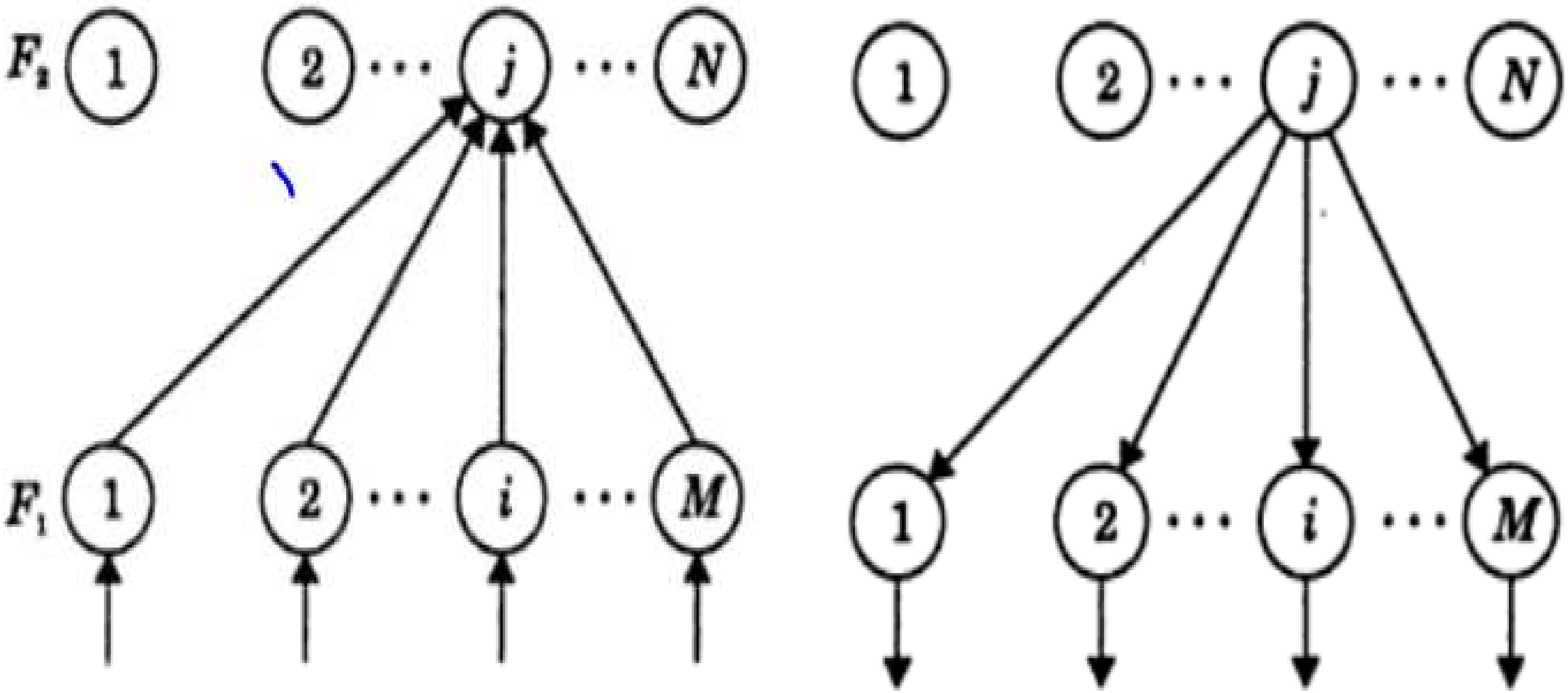
Solution (b)



