Computing and the Brain

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Biological Neural Networks

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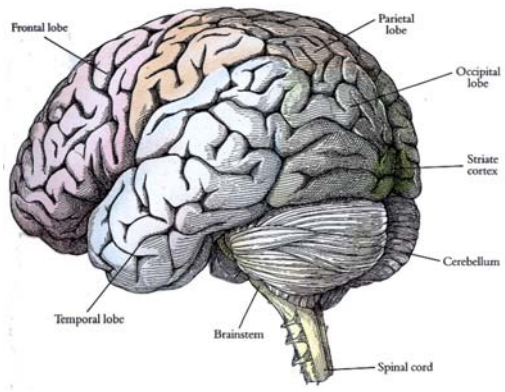
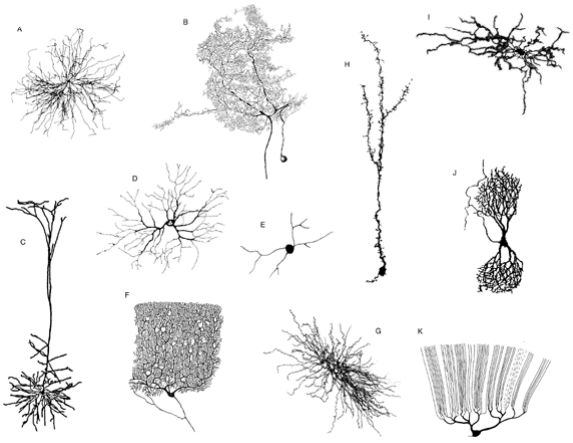
The Brain

- The brain consists of networks of networks of neurons
- The human brain contains around 10^{11} neurons and 10^{15} synapses
- A neuron receives around 10,000 connections from other neurons



Neurons

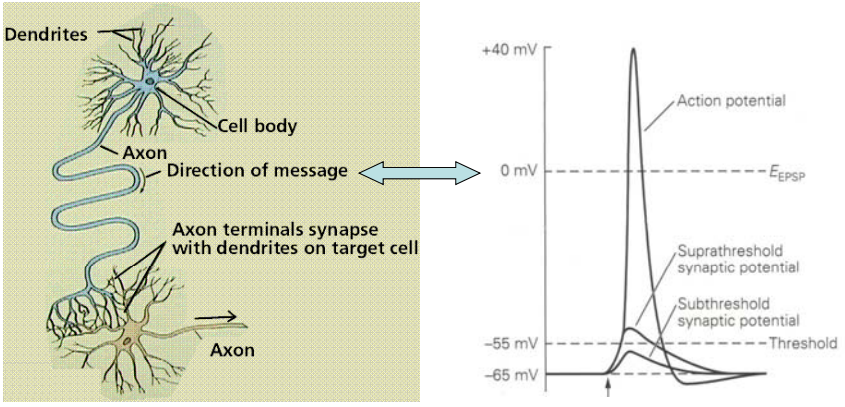
- Neurons are biological cells that a specialised to form networks and send electrical signals to each other
- They come in many different shapes and sizes



(from "Dendrites", Spruston, Stuart & Hauser (eds))

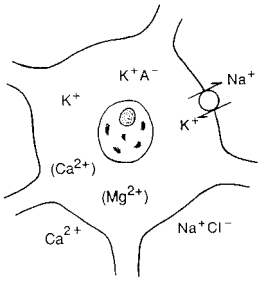
Component Parts of a Neuron

- Soma, or cell body – site of integration of incoming signals
- Dendrites – major site of synapses from source neurons
- Axon – output pathway forming synapses on target neurons

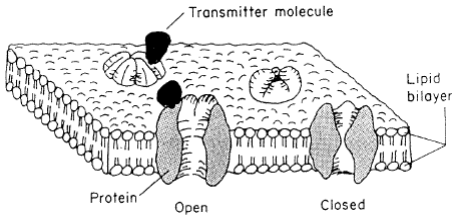


Electrical Properties of Neurons

- Cell membrane separates populations of charged ions
- Differences in the amount of *charge* on either side of the membrane creates a *potential difference* or voltage across the membrane
- Ions can pass across the membrane through ion channels
- Ion channels are selective for particular ionic species
  - E.g. Sodium (Na), potassium (K) and calcium (Ca) ion channels
- Ion channels can be open or shut, depending on the voltage across the membrane



(SH88, Fig 4.1)

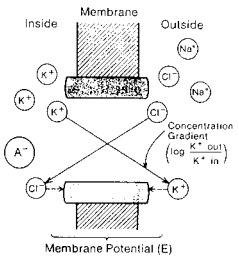


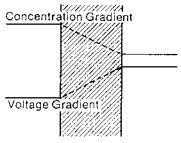
(BR92, Fig 1.17)

