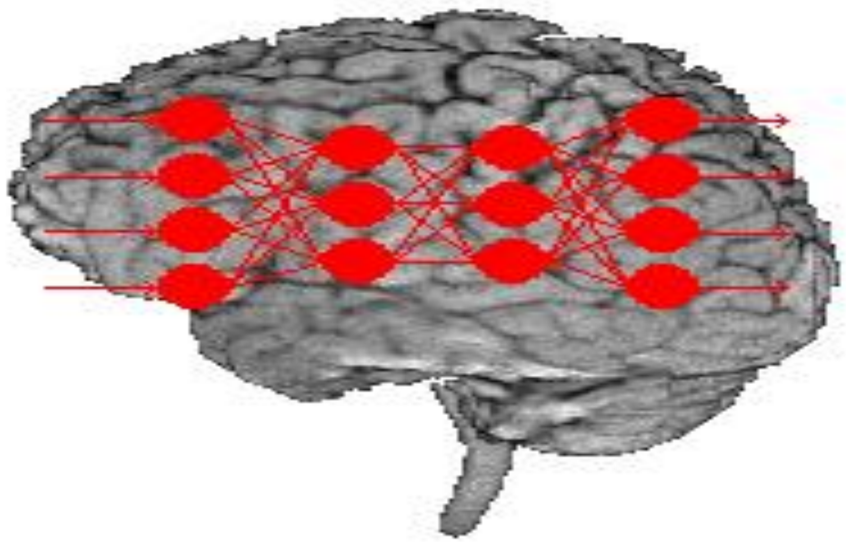
Artificial Neural Networks



Artificial Neural Network

- An artificial neural network consists of a pool of simple processing units which communicate by sending signals to each other over a large number of weighted connections.

Artificial Neural Network

- A set of major aspects of a parallel distributed model include:
  - a set of processing units (cells).
  - a state of activation for every unit, which equivalent to the output of the unit.
  - connections between the units. Generally each connection is defined by a weight.
  - a propagation rule, which determines the effective input of a unit from its external inputs.
  - an activation function, which determines the new level of activation based on the effective input and the current activation.
  - an external input for each unit.
  - a method for information gathering (the learning rule).
  - an environment within which the system must operate, providing input signals and _ if necessary _ error signals.

Computers vs. Neural Networks

"Standard" Computers	**Neural Networks**
• one CPU	highly parallel processing
• fast processing units	slow processing units
• reliable units	unreliable units
• static infrastructure	dynamic infrastructure

Why Artificial Neural Networks?

- There are two basic reasons why we are interested in building artificial neural networks (ANNs):

- **Technical viewpoint:** Some problems such as character recognition or the prediction of future states of a system require massively parallel and adaptive processing.

- **Biological viewpoint:** ANNs can be used to replicate and simulate components of the human (or animal) brain, thereby giving us insight into natural information processing.

Artificial Neural Networks

- The "building blocks" of neural networks are the **neurons**.
  - In technical systems, we also refer to them as **units** or **nodes**.
- Basically, each neuron
  - receives **input** from many other neurons.
  - changes its internal state (**activation**) based on the current input.
  - sends **one output signal** to many other neurons, possibly including its input neurons (recurrent network).

Artificial Neural Networks

- Information is transmitted as a series of electric impulses, so-called **spikes**.
- The **frequency** and **phase** of these spikes encodes the information.
- In biological systems, one neuron can be connected to as many as **10,000** other neurons.
- Usually, a neuron receives its information from other neurons in a confined area, its so-called **receptive field**.

How do ANNs work?

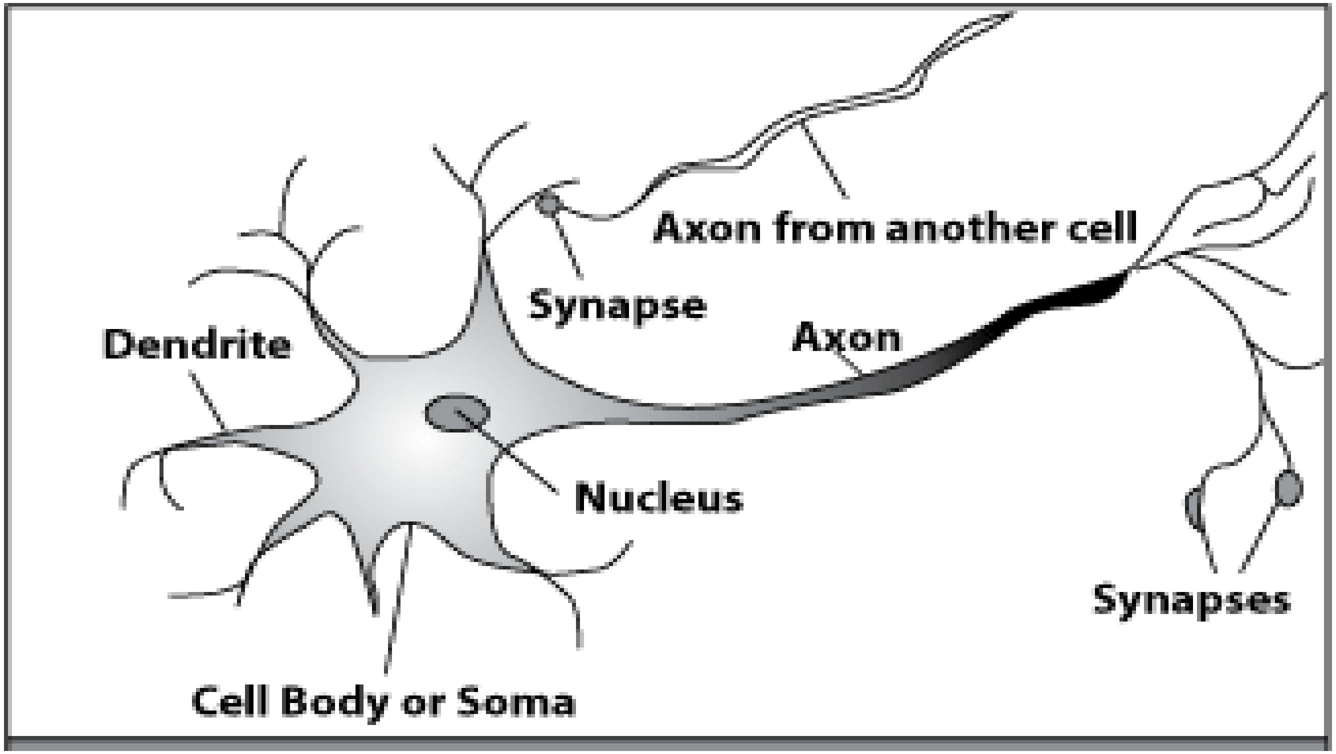
- An artificial neural network (ANN) is either a hardware implementation or a computer program which strives to simulate the information processing capabilities of its biological exemplar. ANNs are typically composed of a great number of interconnected artificial neurons. The artificial neurons are simplified models of their biological counterparts.
- ANN is a technique for solving problems by constructing software that works like our brains.

How do our brains work?

- The Brain is A massively parallel information processing system.
- Our brains are a huge network of processing elements. A typical brain contains a network of 10 billion neurons.

How do our brains work?

