UNIVERSITY OF LINCOLN

NEURAL COMPUTING

Lecture: Binary Neuron Model

LECTURE OVERVIEW

Part I – Lecture 6 slides (Summary & Review)

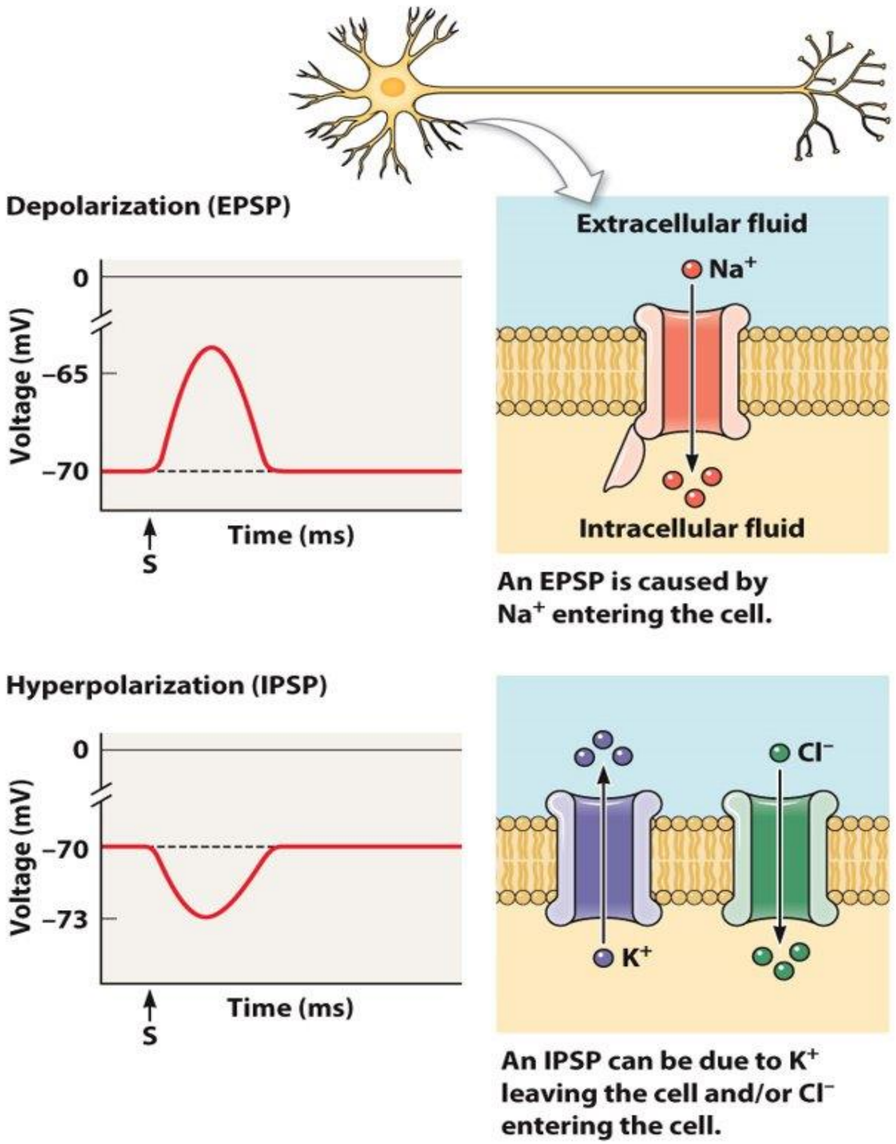
- POSTSYNAPTIC SIGNALS
- EQUIVALENT CIRCUIT MODEL OF A SYNAPSE
- EXCITATORY AND INHIBITORY SYNAPSES
- SYNAPSES & NEUROLOGICAL DISEASES

