Artificial Neural Networks (ANNs) Introduction

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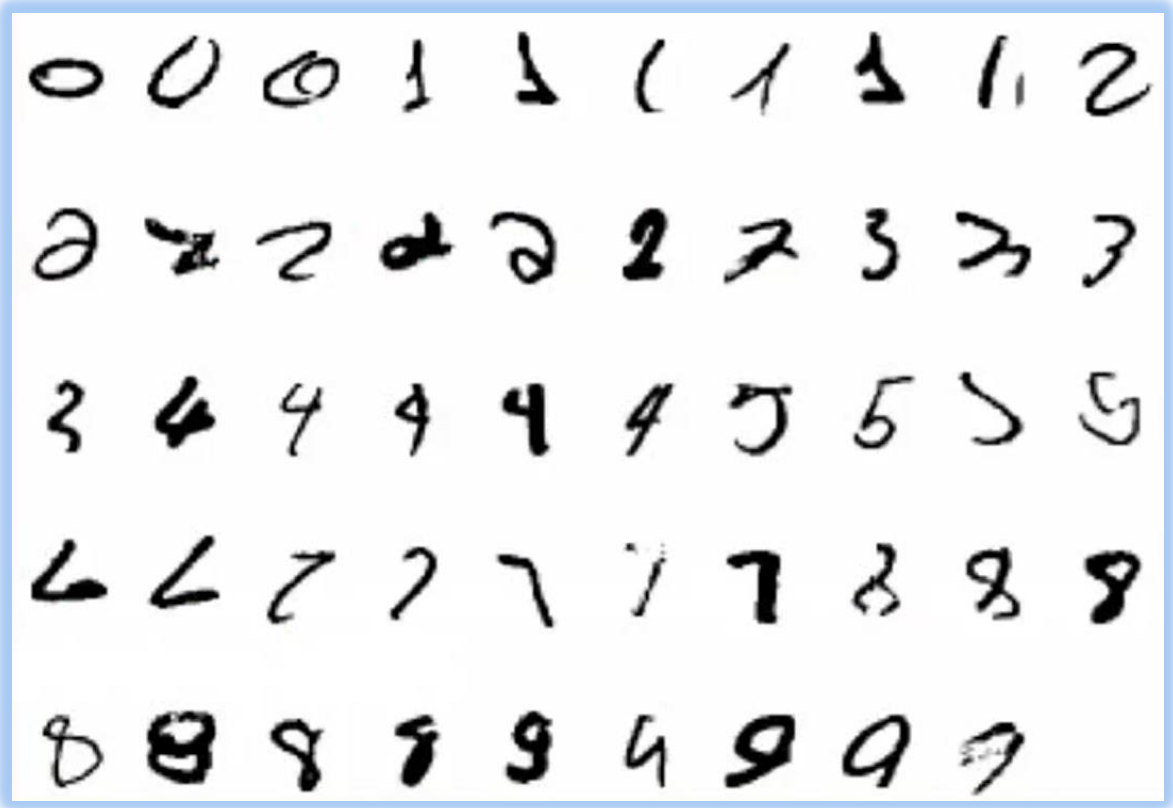
Why we need ANNs?

- There are some advanced operations (like face recognition, hand-writing recognition … etc) that we can do using our brain, but we don't know how it is exactly/internally done.
- We used to successfully do these operations after sufficient amount of training and practice.
- Unfortunately, it is very hard to try writing such a program that can recognize faces or hand-written text.
- Here, the role of the ANNs comes, It mimics the training activities that are internally done using the ***Nerve System*** inside the human brain!
- Training occurs through learning from many already-known past examples.
- A well-trained ANN will be able to yield correct results for new unknown problem instances.

Example: Hand-writing Recognition

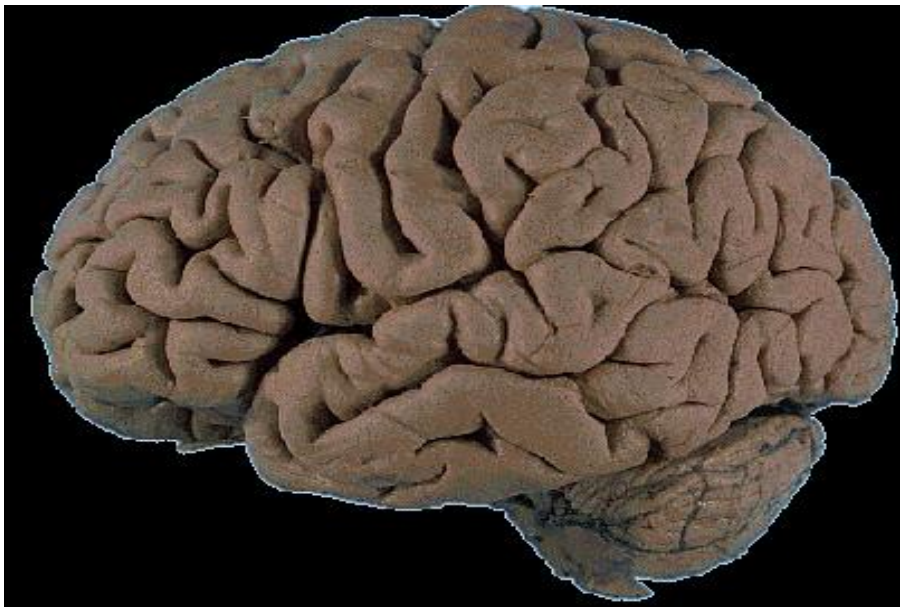
- It is very hard to develop a program that tells what makes a 2



