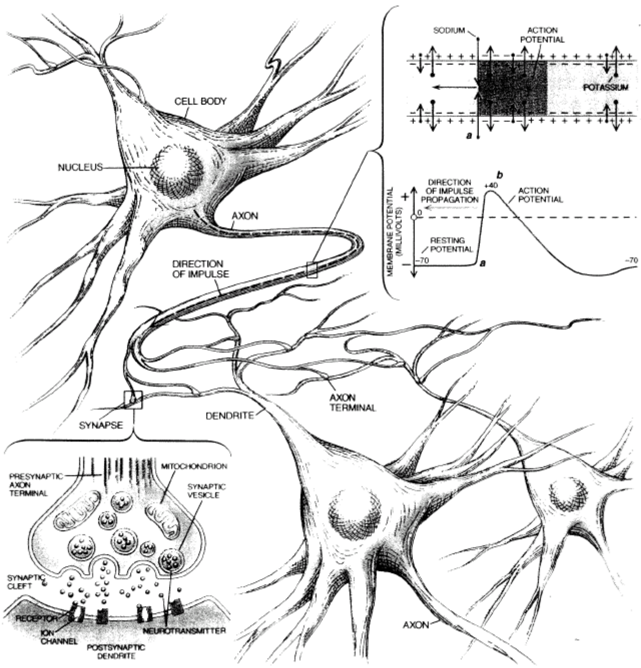
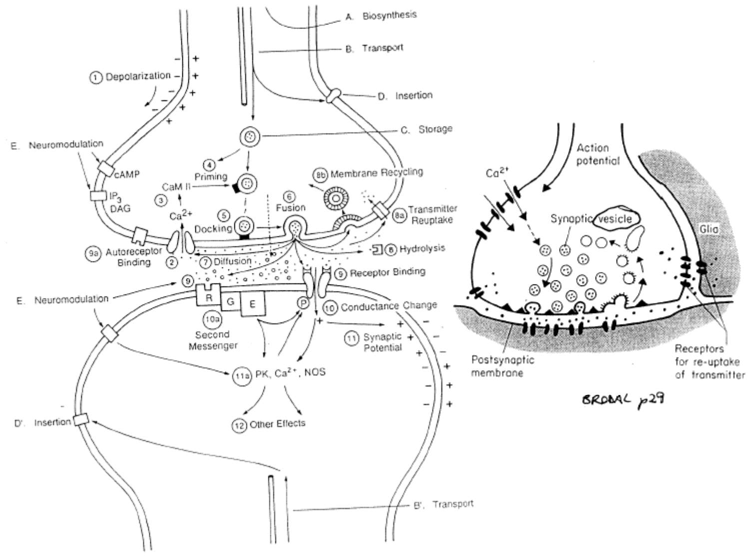
How Neurons Communicate

Computing and the Brain

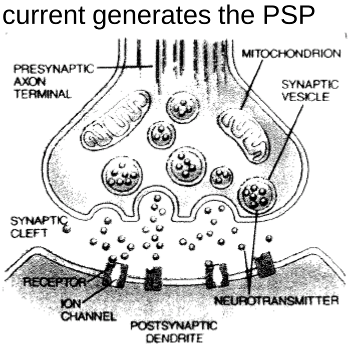


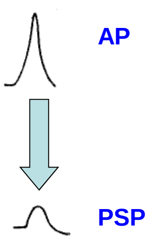
The Synapse



The Synapse

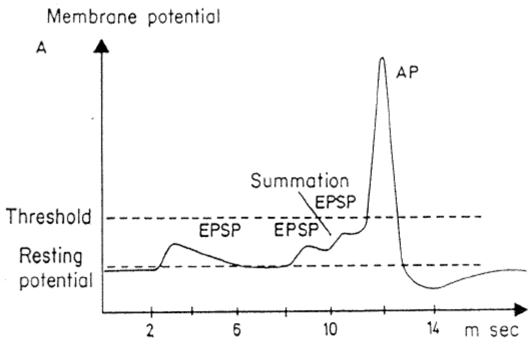
- The synapse converts an action potential (AP) into a postsynaptic potential (PSP)
- The presynaptic AP causes calcium (Ca) entry
- Ca causes vesicles of *neurotransmitter* to be released
- Neurotransmitter binds to postsynaptic receptors (ion channels), causing them to open
- The resulting ionic current generates the PSP





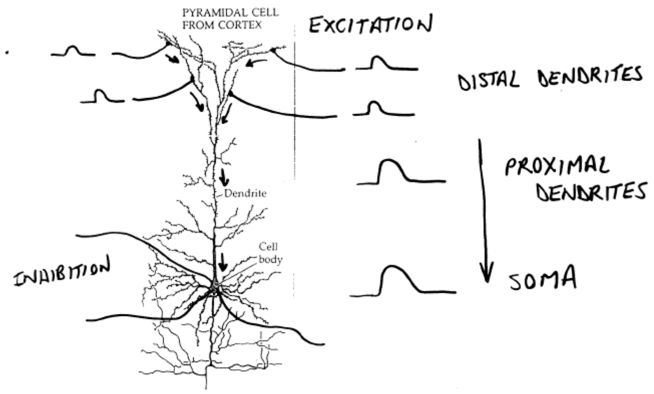
Excitatory Inputs

- A depolarising postsynaptic potential is *excitatory* (EPSP)
- Neurotransmitter is usually glutamate
- Postsynaptic receptor ion channels allow entry of Na and Ca
- Sufficient coincident EPSPs can cause a neuron to fire an AP
  - Commonly 20 to 100 coincident EPSPs