Part II – Lecture 7

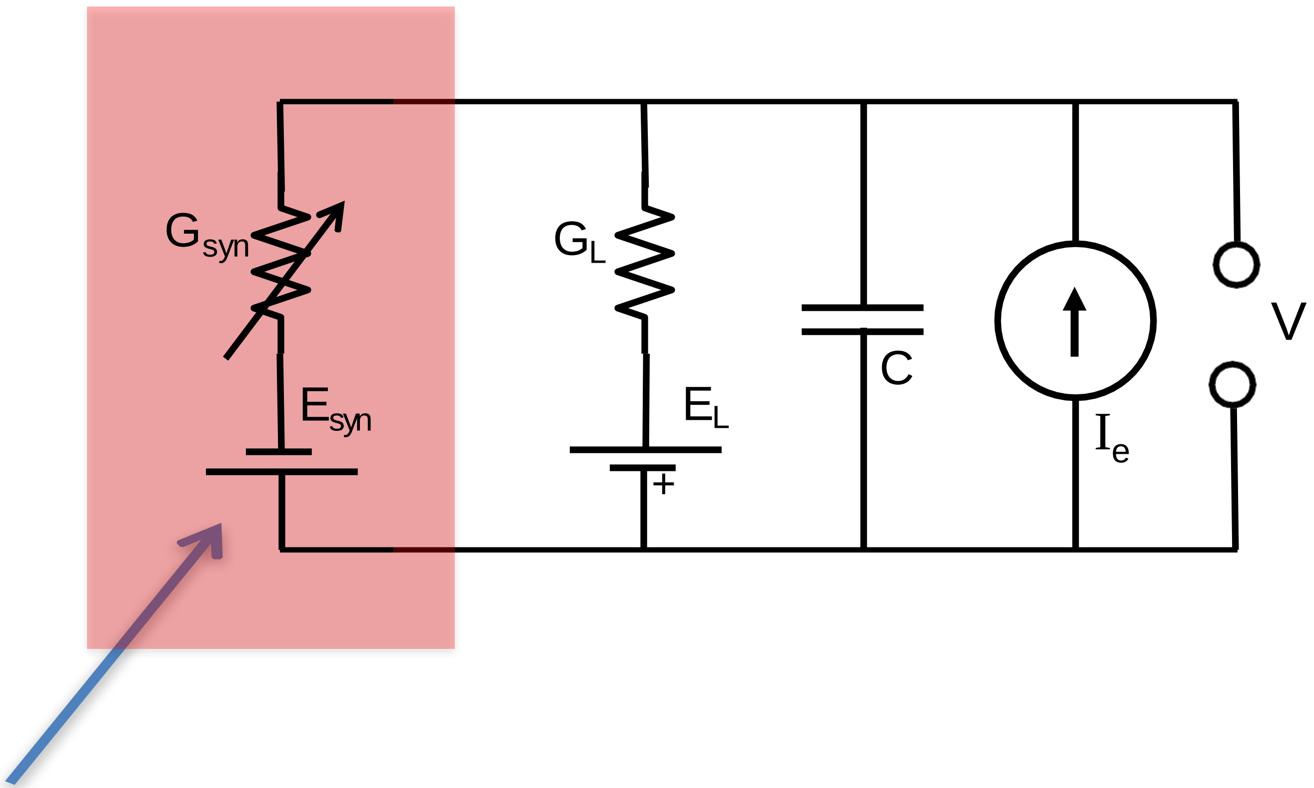
- BUILDING BLOCKS OF ARTIFICIAL NEURAL NETWORKS
- ANATOMY OF A CONNECTIONIST MODEL
- CONNECTION WEIGHTS
- CONNECTION WEIGHTS: ANIMATION VIDEO
- ACTIVATION & OUTPUTS
- TYPES OF ACTIVATION FUNCTIONS
- McCulloch-Pitts Neuron
- EXAMPLES: DECISION BOUNDARY FOR ‘AND’ & 'OR' GATE

POSTSYNAPTIC SIGNALS

- When at rest, there is **a voltage difference** between the inside and the outside of the cell.
- The inside of the cell is more negative than the outside, about **-70 mV**.
- **Excitatory postsynaptic potentials** alter the membrane voltage, moving the voltage closer to 0.
- **Inhibitory postsynaptic potentials** move the voltage further from 0.
- Postsynaptic potentials are tiny (about **1 mV**) and fast (**a few milliseconds**).



EQUIVALENT CIRCUIT MODEL OF A SYNAPSE



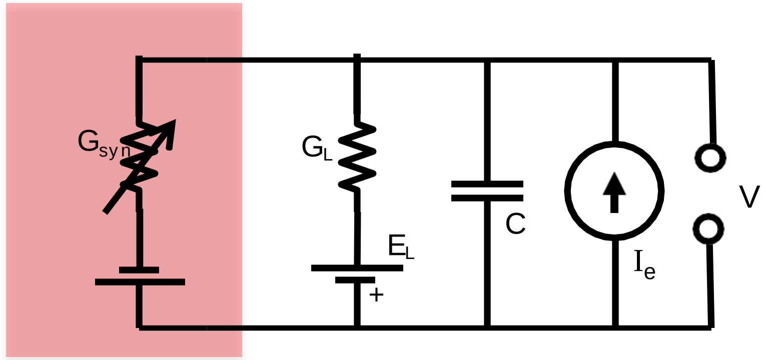
Equivalent circuit of a synapse

$$I_{syn}(t) = G_{syn}(t)\left(V - E_{syn}\right)$$

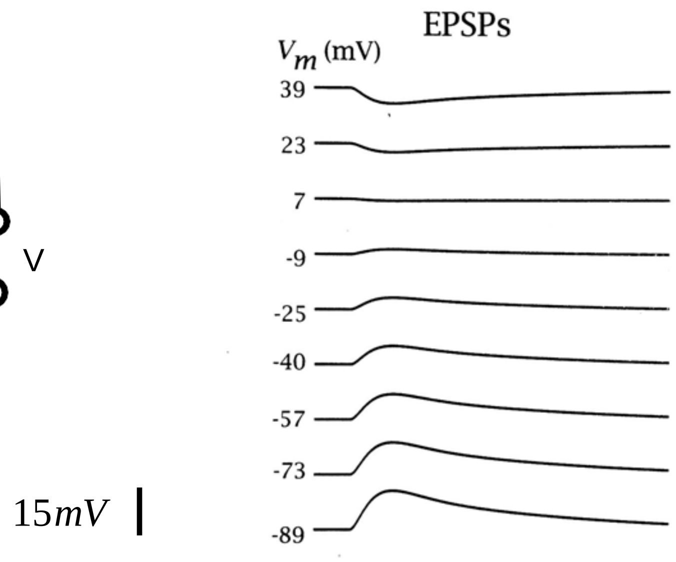
EXCITATORY AND INHIBITORY SYNAPSES

Increased synaptic conductance causes the membrane potential to approach the reversal potential for that synapse.

$$I_{syn}(t) = G_{syn}(t)\left(V - E_{syn}\right)$$



$E_{syn} = 0mV$



Excitatory postsynaptic potential (EPSP)

Figure from Johnston, D. and M.-S. Wu. *Foundations of Cellular Neurophysiology*. 1995. Courtesy of MIT Press.