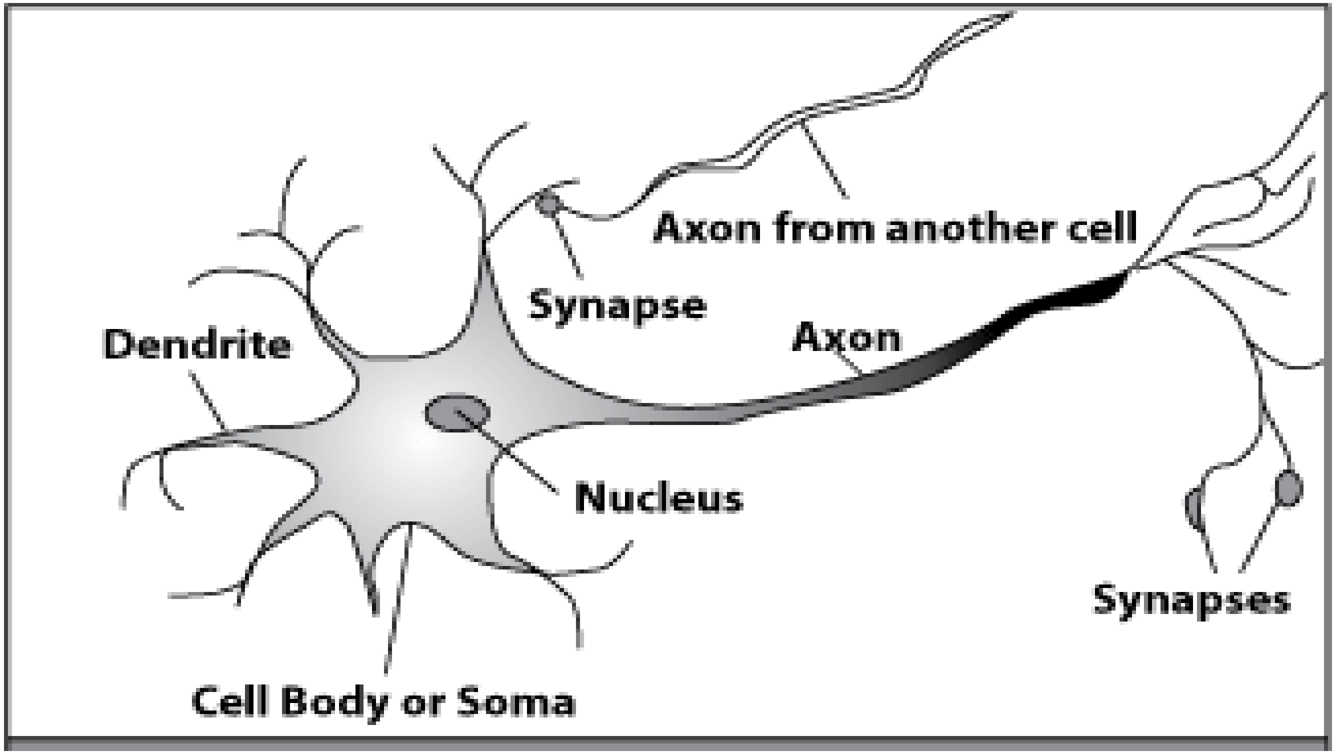
- A processing element



Dendrites: Input
Cell body: Processor
Synaptic: Link
Axon: Output

How do our brains work?

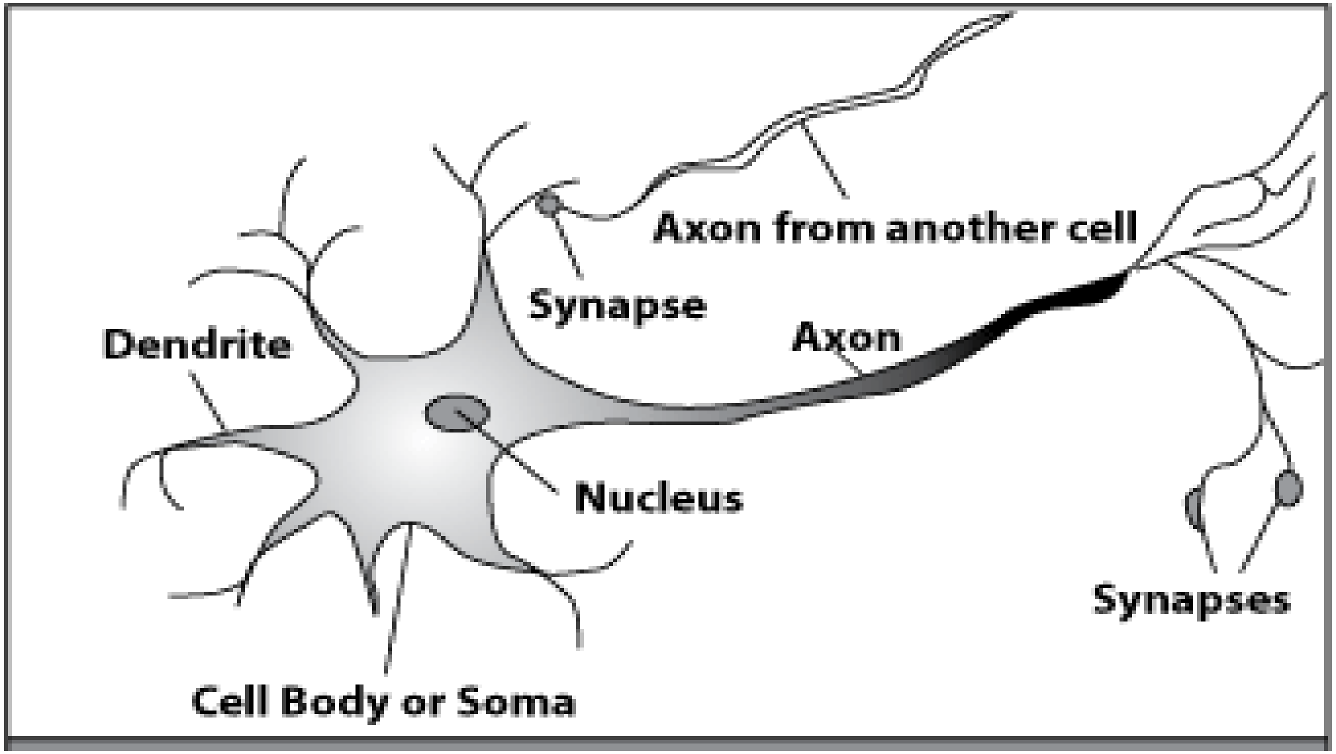
- A processing element



A neuron is connected to other neurons through about *10,000 synapses*

How do our brains work?

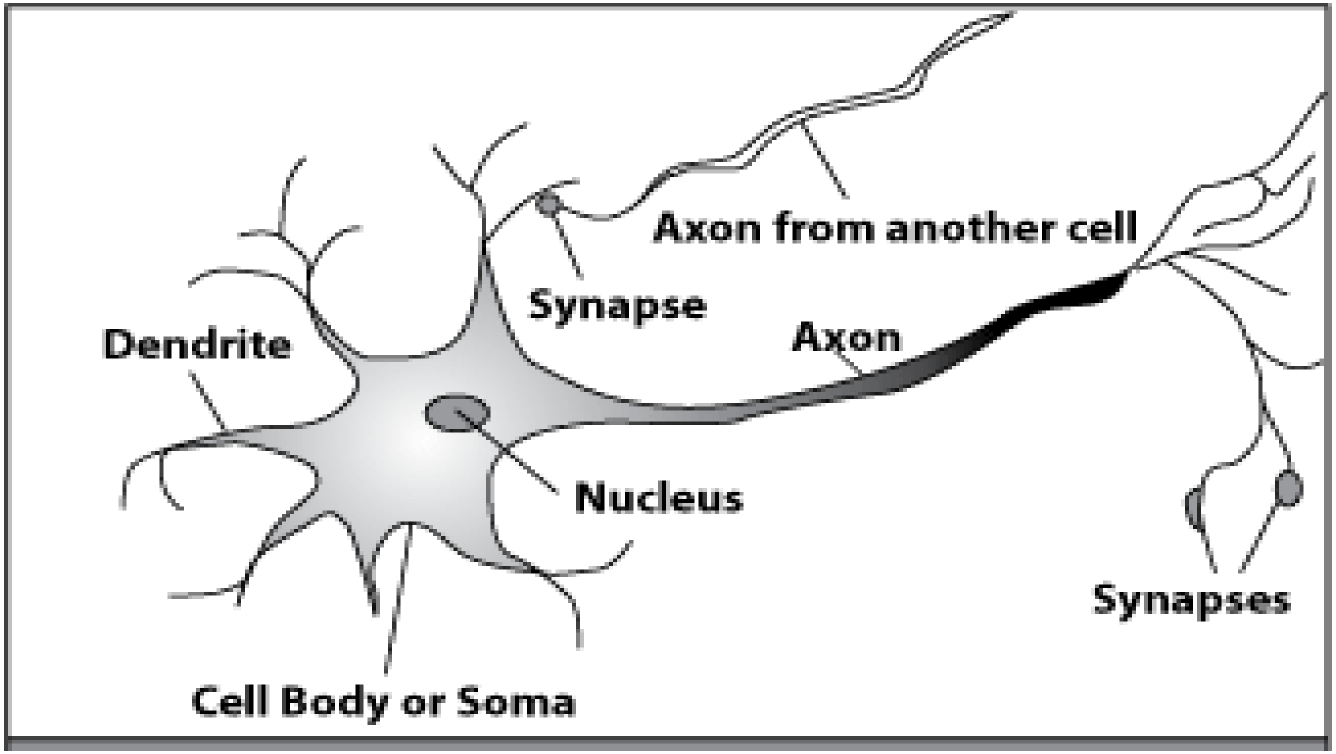
- A processing element



A neuron receives input from other neurons. Inputs are combined.

How do our brains work?

