# Biological and Artificial Neurons

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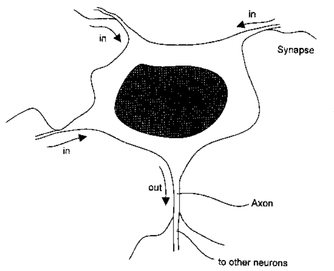
# Lecture Outline

- Biological Neurons
- Biological Neural Networks
- Artificial Neurons
- Artificial Neural Networks

# Biological Neurons

- The "squishy bits" in our brains
- Each neuron is a single cell
- Neuron has:
  - nucleus
  - many processes leading into it
    - dendrites
  - one process leading out of it
    - Axon

# Biological Neurons




From Kasabov, 1996

# Biological Neurons

- Axons branch and connect to other neurons and tissues
- Covered in a sheath of myelin
- Gaps in myelin called "nodes of Ranvier"
  - accelerate travel of signals

# Biological Neurons

- Neurons are electro-chemical
- Electrical potential difference between inside and outside of axon
  - inside is negative
  - outside is positive
  - -70 mV PD inside-outside
    - *resting potential*

## Biological Neurons

- Potential difference is due to different concentrations of sodium (Na) and potassium (K) ions
  - K inside
  - Na outside
- Ion pumps remove Na from the cell while importing K

## Biological Neurons

- When the neuron is stimulated, the ion concentrations change
- Causes a change in the potential of the neuron
  - decreases the resting potential
- Neuron fires when it reaches a threshold
- Action potential

## Biological Neurons

- When the neuron fires, the potential drops down below the resting potential
- After firing, returns to resting potential
- Firing causes a spike of potential to travel along the axon

## Biological Neurons

- Spike is caused by ion gates opening in the cell membrane
- Allow Na ions in
- K ions then forced out
- Reverses potential wrt inside and outside
  - inside becomes positive
  - outside becomes negative

## Biological Neurons

- Gates function sequentially along the axon
- Potential returns to normal as ion balance is restored
- Neuron cannot fire again until the resting potential is restored
- Refractory period

## Biological Neurons

- A neuron is all or nothing
- It will fire or not fire
- Spike is always the same potential
- Firing can emit a “spike train”
- Frequency of spikes influenced by level of stimulation
  - higher stimulation = higher frequency spikes

## Biological Neural Networks

- Axons join to other neurons
- Gap between them is called a synapse
- Signals are carried across the gap by neurotransmitters
  - e.g. acetylcholine
- Amount of neurotransmitter depends on “strength” of neuron firing

## Biological Neural Networks

- Neurotransmitters effect the functioning of the ion pumps
- Excite / inhibit flow of Na ions into the cell
  - changes the potential of the neuron
- Neurotransmitters cleaned up by enzymes
  - firing of neurons can depend on this as well

## Biological Neural Networks

- Synapses can excite the neuron
  - excitatory connections
- Synapses can inhibit the neuron
  - inhibitory connections
- Different amounts of neurotransmitter are released across each synapse

## Biological Neural Networks

- Synapses have different “strengths”
- Synapses that are used more, are stronger
- Hebbian Learning Rule
  - proposed by Donald Hebb in 1949
  - if two connected neurons are simultaneously activated, then the connection between them will be strengthened

## Artificial Neurons

- Abstract mathematical models of biological neurons
- Most don’t attempt to model biological neurons
- First model developed by McCulloch and Pitts in 1943

## Artificial Neurons

- McCulloch and Pitts neuron
  - a boolean automata
  - either on or off
  - will fire if the inputs exceed the threshold value
  - output is constant
  - no time dimension (discrete)

# Artificial Neurons

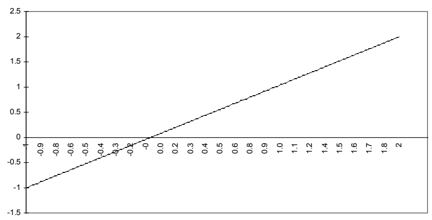
- Most artificial neurons have three things
  - an input transformation function
  - an activation function
  - an output transformation function
- Input transformation functions process the incoming signal
  - usually multiply and sum

# Artificial Neurons

- Activation functions process the input signal
  - linear
  - saturated linear
  - sigmoid
  - tanh
- Output functions process the outgoing signal
  - usually linear

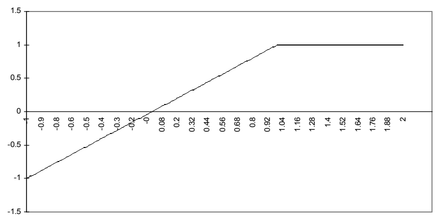
# Activation Functions

- Linear $a = S$
  - what goes in is what comes out



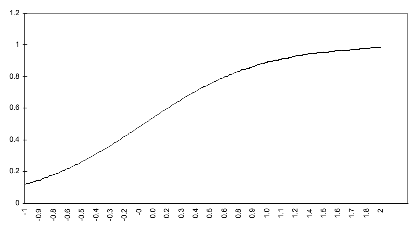

# Saturated Linear Activation Function

- Saturated Linear
  - linear up to a certain limit




# Sigmoid Activation Function

- non-linear function $a = \frac{1}{1 + e^{c.-S}}$
  - limits of 0 and 1




# Artificial Neural Networks

- A network of interconnected artificial neurons
- Connections between neurons have variable values
  - weights
- Signal is fed through the connections and processed by the neurons

## Artificial Neural Networks

- Multiply and sum operation
  - performed when a neuron is receiving signal from other neurons
  - preceding neurons each have an output value
  - each connection has a weighting
  - multiply each output value by the connection weight
  - sum the products

## Artificial Neural Networks

- Learning in ANN is the process of setting the connection weights
  - multi-parameter optimisation problem
- Biggest advantage of ANN
  - learning from data
- No need to know specifics of process
  - cf rule based systems

## Artificial Neural Networks

- Learning can be of two types
  - supervised
  - unsupervised
- Supervised learning
  - learning algorithm will try to match known outputs
  - requires known outputs

## Artificial Neural Networks

- Unsupervised learning
  - learning algorithm will try to learn structure of data
  - no known outputs required

## Artificial Neural Networks

- Knowledge is stored in connection weights
- ANN are also called connectionist systems
- Knowledge can be discovered using ANN
  - usually via rule extraction
  - analysis of performance can also help
- "Black-box" character biggest drawback to using ANN in systems

## Artificial Neural Networks

- Many kinds in existence
- We will be covering only three
  - Perceptrons
  - Multi-layer Perceptrons (MLP)
  - Kohonen Self-Organising Maps (SOM)

# Artificial Neural Networks

- Which networks are used depends on the application
- perceptrons useful for simple problems
  - linear separability
  - supervised learning
- MLPs handle problems perceptrons cannot
  - non linearly separable
  - supervised learning

# Artificial Neural Networks

- SOMs find clusters in data
  - unsupervised learning
- Care must be taken with the data used to train the network
  - It is easy to badly train an ANN
- Other circumstances where ANN don't function well

# Summary

- Biological neurons are specialised cells
- Emit signals in response to stimulation
- Relatively complex cells
- Biological neural networks are extremely complex
  - huge number of connections
- Learning is not entirely understood

# Summary

- Artificial neurons are abstractions of real neurons
- Simple mathematical models
- Internal functions vary
- Networks of these neurons are called artificial neural networks
- Knowledge is stored in the connection weightings of these networks

# Summary

- Learning in ANN is setting these connection weights
- ANN learn from data
- Many kinds of ANN in existence
- Three popular models
  - perceptron
  - MLP
  - Kohonen SOM