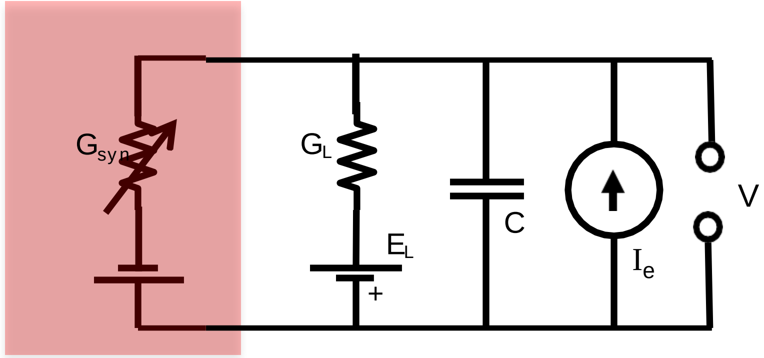
Excitatory synapse if

$$E_{syn} > V_{th}$$

EXCITATORY AND INHIBITORY SYNAPSES

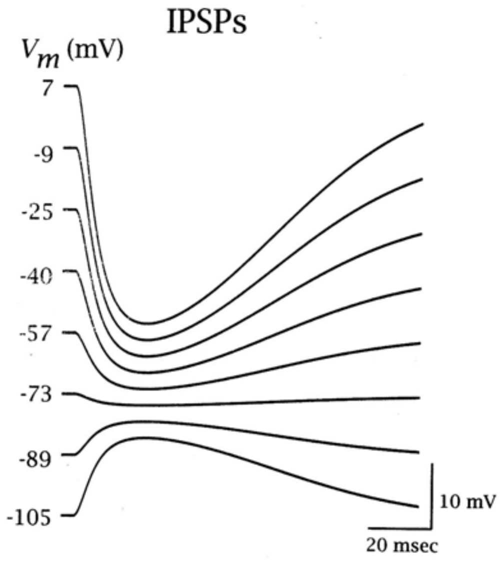
Increased synaptic conductance causes the membrane potential to approach the reversal potential for that synapse.

$$I_{syn}(t) = G_{syn}(t)(V - E_{syn})$$



$$E_{syn} = -75\,mV$$

GABAergic synapse



Inhibitory postsynaptic potential (IPSP)

Figure 13.4 from Johnston, D. and M.-S. Wu. [Foundations of Cellular Neurophysiology](). 1995. Courtesy of MIT Press.

Inhibitory synapse if

$$E_{syn} < V_{th}$$

SYNAPSES & NEUROLOGICAL DISEASES

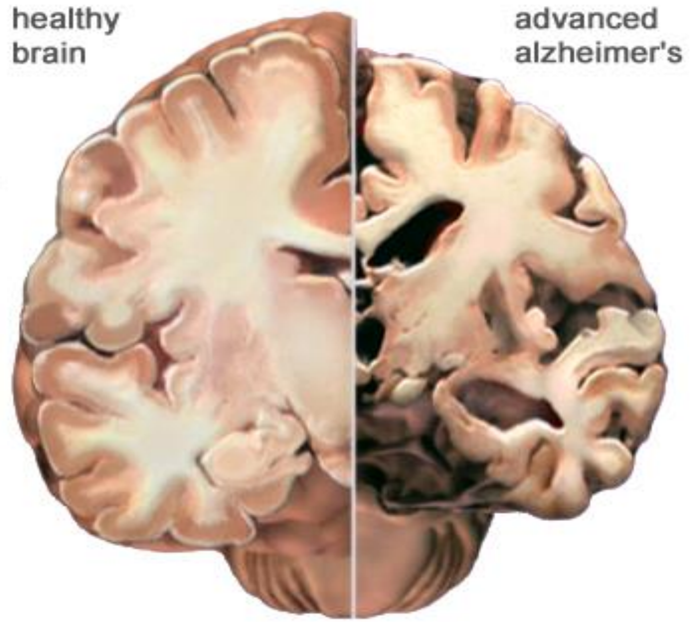
Alzheimer's Disease:

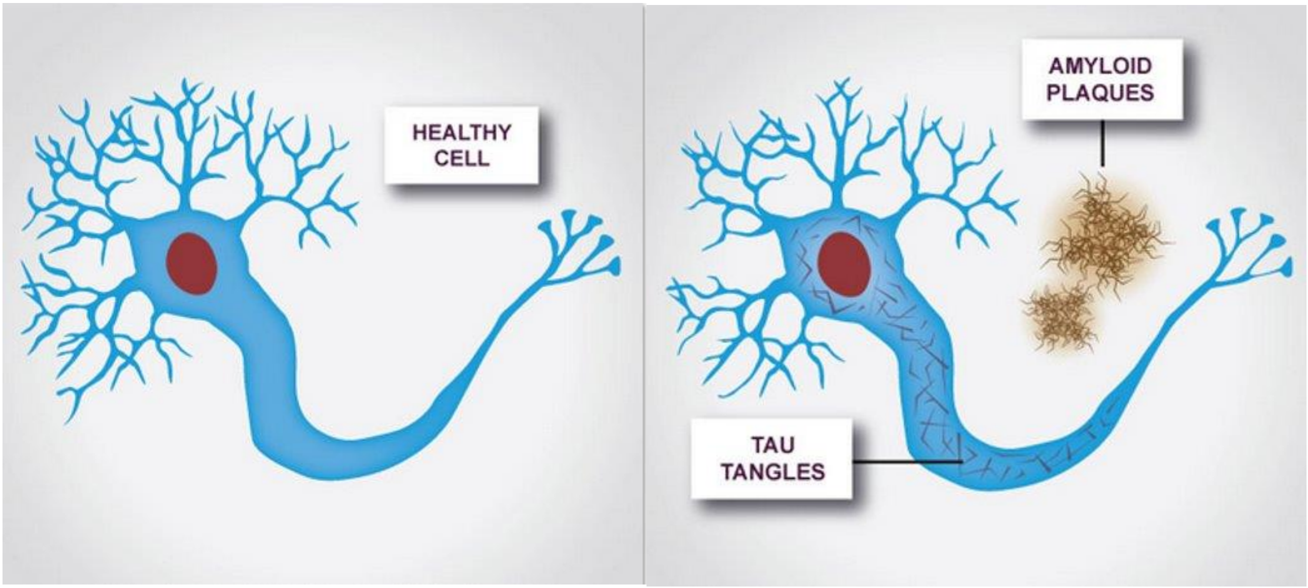
Dementia is caused by physical brain diseases

Nerve cells become damaged and die

Certain parts of the brain start to shrink

A prominent feature of Alzheimer's disease is the progressive loss of synapses





SYNAPSES & NEUROLOGICAL DISEASES

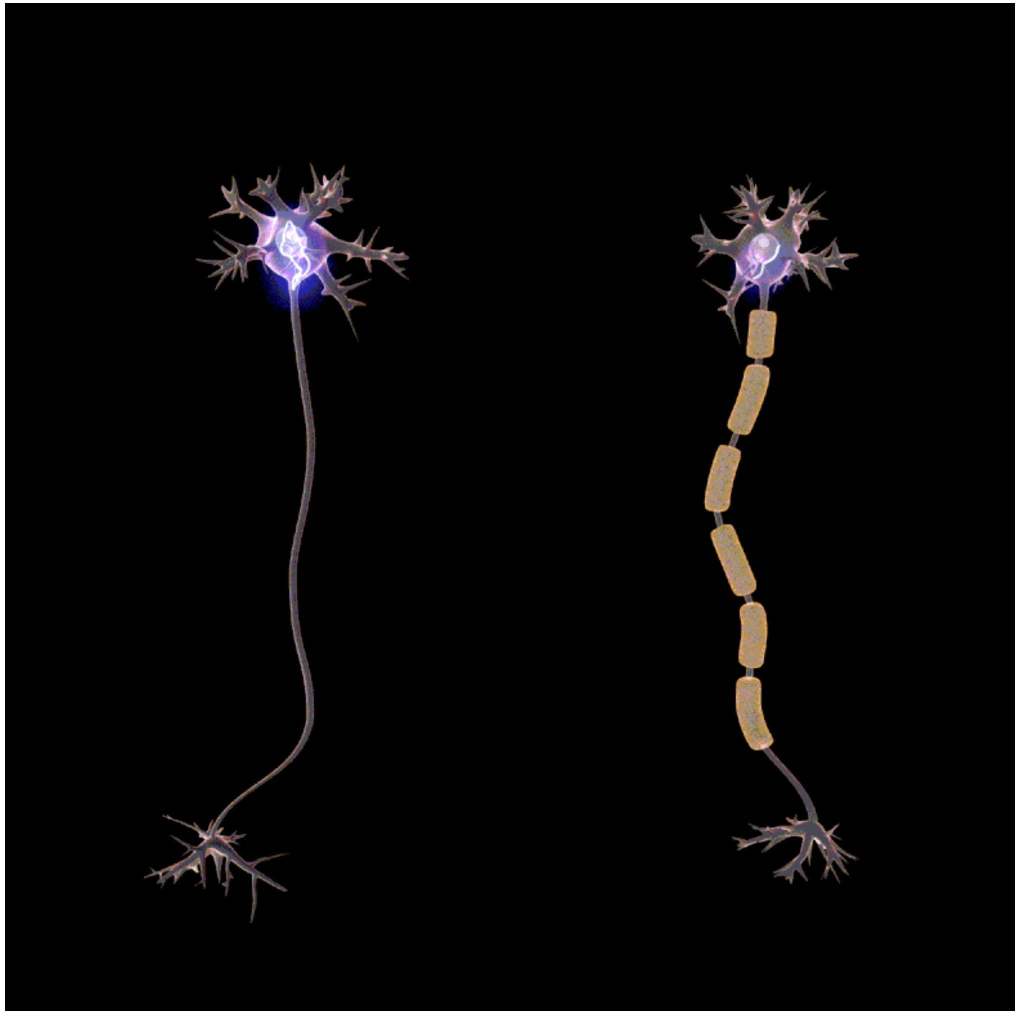
Multiple Sclerosis:

Multiple sclerosis (MS) is a chronic inflammatory disease characterized by the destruction of myelin.