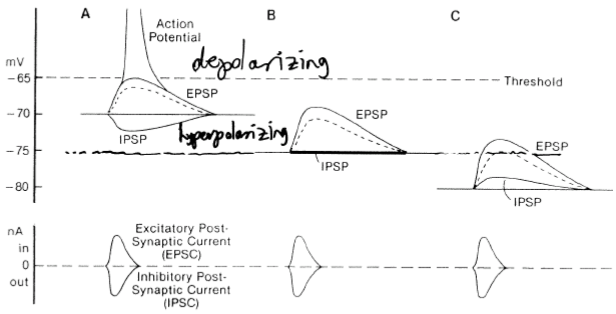
Excitatory Inputs (2)

- Excitatory inputs are often on the dendrites
- They travel down the dendrites, summating on the way
- Final site of integration (summation) is the cell body (soma)
- A pyramidal cell may have 10,000 to 30,000 excitatory synapses

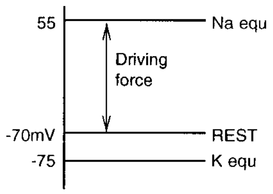


Inhibitory Inputs

- Inhibitory inputs are on the dendrites or around the soma
- They may be depolarising, hyperpolarising or make no change to the membrane potential
- The receptor ion channels pass potassium or chloride ions
  - Equilibrium potential is near threshold (just above or below)
- In any case, an IPSP coincident with an EPSP will reduce the amplitude of the EPSP
  - And so reduce the chance that the neuron will fire an AP

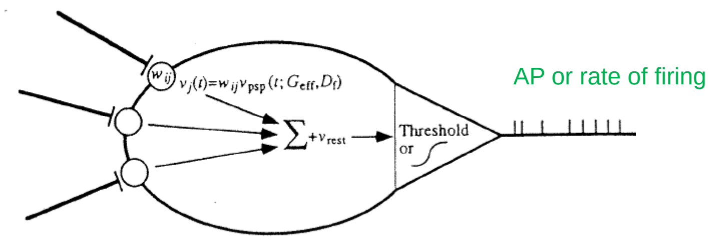


$$I_X = (V_m - E_X)G_X$$



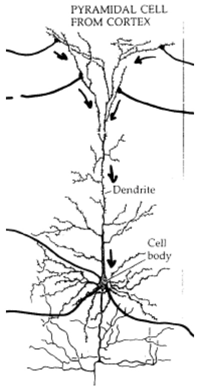
The Summing Neuron

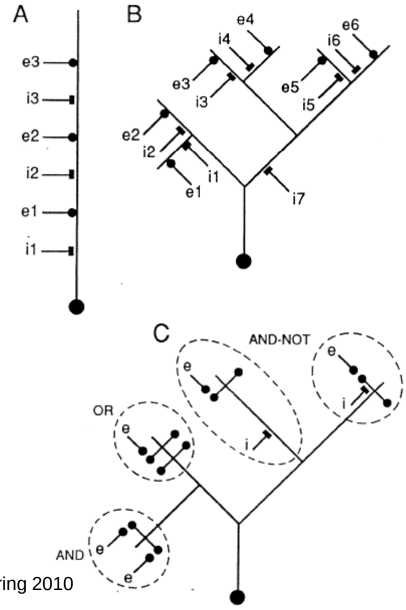
- The conductance, G, and hence the amplitude of a PSP, can be different at each synapse: equivalent to a connection *weight*
- Excitatory inputs form a sum of positive weights: ΣwE
- Hyperpolarising inhibitory inputs are like negative weights
  - Subtract from the sum of EPSPs: ΣwE - ΣwI
- IPSPs that depolarise or do not change Vm are divisive
  - Scale down the summed EPSPs by dividing the sum: ΣwE / ΣwI



Local Logic in the Dendrites

- EPSPs and IPSPs can interact locally in the dendrites





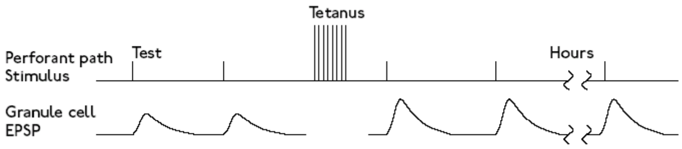
Plasticity in the Nervous System

- Many parts of the nervous system change over time
  - Development over days to years
  - Changes in response to experience: seconds to years

Age	*Major Modification*	*Mechanisms*
Pre-natal	growth and construction	cell division, cell death, cell movement, wiring
Post-natal	reorganisation	rewiring
Childhood and Adulthood	**LEARNING** and **MEMORY**	rewiring and **SYNAPTIC MODIFICATIONS**

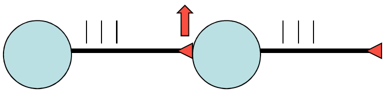
Learning in the Nervous System

- ANNs "learn" by adapting the connection weights
  - Different learning rules
- Synapses change their strength in response to neural activity
  - Long term potentiation (LTP) and depression (LTD)
- Indirect evidence that this corresponds to "learning"
  - Associative or "Hebbian" learning (Hopfield net)

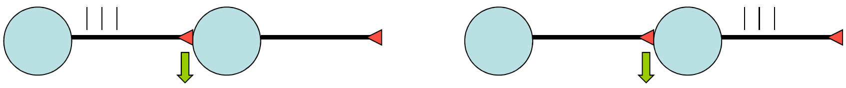


Associative Learning

- What learning rules does the brain use?
- Associative learning
  - Increase synaptic strength if both pre- and postsynaptic neurons are active (LTP; predicted by Donald Hebb, 1949)



  - Decrease synaptic strength when the pre- or postsynaptic neuron is active and the other is silent (LTD)



- This is like the Hopfield network