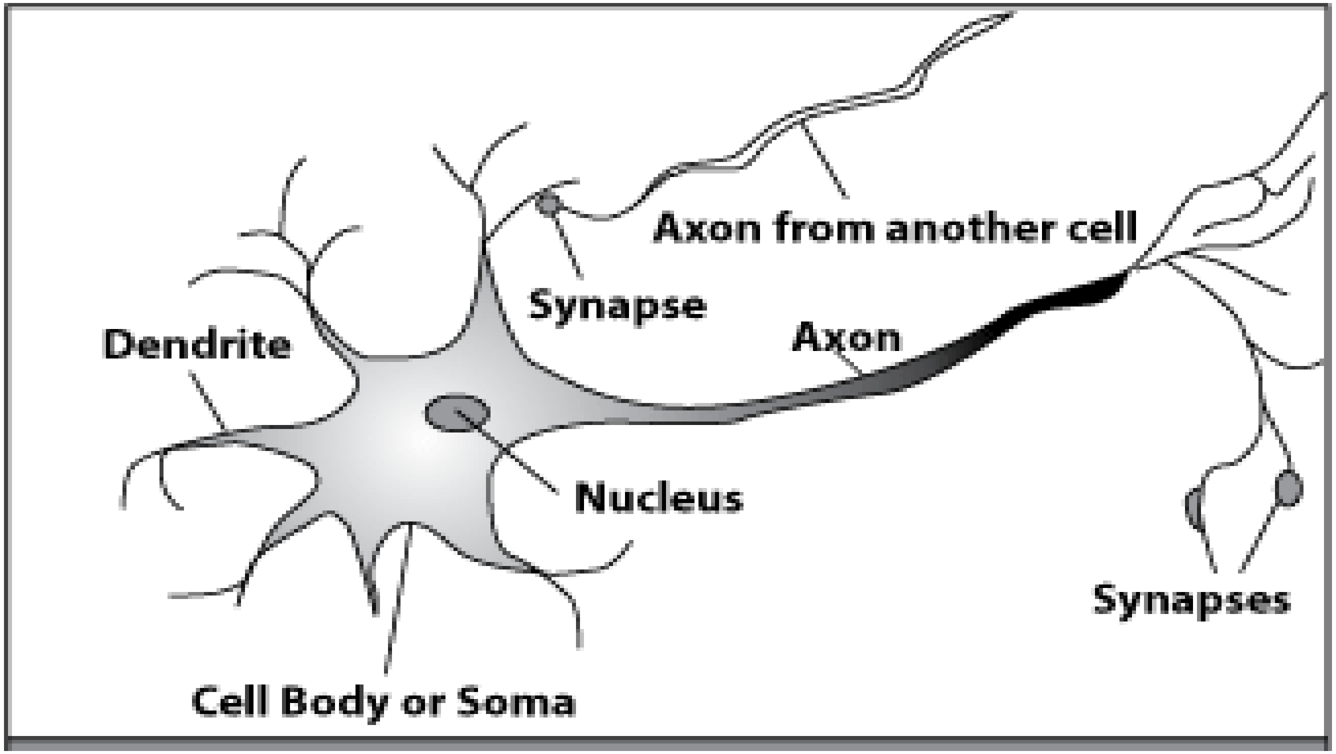
- A processing element



Once input exceeds a critical level, the neuron discharges a spike - an electrical pulse that travels from the body, down the axon, to the next neuron(s)

How do our brains work?

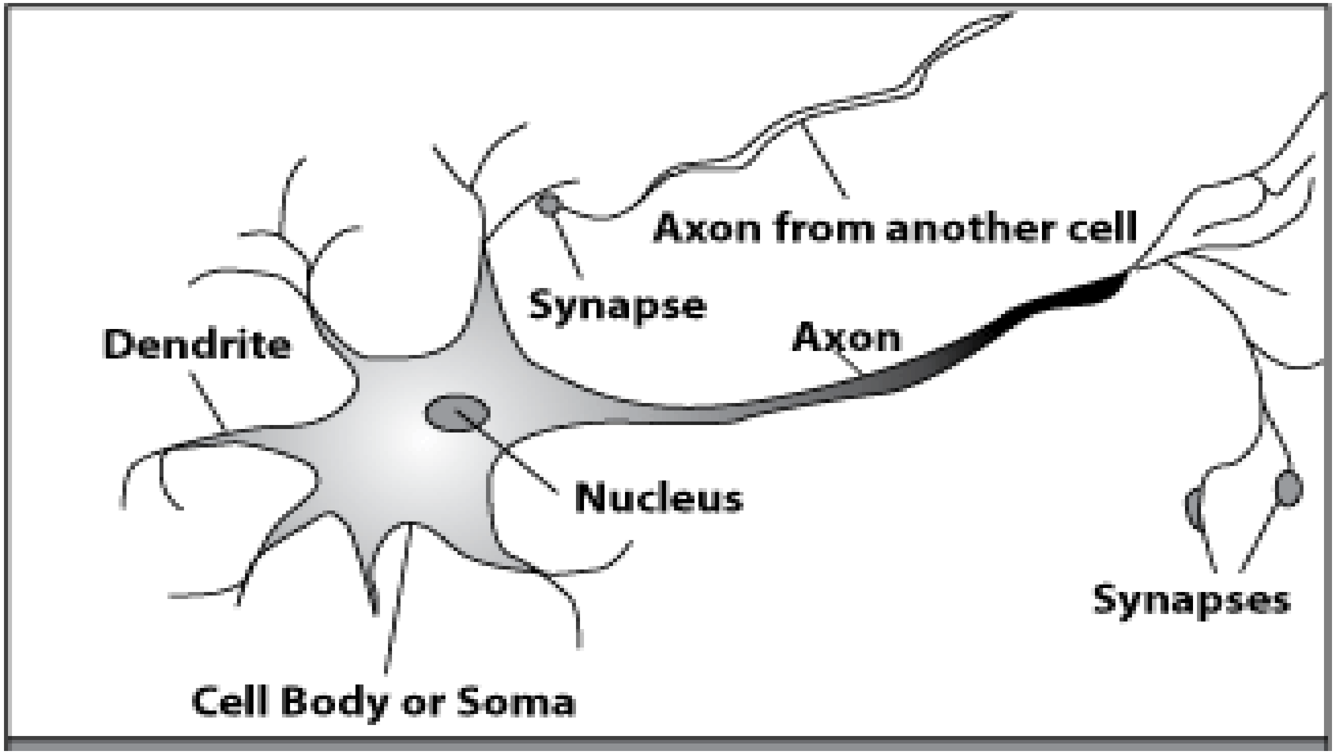
- A processing element



The axon endings almost touch the dendrites or cell body of the next neuron.

How do our brains work?