Brain cells that are covered with myelin propagate signals faster.

Myelin is a fatty layer surrounding some neuron axons, which enhances the speed and efficiency of electrical signals along these axons.

The loss of synapses can occur in the early stages of MS and may contribute to the development of neurological symptoms.



SYNAPSES & NEUROLOGICAL DISEASES

Amyotrophic Lateral Sclerosis (ALS):

Progressive fatal neurodegenerative disorder. Destruction of upper and lower motor neurons in brain and spinal cord.

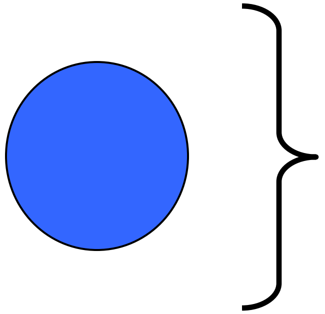
Upper motor neuron: spasticity, clonus, hyperreflexia.
Lower motor neurons: weakness, atrophy, fasciculation.
No known cure.

In ALS, the degeneration of motor neurons leads to a disruption in the signaling process at the synapses. This results in the failure of motor neurons to effectively communicate with the muscles they innervate.

BUILDING BLOCKS OF ARTIFICIAL NEURAL NETWORKS

The “building blocks” of artificial neural networks are the artificial neurons.

Artificial neurons are also known as units or nodes.



unit

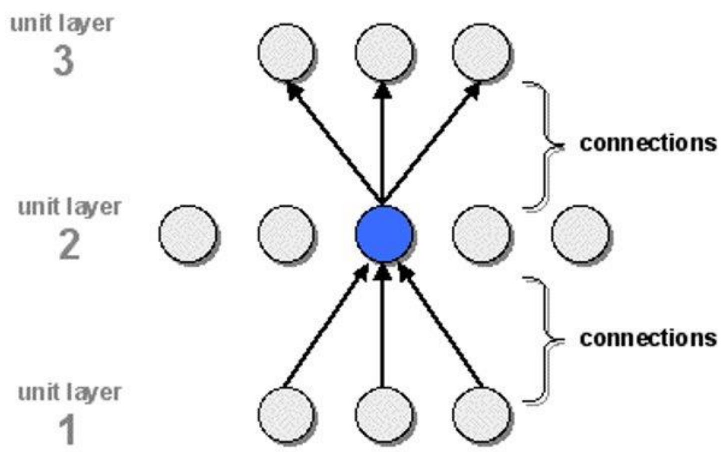
Each unit:

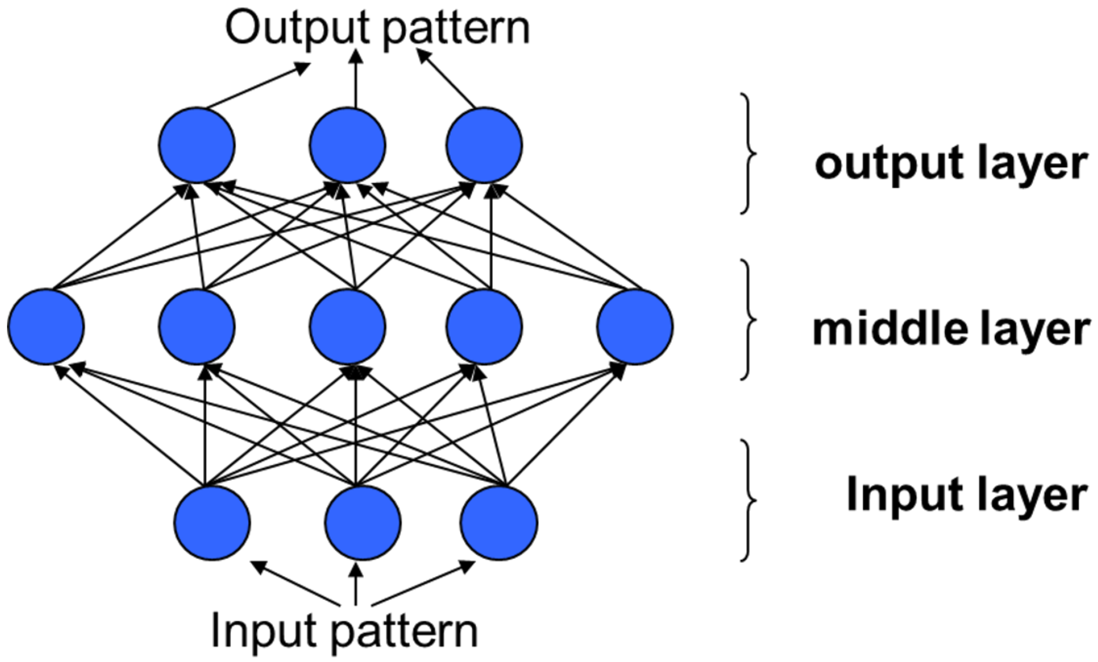
- **Receives input** from many **other units**.
- **Changes** its internal state (activation) based on the **current input**.
- **Sends** one output signal to many different units.