The Membrane Potential

- Cell membrane separates populations of charged ions
- Ions travel down their concentration gradient through open ion channels
- This is balanced against the voltage gradient due to differences in charge across the membrane
- Ions cease to travel at their Nernst (equilibrium) potential:

$$E_X = \frac{RT}{zF} \ln \frac{[X^+]_o}{[X^+]_i}$$





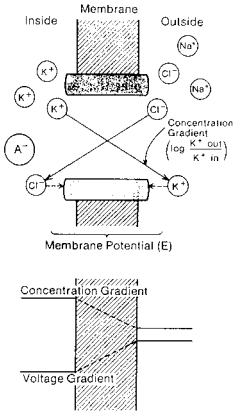
(SH88, Fig 4.3)

Membrane Current

- Movement of ions through ion channels creates an electrical current
- For a given membrane voltage, V, the current, I, is given by Ohm's Law:

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

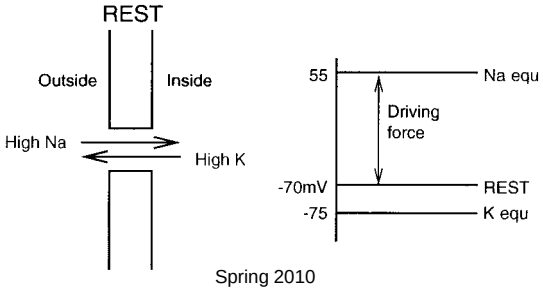
- The difference between V and the ion's equilibrium potential, E_X, gives the *driving force* of the current
- The *conductance*, G_X, is a function of the number of open ion channels
  - Conductance is the inverse of resistance: R=1/G
  - Function of *voltage* or *neurotransmitter*



(SH88, Fig 4.3)

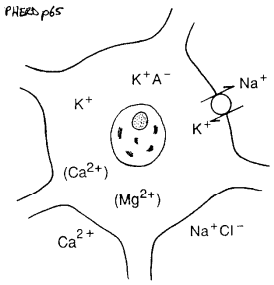
The Resting Membrane Potential

- If the neuron is not receiving any input, then the membrane potential assumes its *resting* level
- This is largely due to small numbers of open sodium (Na) and a larger number of open potassium channels (K)
- Na has a Nernst potential of around 55mV
- K has a Nernst potential of around -75mV
- The resulting rest potential is around -70mV
- Total current is 0 = $I_{Na}+I_K$

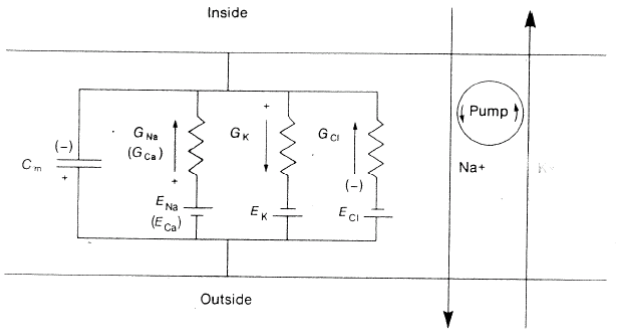


Equivalent Electrical Circuit

- A patch of membrane can be described by an electrical circuit
- Conductances and batteries in parallel with capacitance
  - Capacitance created by separation of charge across membrane
- Conductances may be variable, depending on local membrane potential or presence of neurotransmitter (at a synapse)



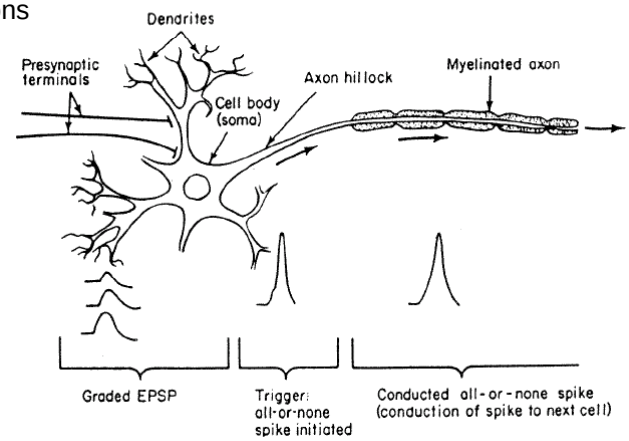
(SH88, Fig 4.1)



(SH88, Fig 4.6)