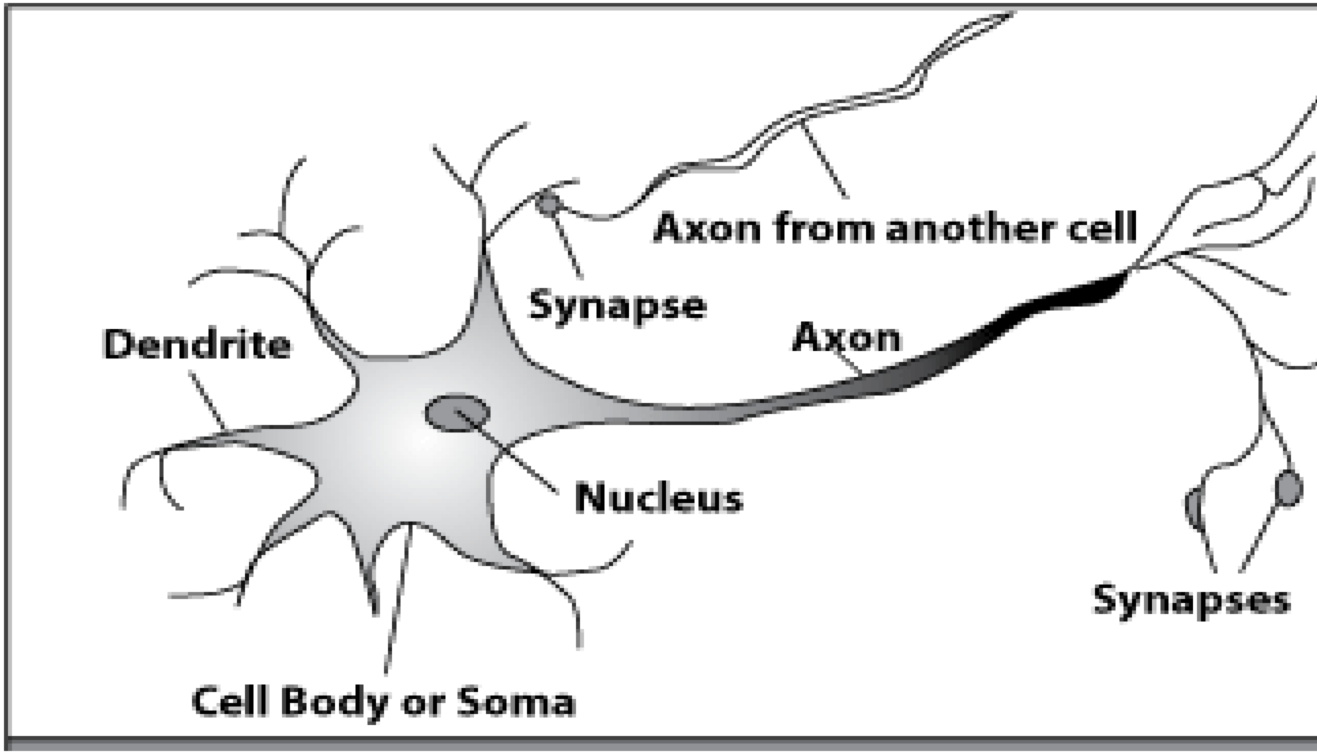
- A processing element



Transmission of an electrical signal from one neuron to the next is effected by neurotransmitters.

How do our brains work?

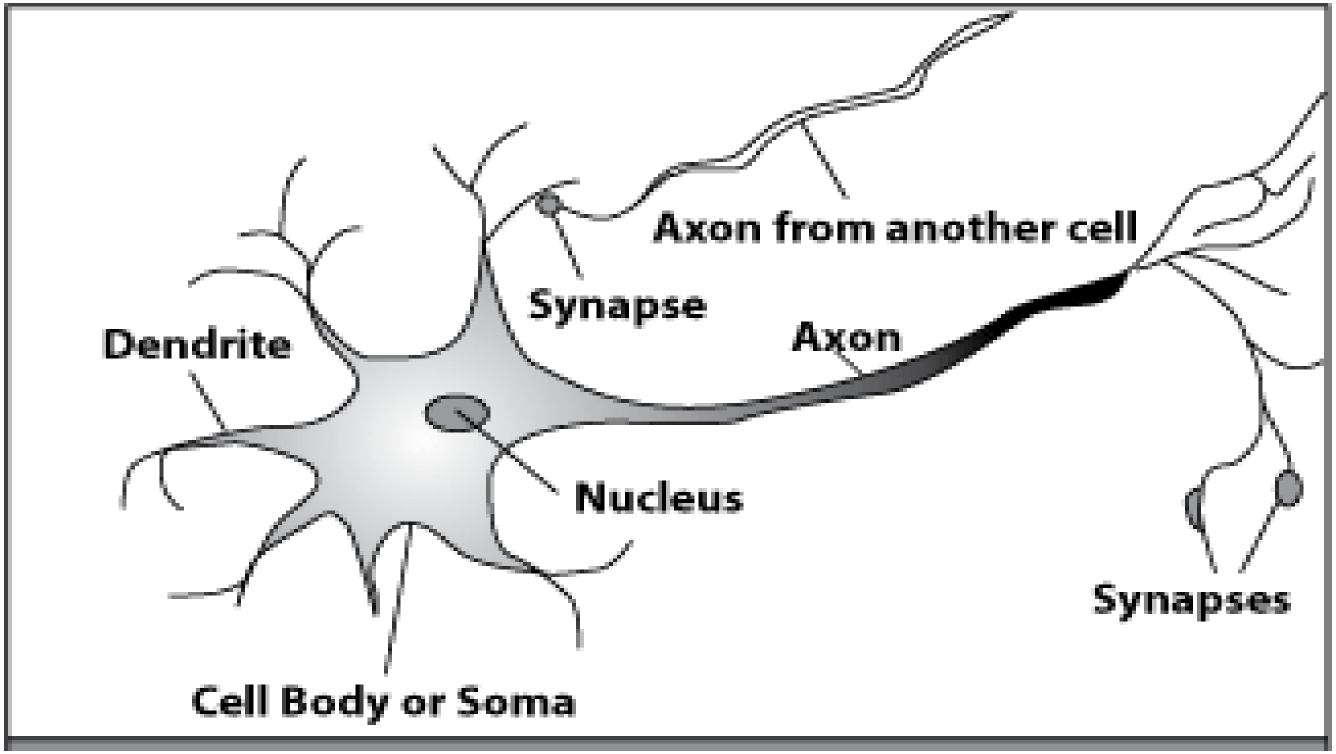
- A processing element



Neurotransmitters are chemicals which are released from the first neuron and which bind to the
Second.

How do our brains work?

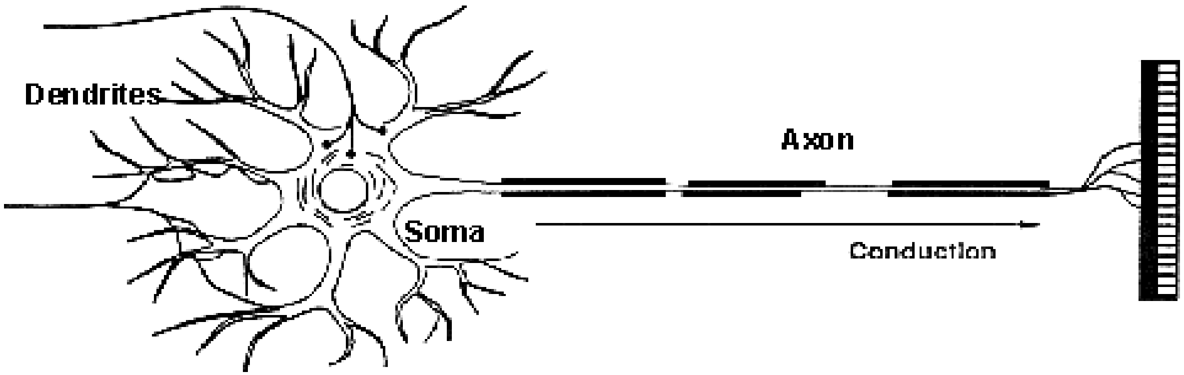
- A processing element



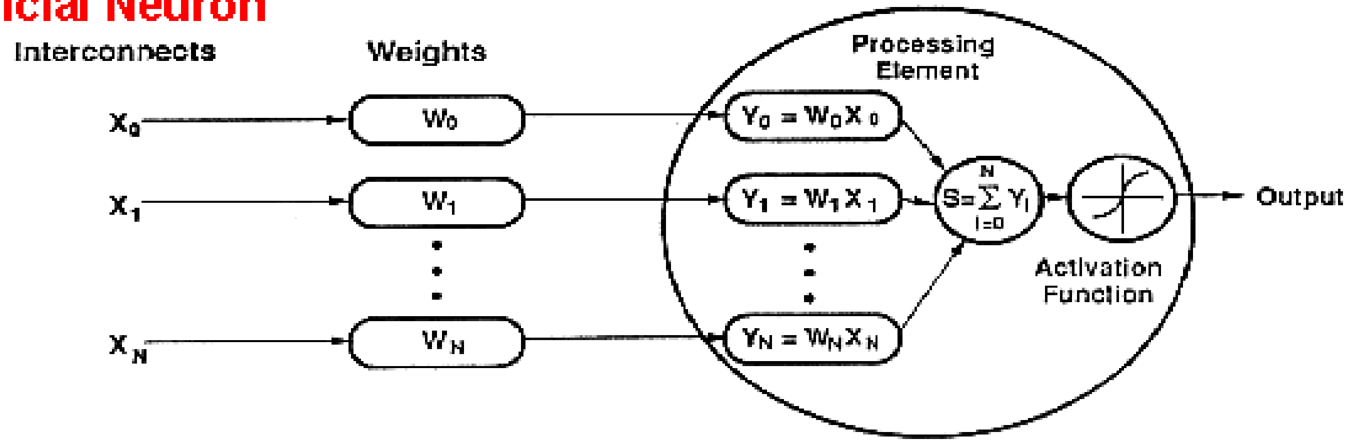
This link is called a synapse. The strength of the signal that reaches the next neuron depends on factors such as the amount of neurotransmitter available.

How do ANNs work?