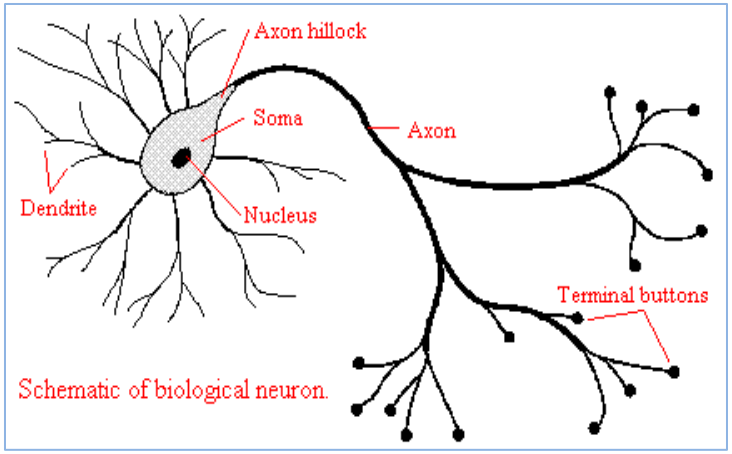
The Brain

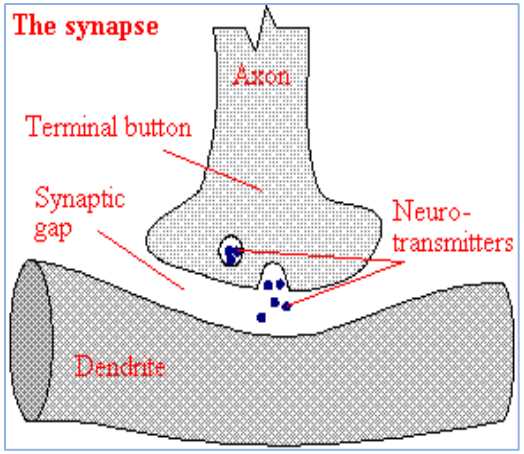
The Brain as an Information Processing System

The human brain contains about **10 billion** nerve cells, or **neurons**. On average, each neuron is connected to other neurons through about **10 000 synapses**.



The Biological Neuron





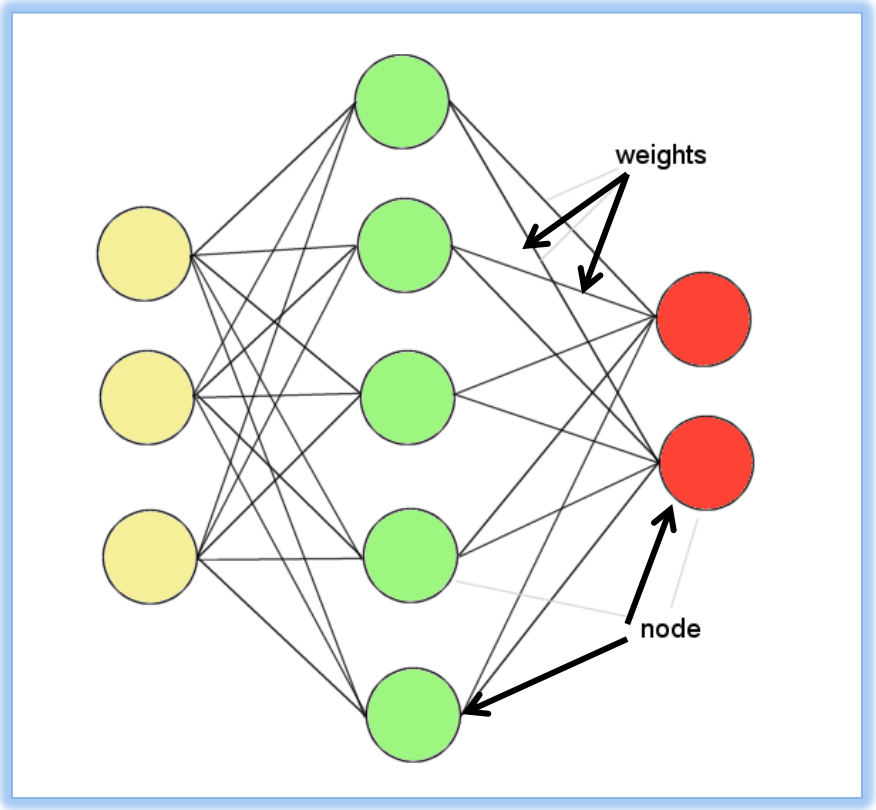
- The brain is a collection of about 10 billion interconnected neurons. Each *neuron* is a cell that uses *biochemical reactions* to ***receive***, ***process*** and ***transmit*** information.

- Each terminal button is connected to other neurons across a small gap called a *synapse*.

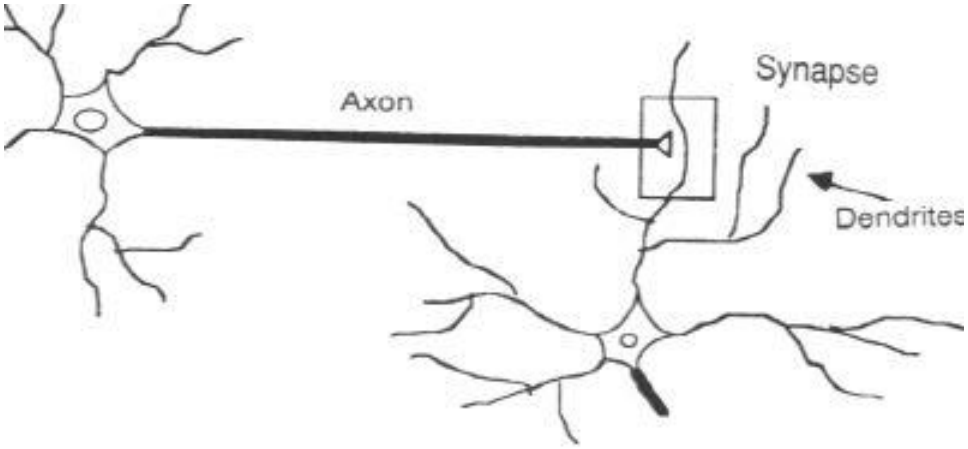
ANNs

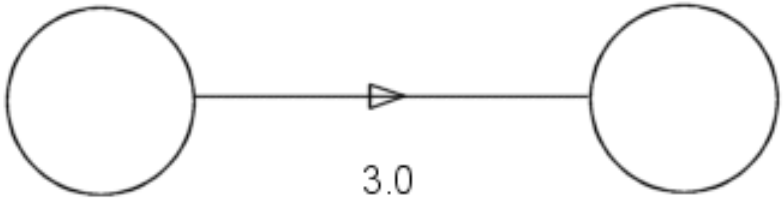
- ANNs incorporate the two fundamental components of biological neural networks:

1. Neurons (nodes)
2. Synapses (weights)

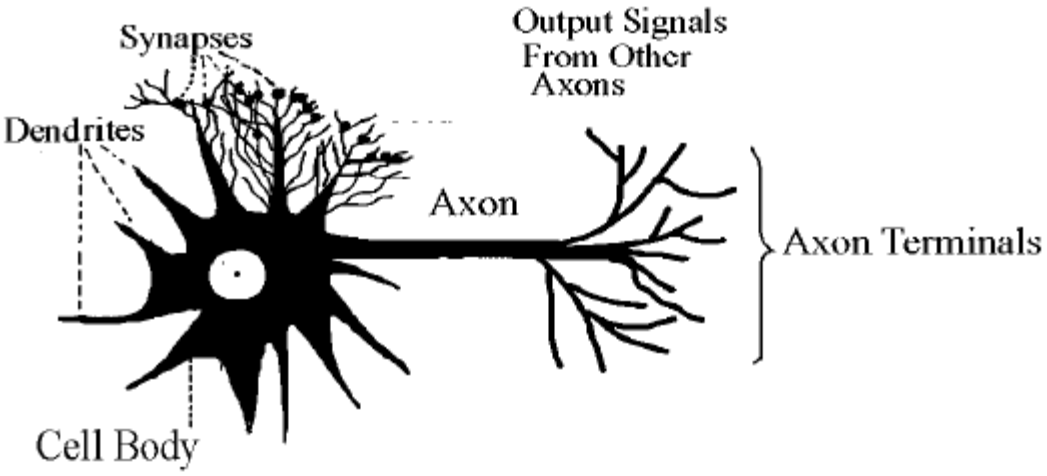


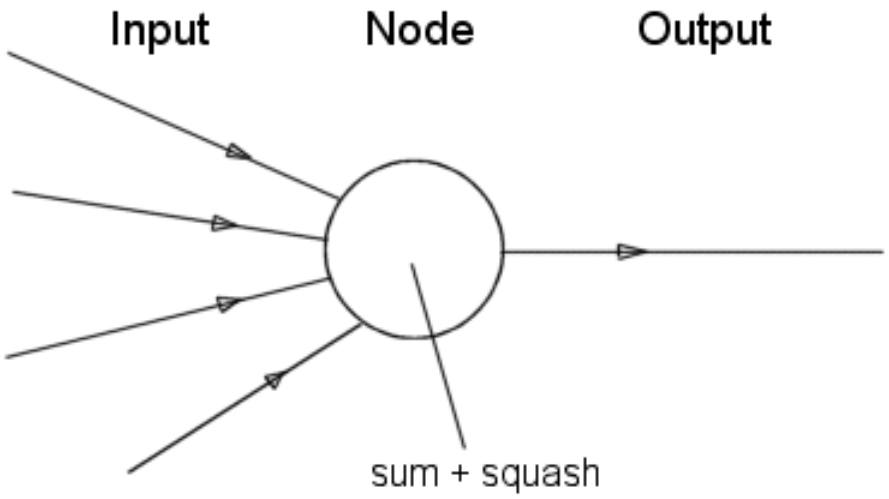
Axon/Synapse vs. Weight



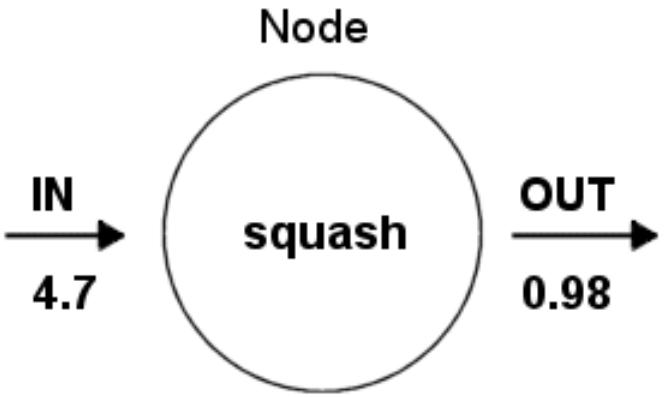


Neuron vs. Node

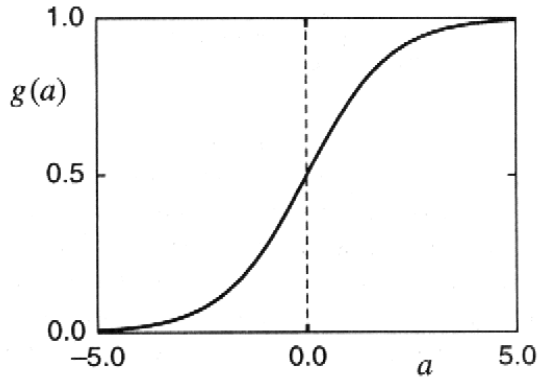




Structure of a node

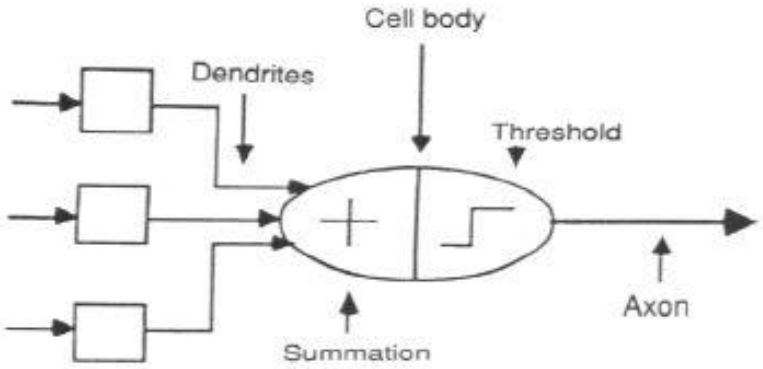


Squashing/Activation function limits node output:



A Neuron Model

- When a neuron receives *excitatory input* that is sufficiently large compared with its *inhibitory input*, it sends a spike of electrical activity down its axon.
- *Learning* occurs by changing the effectiveness of the synapses so that the influence of one neuron on another changes.



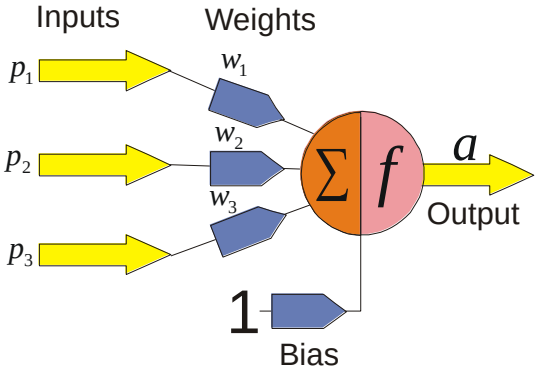
- We conduct these neural networks by first trying to deduce the essential features of neurons and their interconnections.
- We then typically program a computer to simulate these features.