The Action Potential

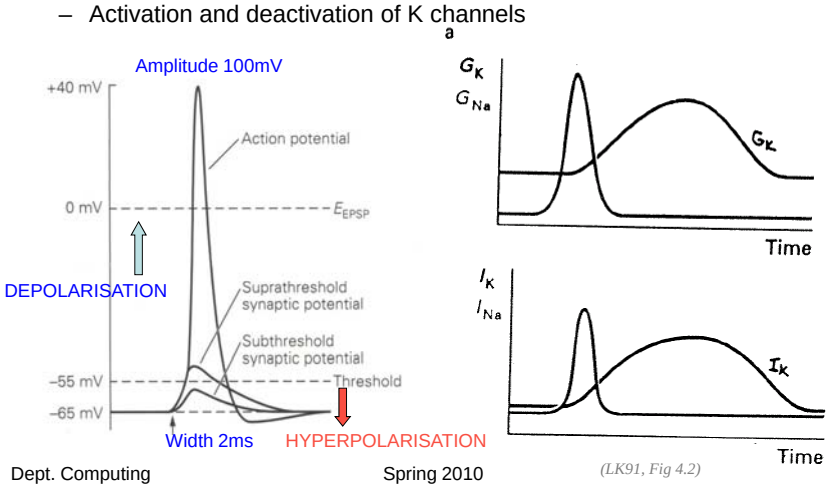
- Incoming signals from other neurons may raise the membrane potential sufficiently to allow the generation of an *action potential*
- The AP then propagates along the axon to synapses on other neurons



(CS94, Fig 2.19)

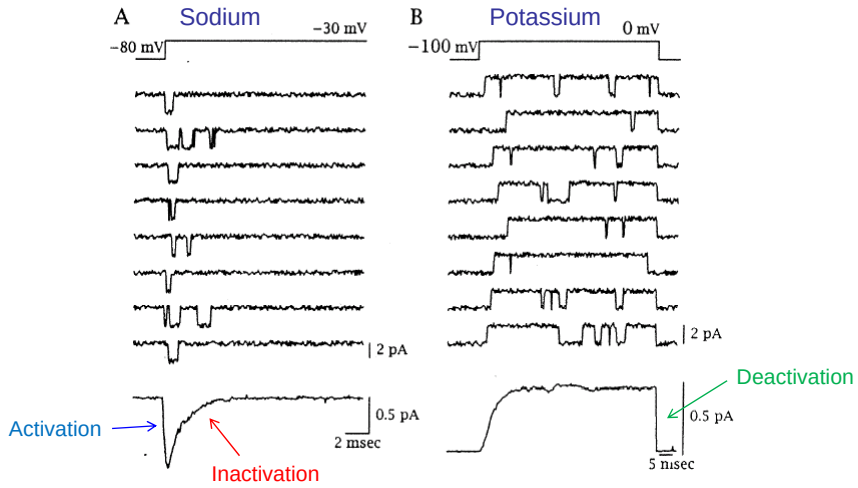
Action Potential Generation

- Action potential (AP) is due to the opening and closing of *voltage-gated* sodium (Na) and potassium (K) channels
  - Activation and inactivation of Na channels
  - Activation and deactivation of K channels



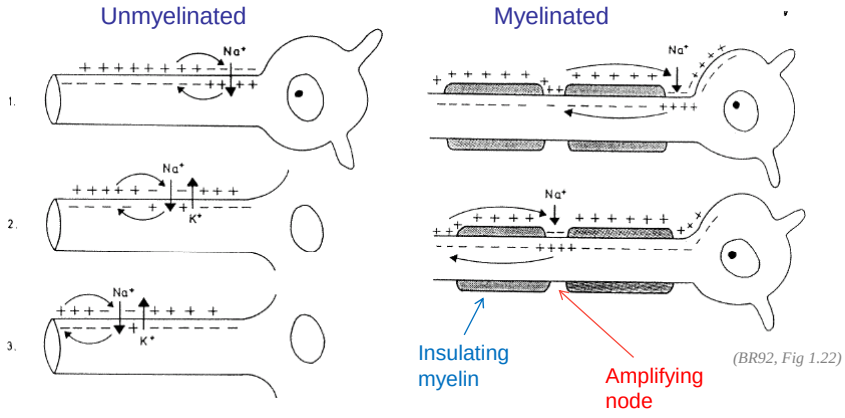
Activation, Inactivation and Deactivation

- *Activation* and *inactivation* of Na channels
- *Activation* and *deactivation* of K channels



Action Potential Propagation

- AP travels along axon from soma to synapses
- Myelinated: 10-120m/sec
- Unmyelinated: <1m/sec



(BR92, Fig 1.21)

(BR92, Fig 1.22)

References

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- SH88: Shepherd, Neurobiology, OUP 1988 (and later editions)
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