Biological Neuron



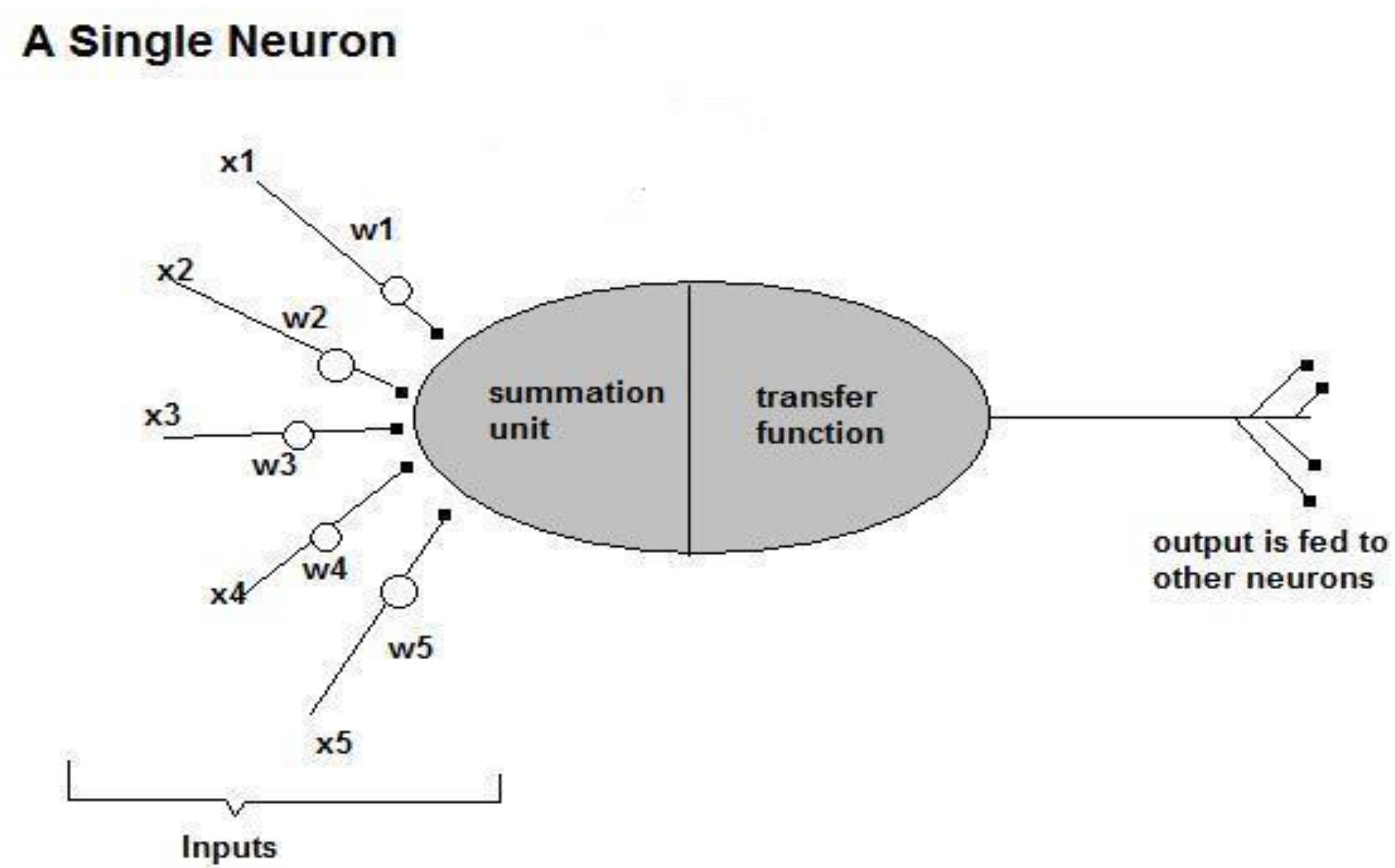
Artificial Neuron



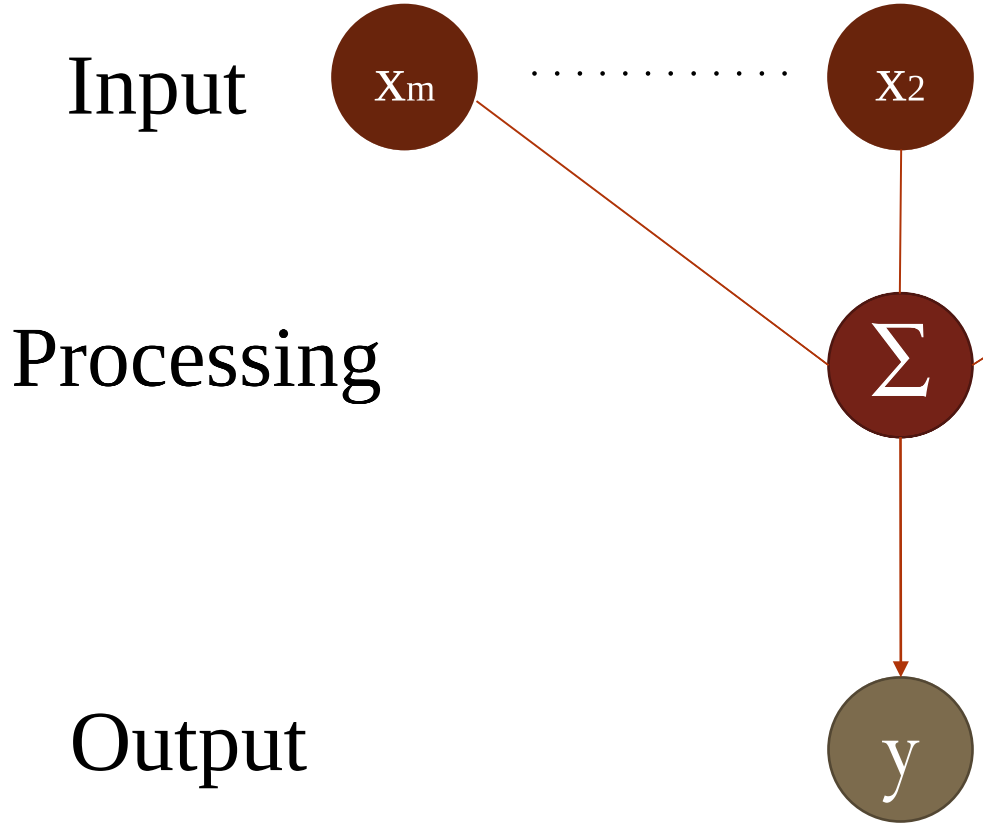
An artificial neuron is an imitation of a human neuron

How do ANNs work?

- Now, let us have a look at the model of an artificial neuron.



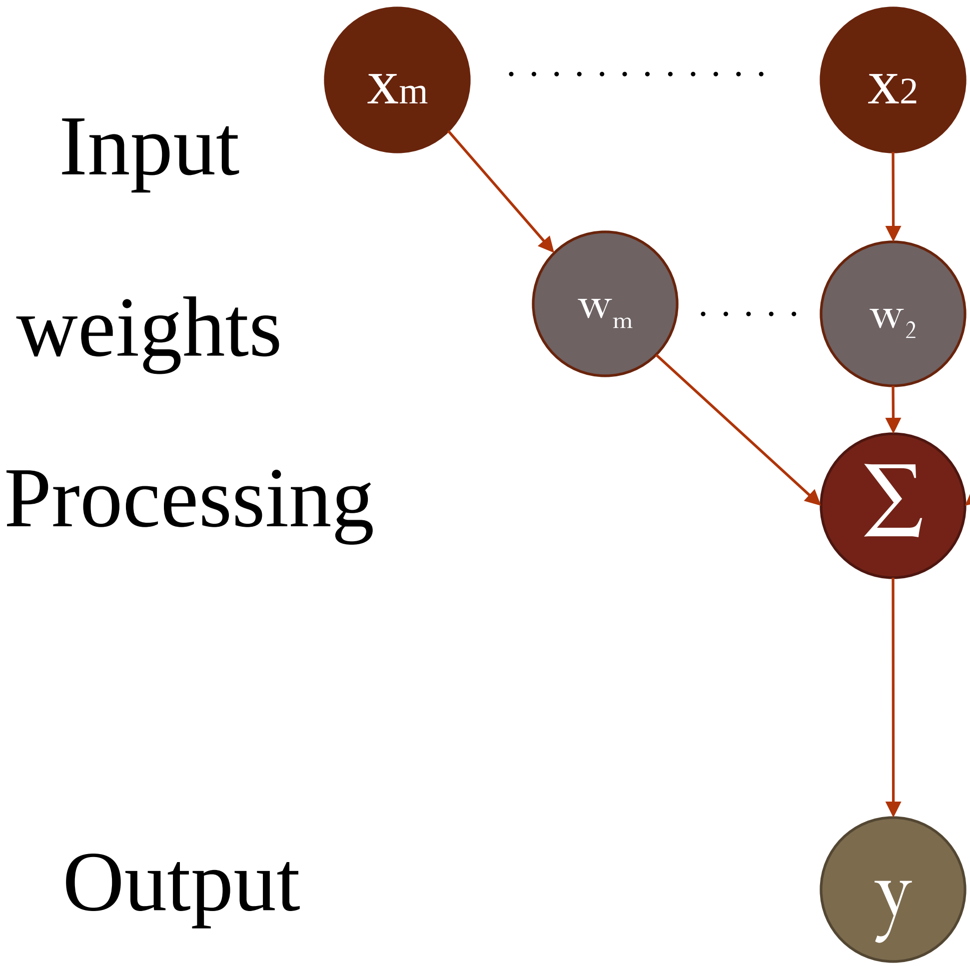
How do ANNs work?



$$\sum = X_1 + X_2 + \ldots. + X_m = y$$

How do ANNs work?