Definition of Neural Network

- A Neural Network is a system composed of many simple processing elements operating in parallel which can acquire, store, and utilize experiential knowledge.
- **Neural network:** *information processing paradigm inspired by biological nervous systems, such as our brain*
- Structure: large number of highly interconnected processing elements (*neurons*) working together
- Like people, they learn *from experience* (by example)

The Key Elements of Neural Networks

- Neural computing requires a number of neurons, to be connected together into a neural network. Neurons are arranged in layers.



$$a = f(p_1w_1 + p_2w_2 + p_3w_3 + b) = f\left(\sum p_iw_i + b\right)$$

- Each *neuron* within the network is usually a *simple processing unit* which takes one or more inputs and produces an output.
- At each neuron, every input has an associated weight which modifies the strength of each input.
- The neuron simply adds together all the inputs and calculates an output to be passed on.

ANN

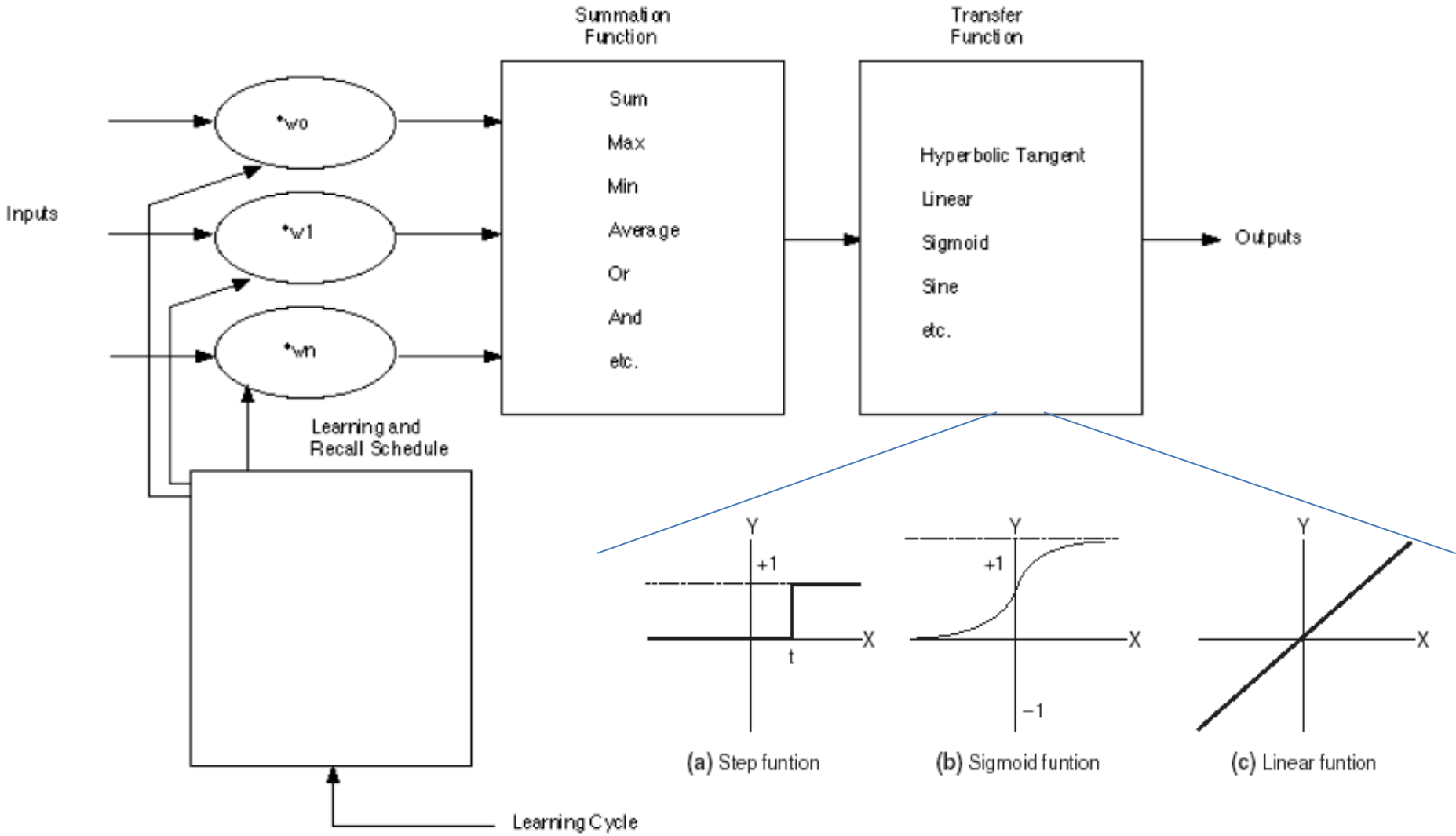
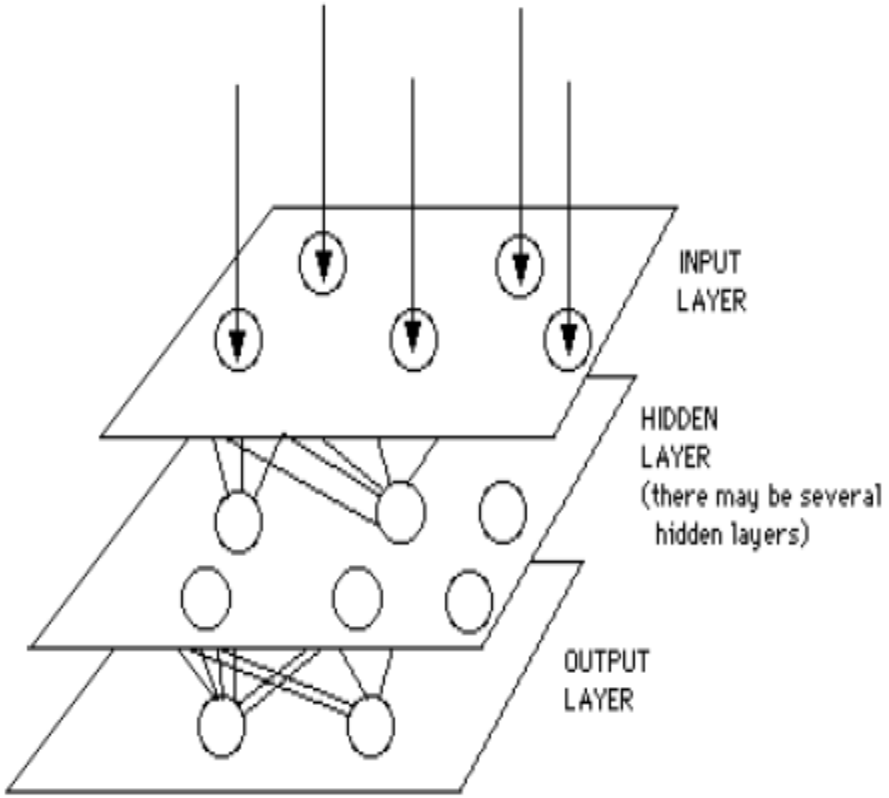
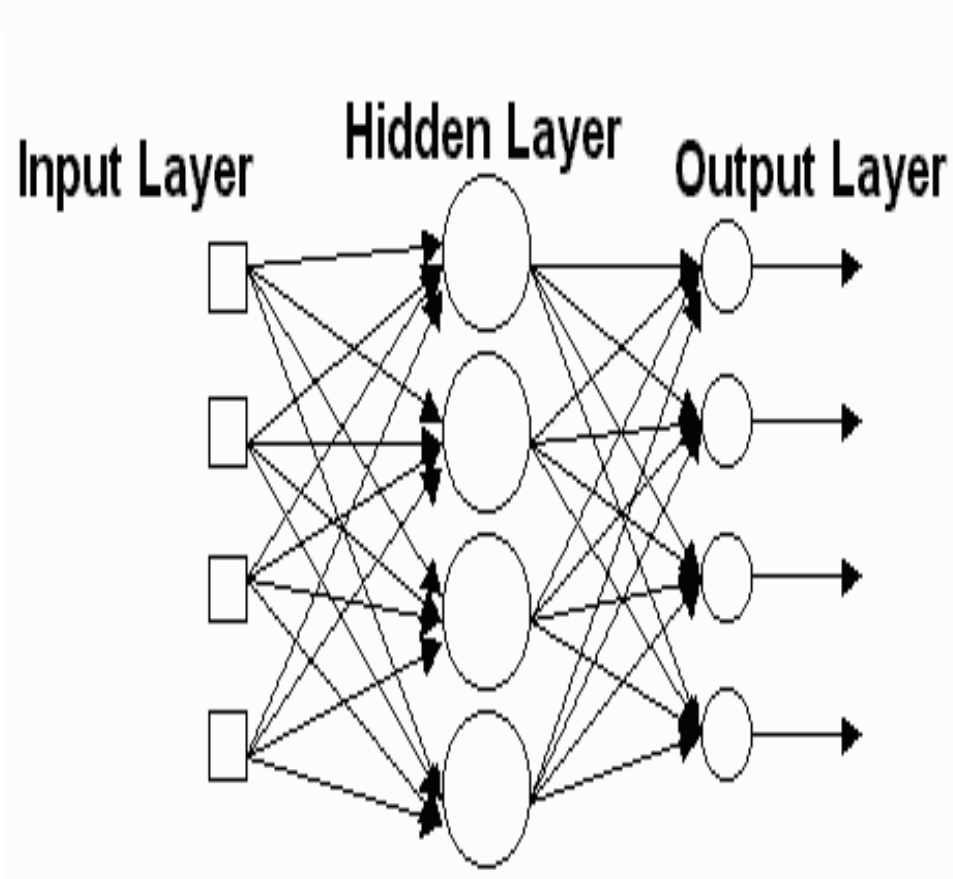
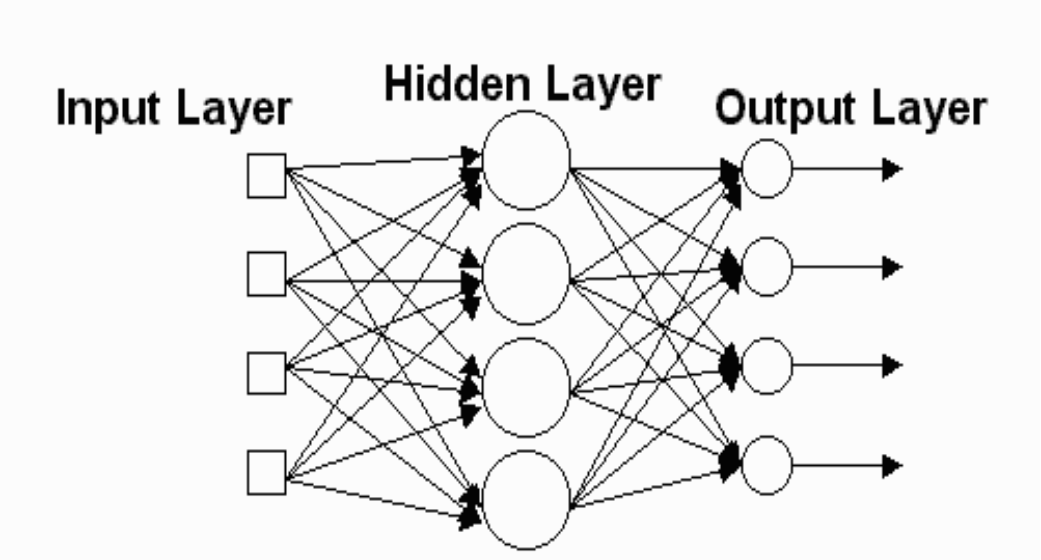