Topology

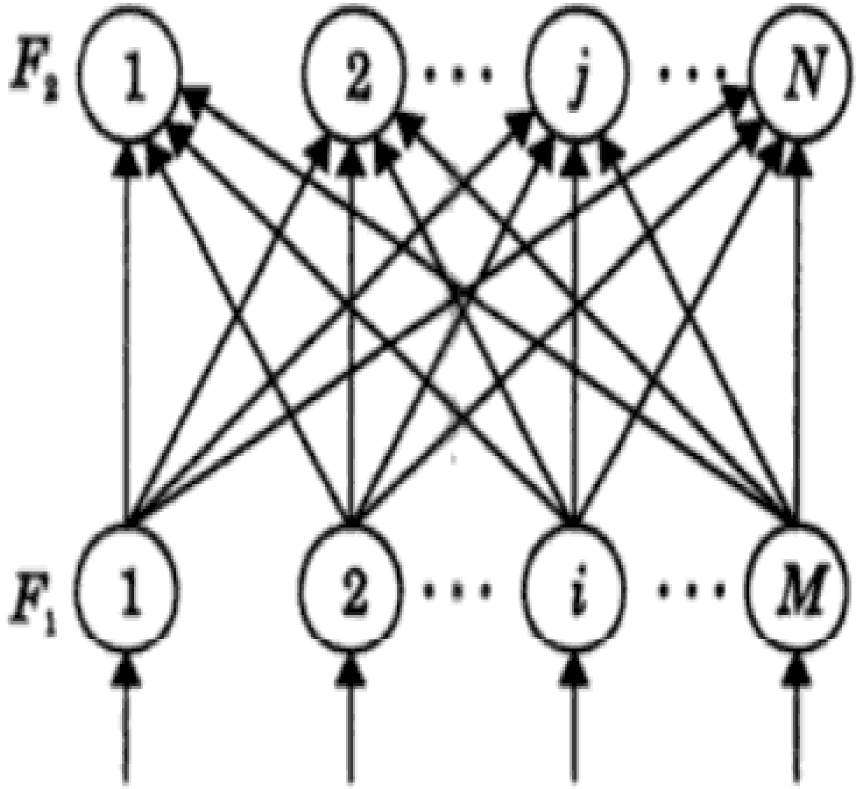
- ANN are organized into layers of processing units.
- The units of layer are similar in the sense that they all have the same activation dynamics and output function.
- The arrangement of the processing units, connections, and pattern input/output is referred to as topology.
- The connections can be made either from the units of one layer to the units of another layer (interlayer connections) or among the units within layer (intralayer connection) or both interlayer and Intralayer connection.
- Some basic structure of ANN are:
  - Instar
  - Outstar
  - Group of instars
  - Group of outstars
  - Bidirectional associative memory
  - Autoassociative memory