- Units are to a connectionist model what neurons are to a **biological neural network**.
- The basic information processing structures.
- Circles represent units.

ANATOMY OF A CONNECTIONIST MODEL

Connections in a connectionist model are **represented with lines**.
Arrows in a connectionist model indicate the flow of information **from one unit to the next**.

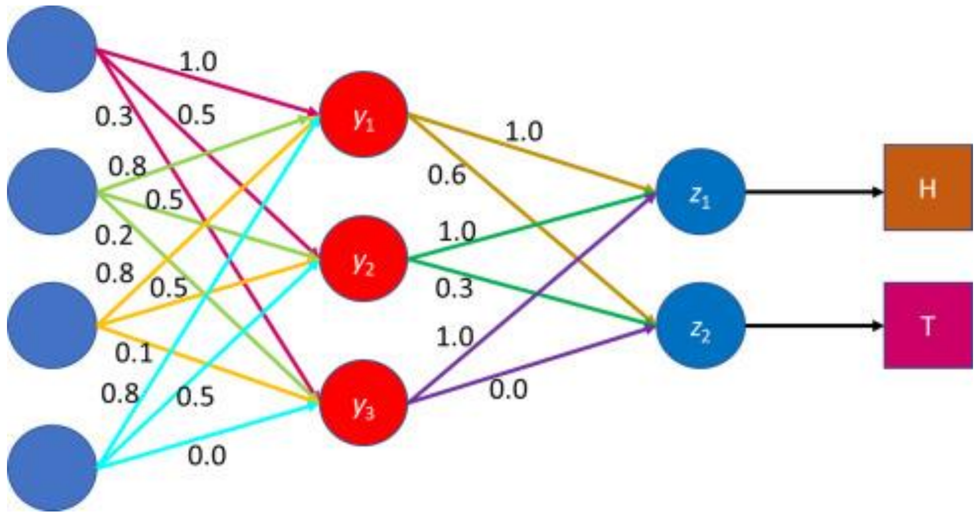




Example: fully-connected feedforward network

CONNECTION WEIGHTS

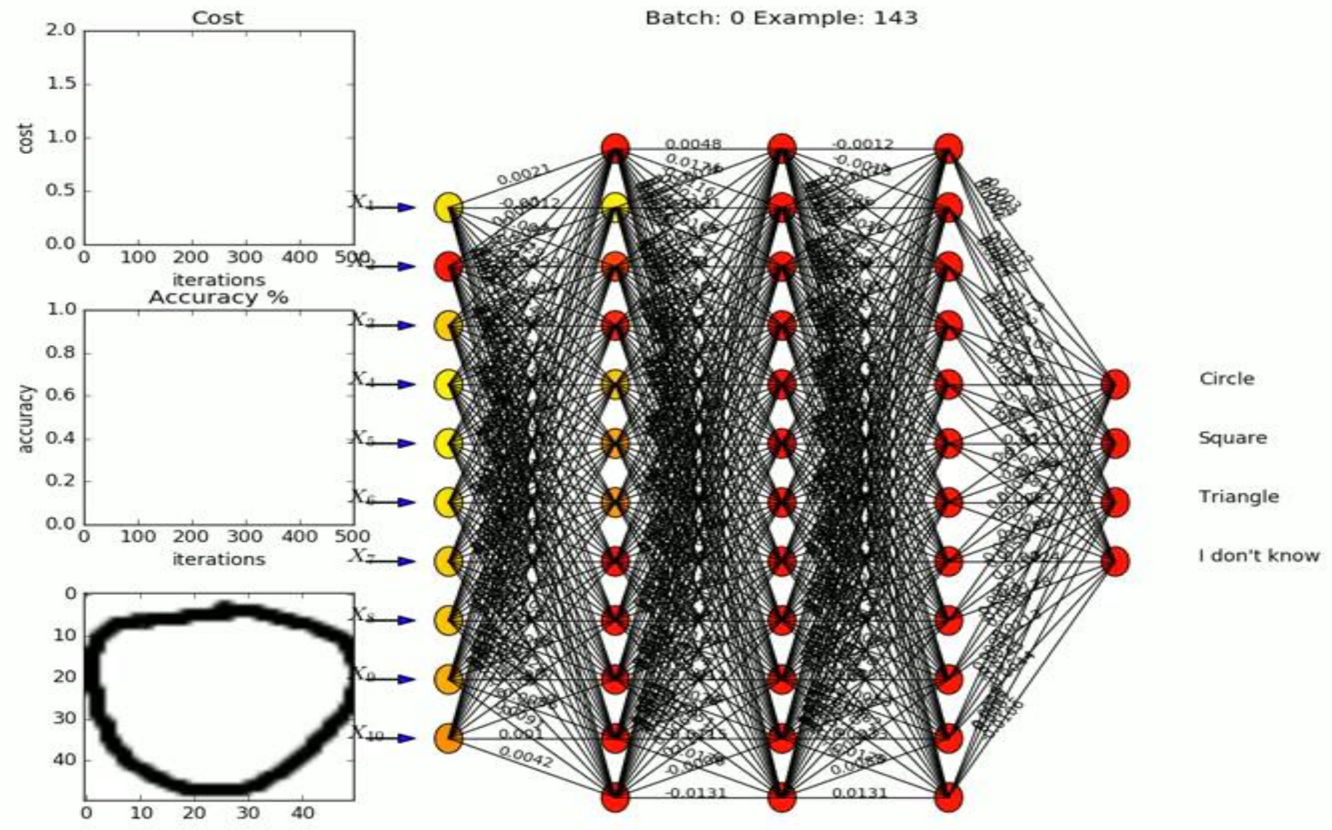
Connection weights are usually **non-discrete values** between **a certain range, usually -1 to 1**.
A **low connection weight** (say, -0.8) represents a weak connection (**inhibition**).
A **high connection weight** (say, 0.7) represents a strong connection (**excitation**).