Summation Function
Transfer Function
Inputs
*w0
*w1
*wn
Sum
Max
Min
Average
Or
And
etc.
Hyperbolic Tangent
Linear
Sigmoid
Sine
etc.
Outputs
Learning and Recall Schedule
Learning Cycle
Y
+1
X
t
(a) Step funtion
Y
+1
X
−1
(b) Sigmoid funtion
Y
X
(c) Linear funtion

Diagram of a simple ANN



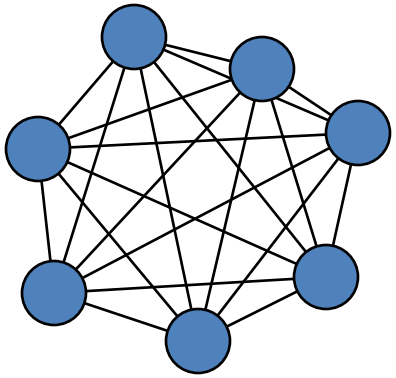


Network Layers

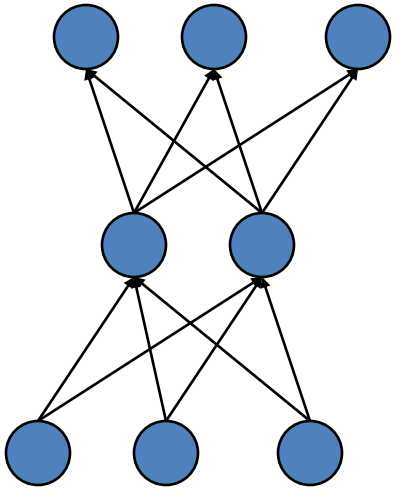


- **Input Layer** - The activity of the input units represents the raw information that is fed into the network.
- **Hidden Layer** - The activity of each hidden unit is determined by:
  - The activities of the input units and
  - The weights on the connections between the input and the hidden units.
- **Output Layer** - The behavior of the output units depends on:
  - The activity of the hidden units and
  - The weights between the hidden and output units.