Instar and Outstar

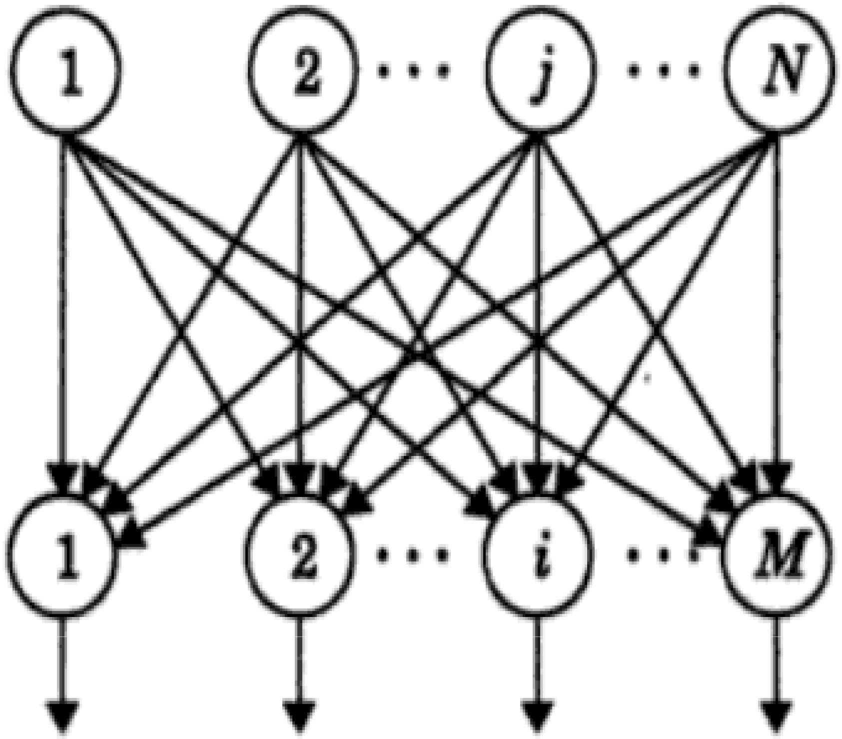


(a) Instar

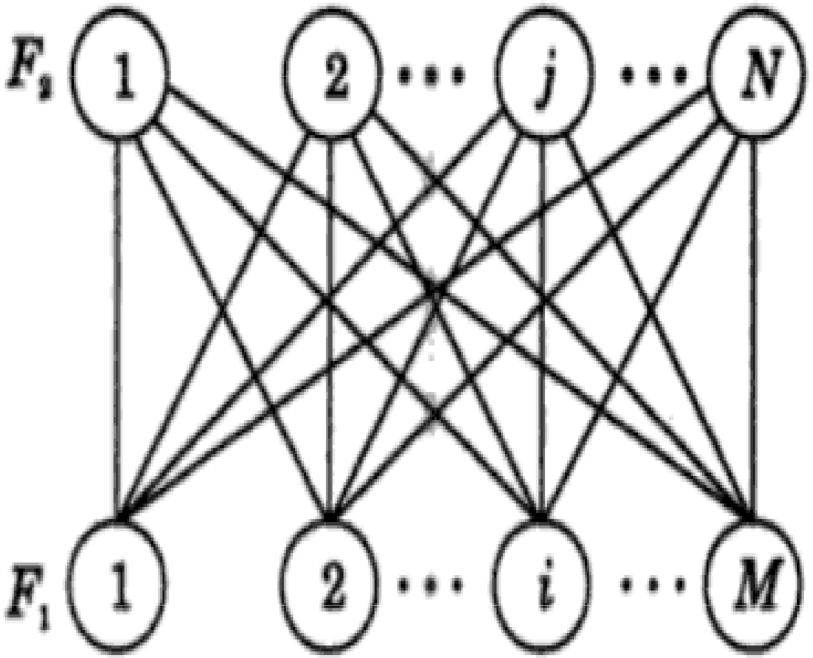
(b) Outstar



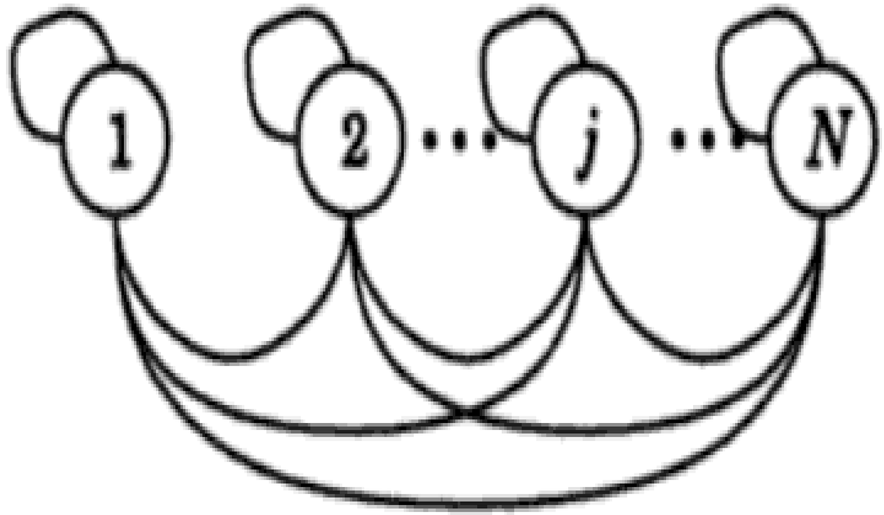
(c) Group of instars



(d) Group of outstars



(e) Bidirectional associative memory



(f) Autoassociative memory