Not all inputs are equal

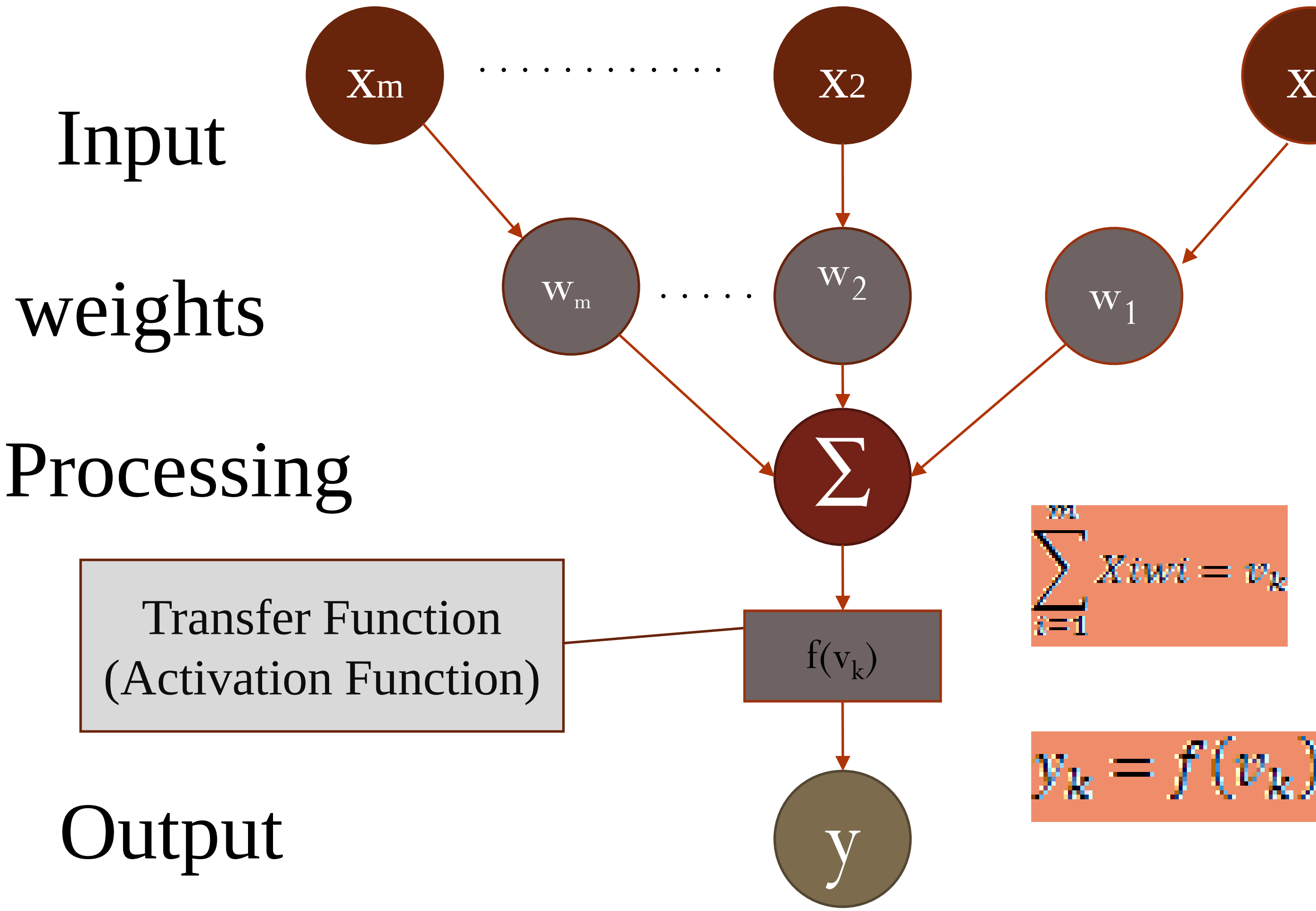


$$\sum = X_1 w_1 + X_2 w_2 + \ldots + X_m w_m = y$$

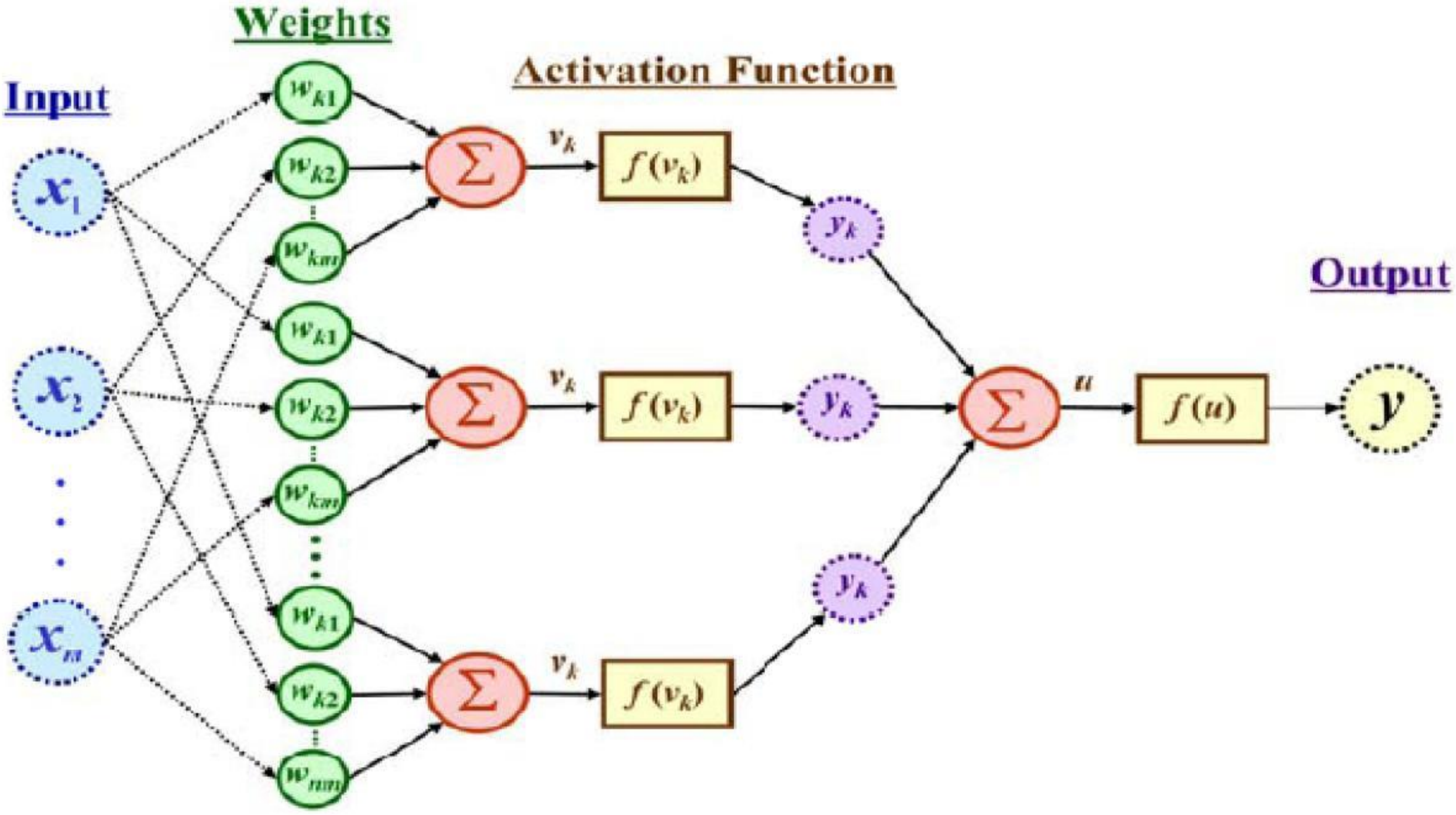
$$\sum_{i=1}^{m} X_i w_i = y$$

How do ANNs work?