A unit computes its output in two steps:

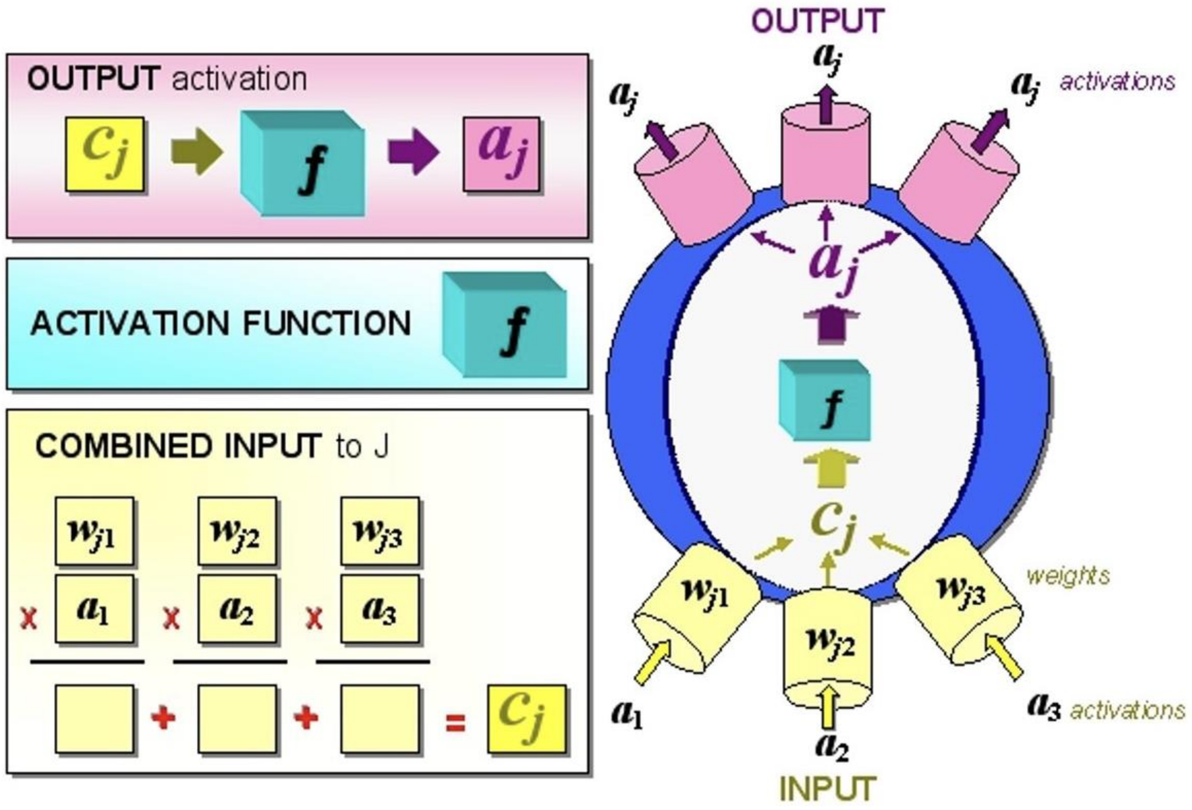
- **Step 1: Computes its combined input.**
- **Step 2: It "squashes" it via its activation function.**

CONNECTION WEIGHTS: ANIMATION VIDEO



Watch the video here: https://www.youtube.com/shorts/pKJYHt6AKvU

ACTIVATION & OUTPUTS

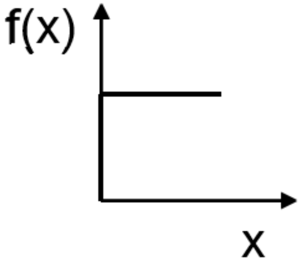


Since **J**'s OUTPUT becomes the INPUT activation to each of the units to which it is connected, the cycle of INPUT-to-OUTPUT information processing just described is then repeated within each of the units in the layer above **J**