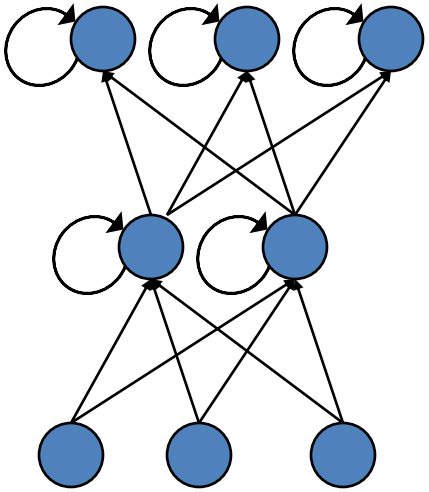
Topologies of Neural Networks



completely connected



feedforward (directed, a-cyclic)



recurrent (feedback connections)

History

- 1943: McCulloch–Pitts “neuron”
  - Started the field
- 1962: Rosenblatt’s perceptron
  - Learned its own weight values; convergence proof
- 1969: Minsky & Papert book on perceptrons
  - Proved limitations of single-layer perceptron networks
- 1982: Hopfield and convergence in symmetric networks
  - Introduced energy-function concept
- 1986: Backpropagation of errors
  - Method for training multilayer networks
- Present: Probabilistic interpretations, Bayesian and spiking networks

Artificial Neural Networks vs. Computers

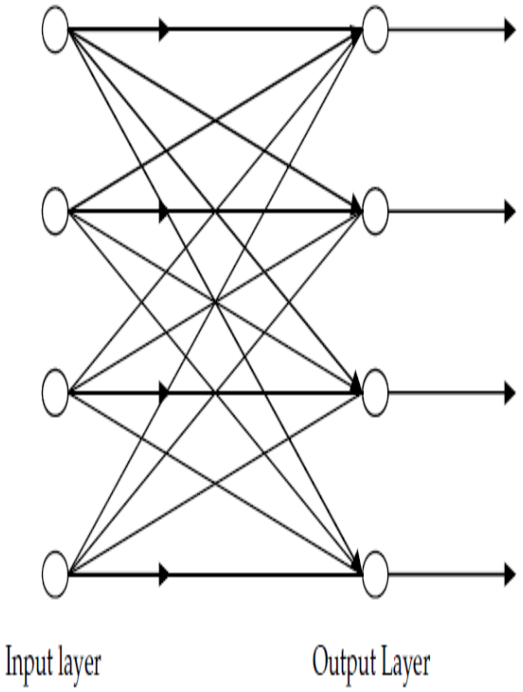
- Computers have to be explicitly programmed:
  - Analyze the problem to be solved.
  - Write the code in a programming language.
- Neural networks learn from examples:
  - No requirement of an explicit description of the problem.
  - No need for a programmer.
  - The neural network adapts itself during a ***training period***, based on examples of similar problems even without a desired solution to each problem.
  - After sufficient training, the neural network is able to relate the problem data to the solutions, inputs to outputs, and it is then able to offer a viable solution to a brand new problem.
  - Able to generalize or to handle incomplete data.

The ANN applications

- ***Classification, the aim is to predict the class of an input vector***
- ***Pattern matching, the aim is to produce a pattern best associated with a*** given input vector
- ***Pattern completion, the aim is to complete the missing parts of a given*** input vector
- ***Optimization, the aim is to find the optimal values of parameters in an*** optimization problem
- ***Control, an appropriate action is suggested based on given an input*** *vectors*
- ***Function approximation/times series modeling, the aim is to learn the*** functional relationships between input and desired output vectors;
- ***Data mining, with the aim of discovering hidden patterns from data*** (knowledge discovery)
- **Noise Reduction**

Different types of Neural Networks

- **Feed-forward Neural Network: (FFNN)**
  - It allows signals to travel one way only; from input to output.
  - There is no feedback (loops) i.e. the output of any layer does not affect that same layer.
  - It tends to be straight forward networks that associate inputs with outputs. They are extensively used in pattern recognition.
  - This type of organization is also referred to as bottom-up or top-down.