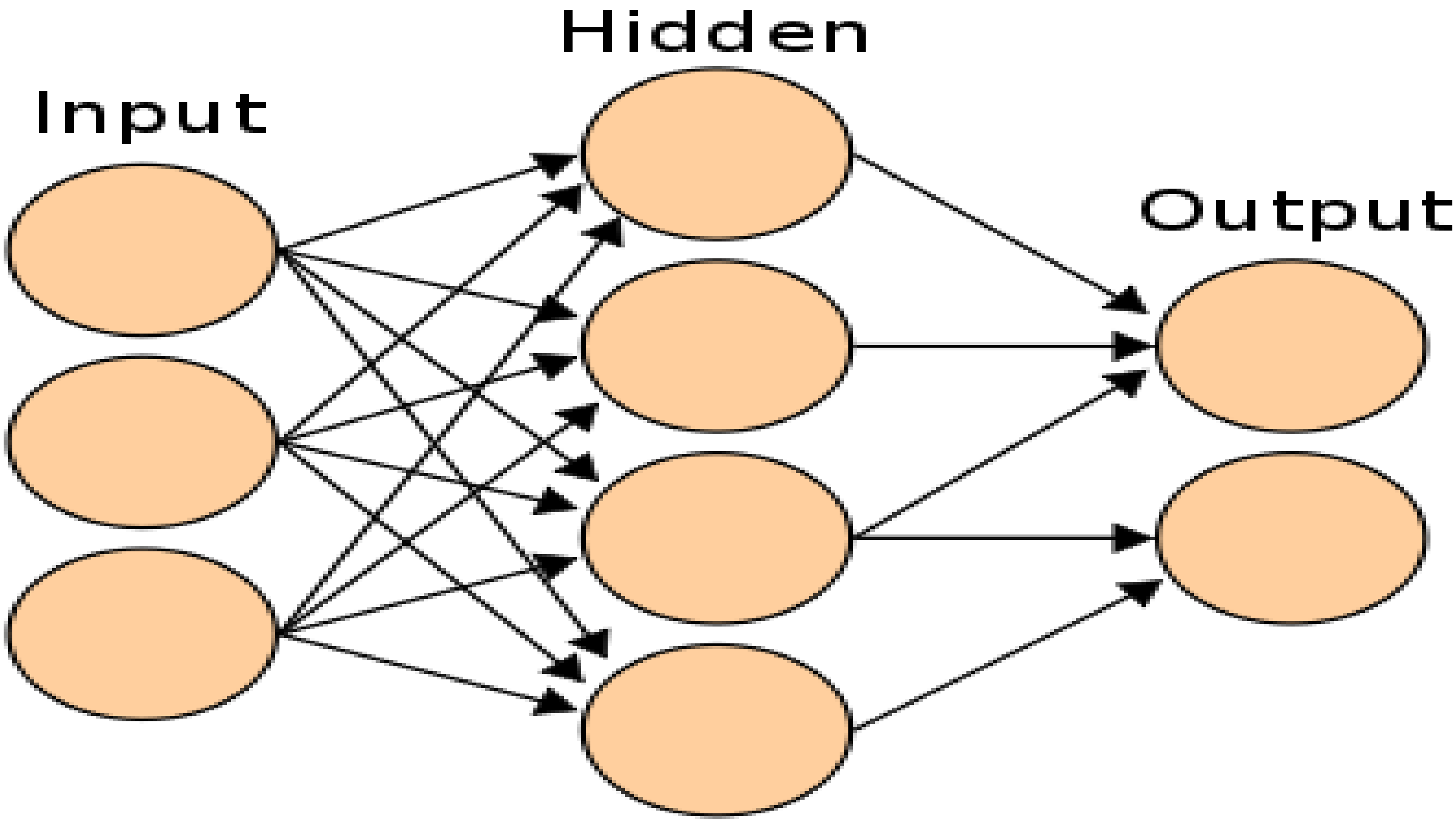
The signal is not passed down to the next neuron verbatim



The output is a function of the input, that is affected by the weights, and the transfer functions



Three types of layers: Input, Hidden, and Output



Artificial Neural Networks

- An ANN can:
  1. compute *any computable* function, by the appropriate selection of the network topology and weights values.
  2. learn from experience!
  - Specifically, by trial-and-error

Learning by trial-and-error

Continuous process of:

- **Trial:**

Processing an input to produce an output (In terms of ANN: Compute the output function of a given input)

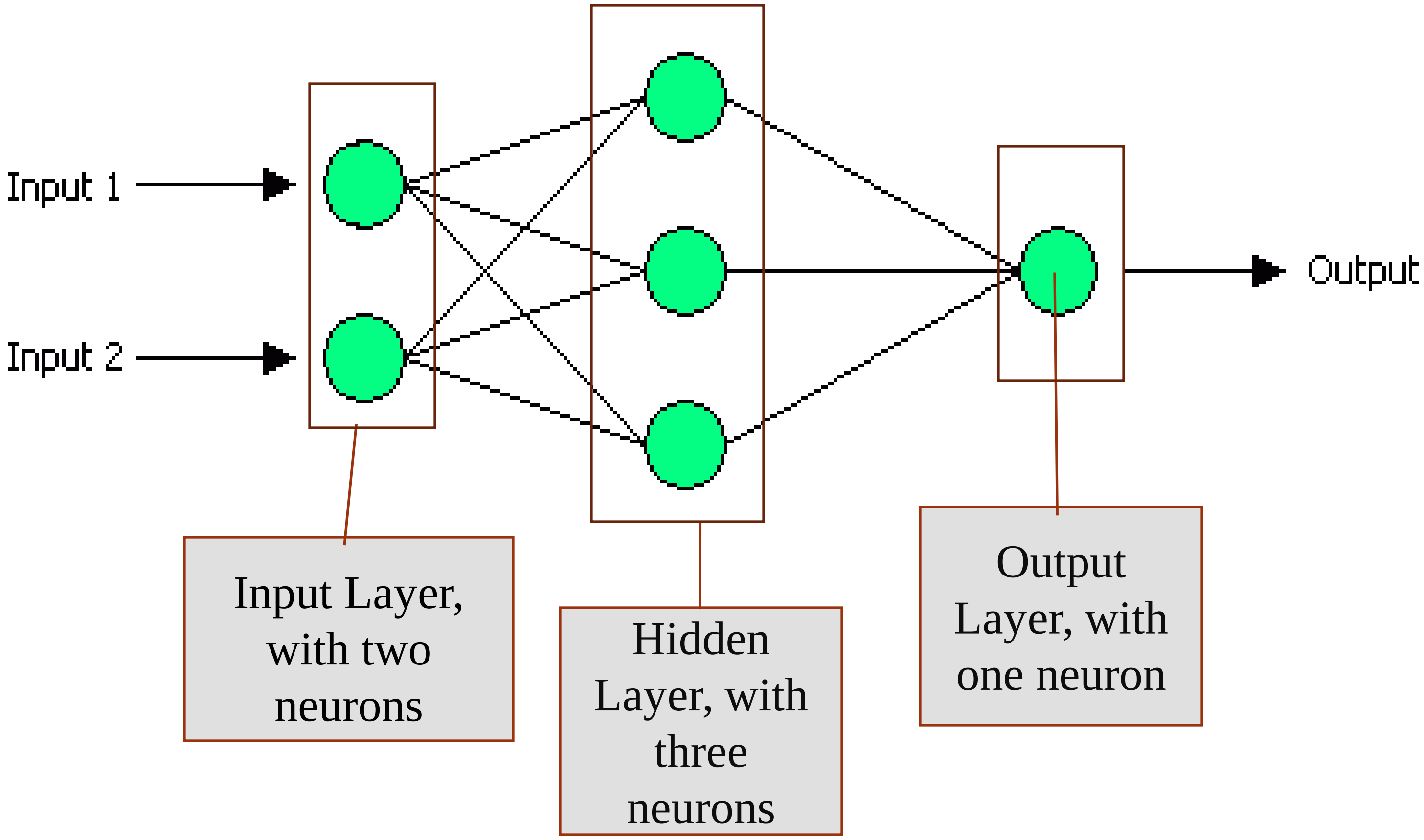
- **Evaluate:**

Evaluating this output by comparing the actual output with the expected output.