TYPES OF ACTIVATION FUNCTIONS

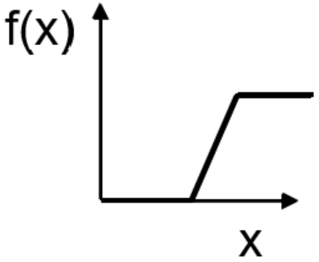
Threshold Function

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



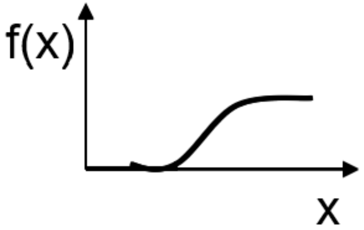
Piecewise-Linear Function

$$f(x)=\begin{cases}1 & if\ x\geq 1.5\\ x-0.5 & if\ 0.5<x<1.5\\ 0 & if\ x\leq 0.5\end{cases}$$



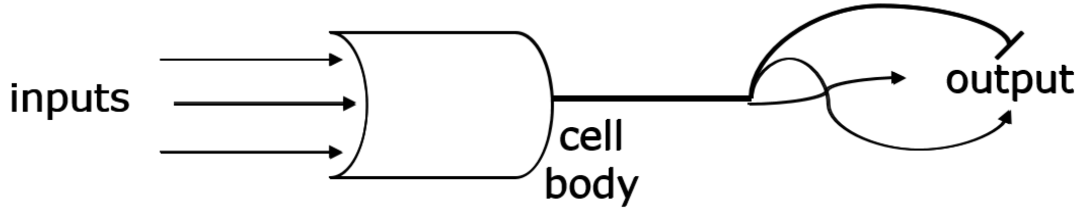
Sigmoid Function

$$f(x)=\frac{1}{1+e^{-x}}$$



McCulloch-Pitts Neuron

In analogy to a biological neuron, we can think of a virtual neuron that crudely mimics the biological neuron and performs analogous computation.



Just like biological neurons, this artificial neuron neuron will have:

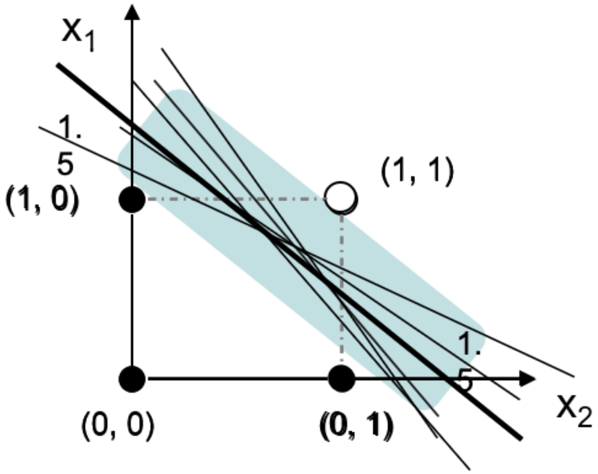
Inputs (like biological dendrites) carry signal to cell body.

A body (like the soma), sums over inputs to compute output, and outputs (like synapses on the axon) transmit the output downstream

EXAMPLES: DECISION BOUNDARY FOR 'AND' GATE

AND
w1=1, w2=1, θ=1.5

AND		
x_1	x_2	out
0	0	0
0	1	0
1	0	0
1	1	1



slope

intercept

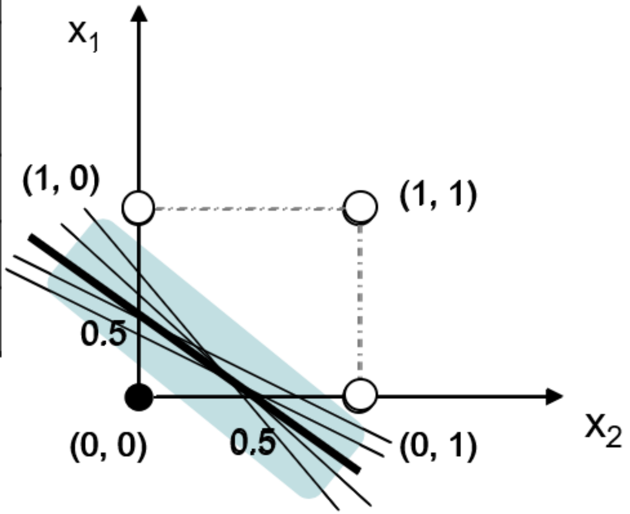
$$\sum_i w \cdot x_i = \theta \Leftrightarrow w_1x_1 + w_2x_2 = \theta \Leftrightarrow x_2 = -\left(\frac{w_1}{w_2}\right)x_1 + \left(\frac{\theta}{w_2}\right)$$

EXAMPLES: DECISION BOUNDARY FOR 'OR' GATE

OR

w1=1, w2=1, θ=0.5

OR		
x_1	x_2	out
0	0	0
0	1	1
1	0	1
1	1	1



slope

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$$\sum_i w\cdot x_i = \theta \Leftrightarrow w_1x_1 + w_2x_2 = \theta \Leftrightarrow x_2 = -\left(\frac{w_1}{w_2}\right)x_1 + \left(\frac{\theta}{w_2}\right)$$

Any Questions?

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