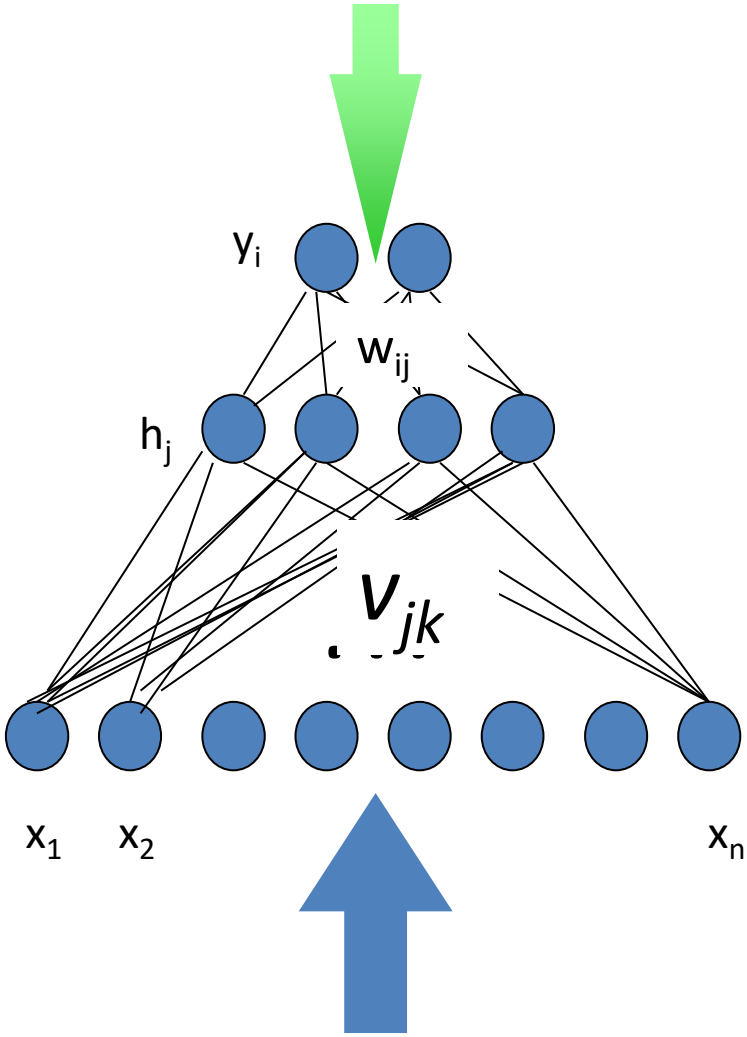


Single Layer FFNN

- Single layer FFNN
- Multilayer FFNN

Different types of Neural Networks

- **Feedback Neural Networks**
  - Feedback networks can have signals traveling in both directions by introducing loops in the network.
  - Feedback networks are dynamic; their 'state' is changing continuously until they reach an equilibrium point.
  - They remain at the equilibrium point until the input changes and a new equilibrium needs to be found.
  - Feedback architectures are also referred to as interactive or recurrent, although the latter term is often used to denote feedback connections in single-layer organizations.



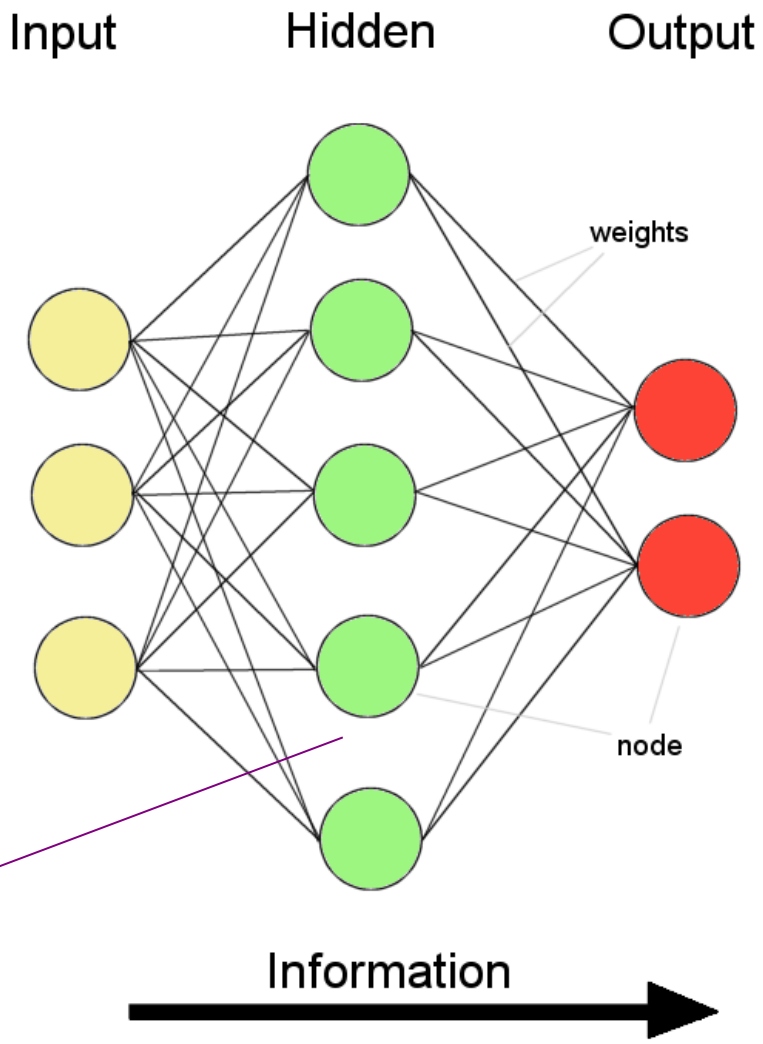
Feed-forward Neural Networks (FFNNs)

Information flow is unidirectional

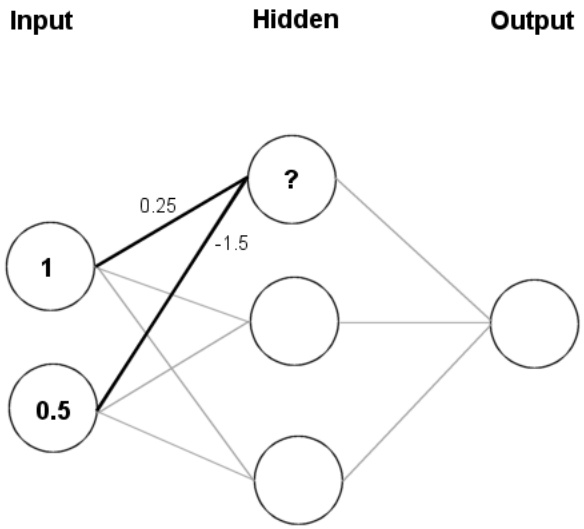
- Data is presented to *Input layer*
- Passed on to *Hidden Layer*
- Passed on to *Output layer*

Information is distributed

Information processing is parallel



Feeding data through the Network



$(1 \times 0.25) + (0.5 \times (-1.5)) = 0.25 + (-0.75) = -\mathbf{0.5}$

Squashing:

$$Sigmoid(x) = \frac{1}{1+e^{-x}} \qquad \frac{1}{1+e^{0.5}} = 0.3775$$

Phases and Data of an ANN

- Phases:
  - Learning (training)
    - Training can be done using **Back-propagation** technique (will be seen later).
    - Training is done using a big part of known historical (labeled) data.
      - The dataset contains both inputs and their corresponding output(s).
    - This phase is *time consuming*
  - Testing
    - Testing is done using the **Feed-forward** technique.
    - A small part of the historical data is used in this phase.
  - Execution
    - The **Feed-forward** technique is used.
    - New unlabeled data (inputs with unknown outputs) are fed to the NN.
- Labeled Data:
  - Data is usually given in one or more consistent dataset(s)
  - Data is divided into two parts:
    - One part for the training/learning phase
    - Another part for the testing phase

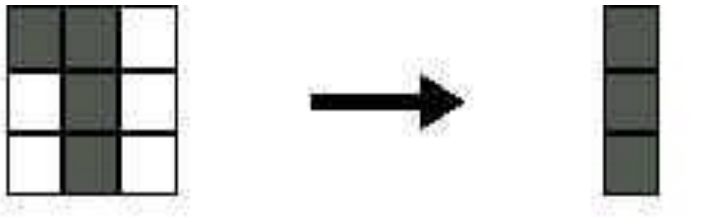
Example: Pattern Recognition

- An important application of neural networks is pattern recognition. Pattern recognition can be implemented by using a feed-forward neural network that has been **trained** accordingly.
- During training, the network is trained to associate outputs with input patterns.
- When the network is used, it identifies the input pattern and tries to output the associated output pattern.
- The power of neural networks comes to life when a pattern that has no output associated with it, is given as an input.
- In this case, **the network gives the output that corresponds to a taught input pattern that is least different from the given pattern**.