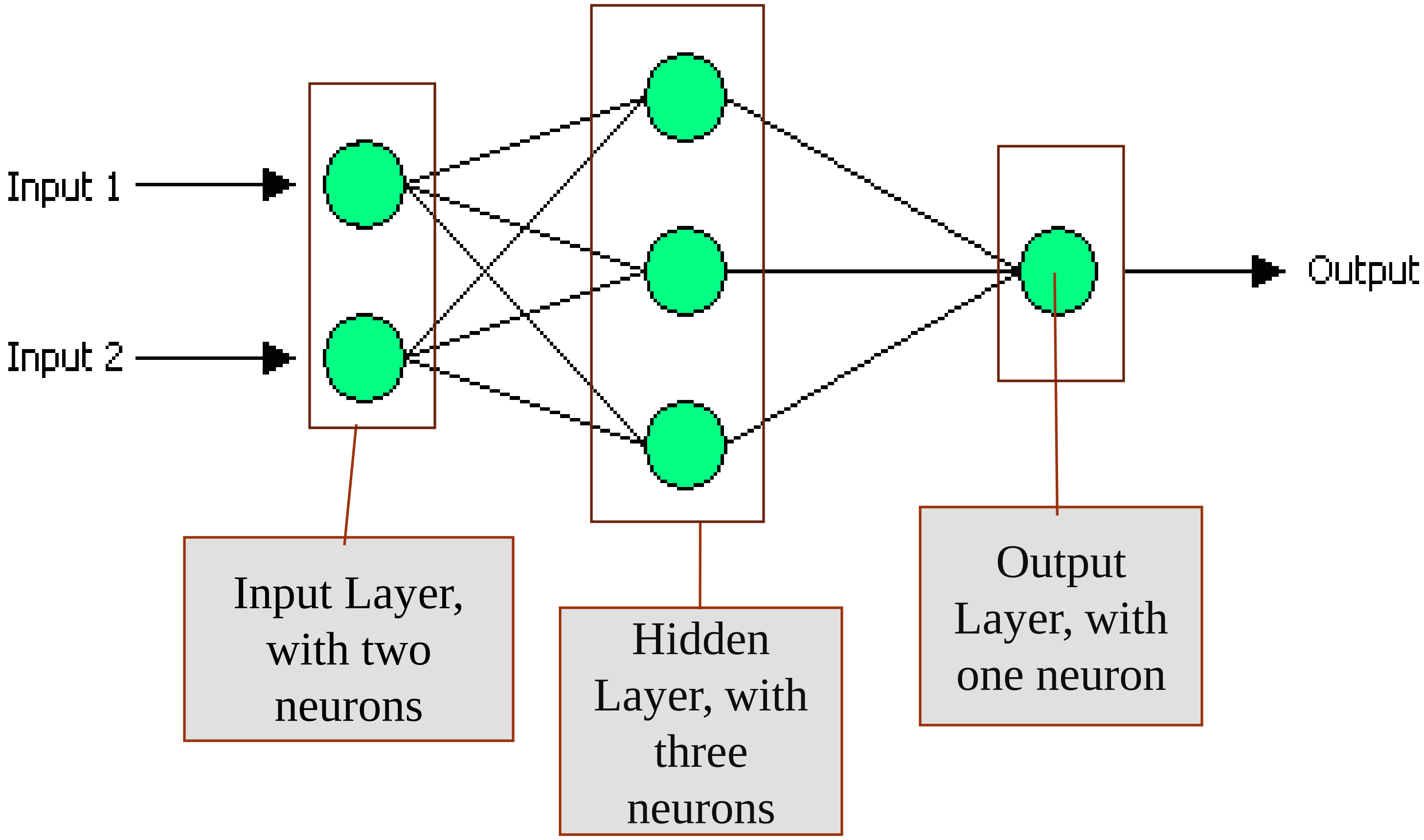
- **Adjust:**

Adjust the *weights*.

Example: XOR


Input 1
Input 2
Output
Input Layer, with two neurons
Hidden Layer, with three neurons
Output Layer, with one neuron

How it works?



Input 1
Input 2
Output
Input Layer, with two neurons
Hidden Layer, with three neurons
Output Layer, with one neuron

How it works?

- Set initial values of the weights randomly.
- Input: truth table of the XOR
- Do
  - Read input (e.g. 0, and 0)
  - Compute an output (e.g. 0.60543)
  - Compare it to the expected output. (Diff= 0.60543)
  - Modify the weights *accordingly*.
- Loop until a condition is met
  - Condition: certain number of iterations
  - Condition: error threshold

Design Issues

- Initial weights (small random values $\in[-1,1]$)
- Transfer function (How the inputs and the weights are combined to produce output?)
- Error estimation
- Weights adjusting
- Number of neurons
- Data representation
- Size of training set

Transfer Functions

- **Linear:** The output is proportional to the total weighted input.
- **Threshold:** The output is set at one of two values, depending on whether the total weighted input is greater than or less than some threshold value.
- **Non-linear:** The output varies continuously but not linearly as the input changes.

Error Estimation

- The **root mean square error (RMSE)** is a frequently-used measure of the differences between values predicted by a model or an estimator and the values actually observed from the thing being modeled or estimated

Weights Adjusting

- After each iteration, weights should be adjusted to minimize the error.
  - All possible weights
  - Back propagation

Back Propagation

- Back-propagation is an example of supervised learning is used at each layer to minimize the error between the layer's response and the actual data
- The error at each hidden layer is an average of the evaluated error
- Hidden layer networks are trained this way

Back Propagation

- N is a neuron.
- N_w is one of N's inputs weights
- N_{out} is N's output.
- $N_w = N_w + \Delta N_w$
- $\Delta N_w = N_{out} * (1 - N_{out}) * N_{ErrorFactor}$
- $N_{ErrorFactor} = N_{ExpectedOutput} - N_{ActualOutput}$
- This works only for the last layer, as we can know the actual output, and the expected output.

Number of neurons

- Many neurons:
  - Higher accuracy
  - Slower
  - Risk of over-fitting
    - Memorizing, rather than understanding
    - The network will be useless with new problems.
- Few neurons:
  - Lower accuracy
  - Inability to learn at all
- Optimal number.

Data representation

- Usually input/output data needs pre-processing
- Pictures
  - Pixel intensity
- Text:
  - A pattern

Size of training set

- No one-fits-all formula
- Over fitting can occur if a “good” training set is not chosen
- What constitutes a “good” training set?
  - Samples must represent the general population.
  - Samples must contain members of each class.
  - Samples in each class must contain a wide range of variations or noise effect.
- The size of the training set is related to the number of hidden neurons

Learning Paradigms

- Supervised learning
- Unsupervised learning
- Reinforcement learning

Supervised learning

- This is what we have seen so far!
- A network is fed with a set of training samples (inputs and corresponding output), and it uses these samples to learn the general relationship between the inputs and the outputs.
- This relationship is represented by the values of the weights of the trained network.

Unsupervised learning

- No desired output is associated with the training data!
- Faster than supervised learning
- Used to find out *structures within data:*
  - Clustering
  - Compression

Reinforcement learning

- Like supervised learning, but:
  - Weights adjusting is not directly related to the error value.
  - The error value is used to randomly, shuffle weights!
  - Relatively slow learning due to ‘randomness’.

Applications Areas

- Function approximation
  - including time series prediction and modeling.
- Classification
  - including patterns and sequences recognition, novelty detection and sequential decision making.
    - (radar systems, face identification, handwritten text recognition)
- Data processing
  - including filtering, clustering blinds source separation and compression.
    - (data mining, e-mail Spam filtering)

Advantages / Disadvantages

- Advantages
  - Adapt to unknown situations
  - Powerful, it can model complex functions.
  - Ease of use, learns by example, and very little user domain-specific expertise needed
- Disadvantages
  - Forgets
  - Not exact
  - Large complexity of the network structure

Conclusion

- Artificial Neural Networks are an imitation of the biological neural networks, but much simpler ones.
- The computing would have a lot to gain from neural networks. Their ability to learn by example makes them very flexible and powerful furthermore there is need to device an algorithm in order to perform a specific task.

Conclusion

- Neural networks also contributes to area of research such a neurology and psychology. They are regularly used to model parts of living organizations and to investigate the internal mechanisms of the brain.
- Many factors affect the performance of ANNs, such as the transfer functions, size of training sample, network topology, weights adjusting algorithm, …

References

- Craig Heller, and David Sadava, *Life: The Science of Biology, fifth edition*, Sinauer Associates, INC, USA, 1998.
- Introduction to Artificial Neural Networks, Nicolas Galoppo von Borries
- Tom M. Mitchell, *Machine Learning*, *WCB McGraw-Hill*, *Boston*, *1997*.