Pattern Recognition (cont.)

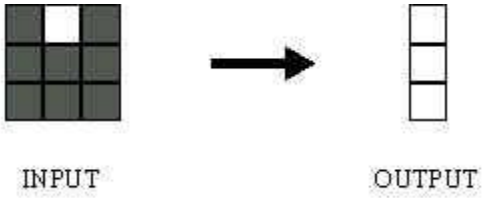
- Suppose a network is trained to recognize the patterns T and H.
- The associated patterns are all black and all white respectively as shown above.

Pattern Recognition (cont.)



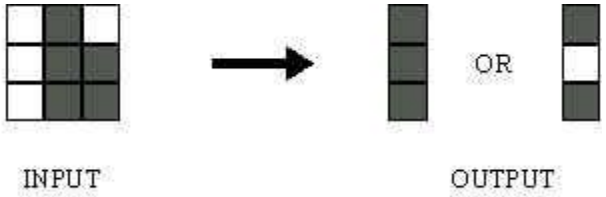
Since the input pattern looks more like a ‘T’, when the network classifies it, it sees the input closely resembling ‘T’ and outputs the pattern that represents a ‘T’.

Pattern Recognition (cont.)



The input pattern here closely resembles ‘H’ with a slight difference. The network in this case classifies it as an ‘H’ and outputs the pattern representing an ‘H’.

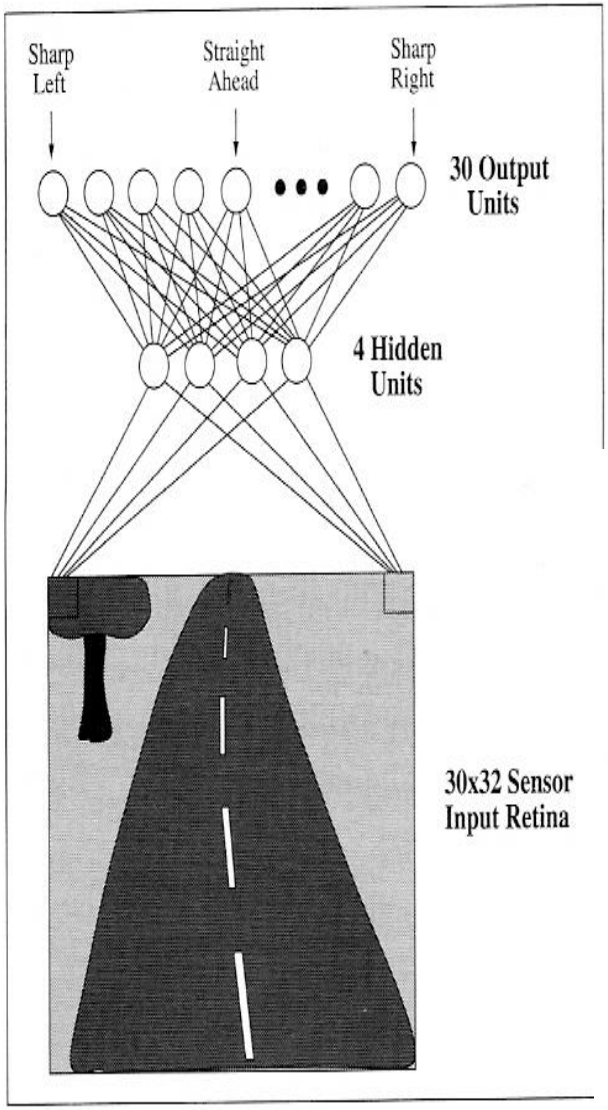
Pattern Recognition (cont.)

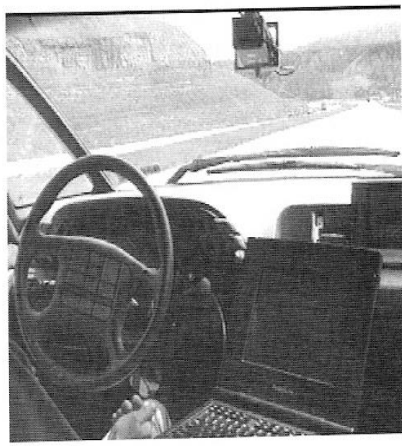


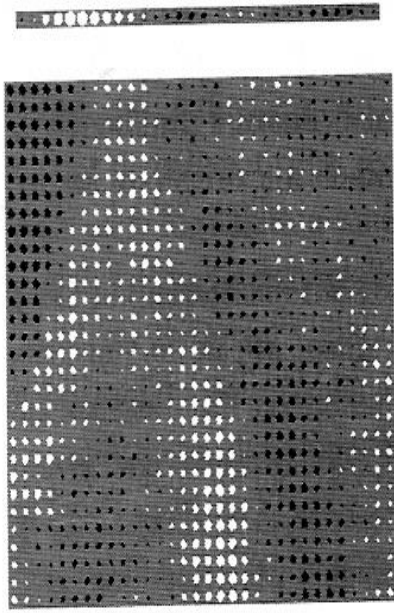
- Here the top row is 2 errors away from a ‘T’ and 3 errors away from an H. So the top output is a black.
- The middle row is 1 error away from both T and H, so the output is random.
- The bottom row is 1 error away from T and 2 away from H. Therefore the output is black.
- Since the input resembles a ‘T’ more than an ‘H’ the output of the network is in favor of a ‘T’.

Example

- ALVINN uses a learned ANN to steer an autonomous vehicle driving at normal speeds on public highways
  - Input to network: 30x32 grid of pixel intensities obtained from a forward-pointed camera mounted on the vehicle
  - Output: direction in which the vehicle is steered
  - Trained to mimic observed steering commands of a human driving the vehicle for approximately 5 minutes







Issues to be discussed

- Initializing the weights.
- Use of a learning algorithm.
- Set of training examples.
- Encode the examples as inputs.
- Convert output into meaningful results.