Introduction to neuroscience for PSIBS

Overview of nervous system
How neurons work
Simple sensory-motor circuits
Complex function
Why do we have a nervous system?

Information processing

Information transmission

Adaptation (learning)
Human cerebral cortex

But remember there is also a lot of brain-stem and spinal cord function.
Neuronal processing

Drawing by Santiago Ramón y Cajal of neurons in the pigeon cerebellum.

**Inputs**

**Integration**

**Outputs**

*A neuron*

*Caenorhabditis elegans* has 302 neurons. Scientists have mapped all the neurons & connections.

*Drosophila melanogaster* has ~ 300,000 neurons.

The human brain at ~ 100 billion ($10^{11}$) neurons and 100 trillion ($10^{14}$) synapses.
Neurons

- Dendrites
- Spina
- Perikaryon (soma)
- Axon
- Axon collateral
- Terminal ramifications
- Dendrites
- Cell body (soma)
- Axon
- Terminal and synapse
- (a)
- (b)
- (c)
- (d)
- (e)
Local potentials
• changes in membrane potential

• measured as potential difference across membrane

• cannot transmit signals any long distance
Axons are “insulated” with fatty sheath (myelin) to improve performance.

White matter - myelinated axons

Grey matter - cell bodies, synapses and non-myelinated axons
“Action potentials” and rate coding

- large brief changes in membrane potential
- travel along the membrane as a “wave”
- can travel as far as the axon goes

**Figure 7-13.**
Four types of firing patterns in the abdominal ganglion: R2, silent; R3, regular beating rhythm; R15, regular bursting rhythm; L10, irregular bursting rhythm.
(Time and voltage calibrations for L10 are different from those for the other cells.)
Membrane potential

- due to unequal distribution of charged ions
- maintained by active ion pumping pushing Na\(^+\) out and K\(^+\) in
- membrane potential is energy consuming
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Equilibrium potential

the potential at which a particular ion is in balance from:
- **electric force** (opposite charges attract) vs
- **concentration gradient** (ions move into weaker solutions)
Equilibrium potential
distance from EP
describes **short term**
ionic behaviour

In the **long term**, ion
movements would affect
conc. gradient &
electrical gradient

**Nernst equation:**

\[
E_{Na} = \frac{RT \ln [Na]_o}{ZF} \quad [Na]_i
\]

\[
RT = 26\text{mV for } Z = +1 \text{ at } 25^\circ C
\]

ZF

- **R**: Gas constant,
- **T**: temp,
- **Z**: valence,
- **F**: Faraday constant.

\[
E_K = -75\text{mV} \quad E_{Na} = +55\text{mV}
\]

\[
E_{Cl} = -60\text{mV}
\]
Membrane potential is close to EP for potassium and far from the EP of sodium.

Permeability determines actual ion balance.

Goldman equation:

$$V_m = \frac{RT \ln \left( \frac{P_{Na}[Na]_o + P_K[K]_o + P_{Cl}[Cl]_i}{P_{Na}[Na]_i + P_K[K]_i + P_{Cl}[Cl]_o} \right)}{F}$$

$P_{Na}$ is membrane permeability to Na ions.
## Ionic distributions and flux

<table>
<thead>
<tr>
<th></th>
<th>Intracellular conc.</th>
<th>Extracellular conc.</th>
<th>Driving force</th>
<th>Permeability</th>
<th>Net Flux</th>
</tr>
</thead>
<tbody>
<tr>
<td>Na+</td>
<td>low</td>
<td>high</td>
<td>+++ in</td>
<td>very low</td>
<td>in</td>
</tr>
<tr>
<td>K+</td>
<td>high</td>
<td>low</td>
<td>+ out</td>
<td>low</td>
<td>out</td>
</tr>
<tr>
<td>Cl−</td>
<td>low</td>
<td>high</td>
<td>zero (at EP)</td>
<td>moderate</td>
<td>zero</td>
</tr>
<tr>
<td>Anions</td>
<td>high</td>
<td>very low</td>
<td>+++ out</td>
<td>zero</td>
<td>zero</td>
</tr>
</tbody>
</table>
How to change permeability

1. Receptors (e.g., mechanoreceptors)
How to change permeability

2. Voltage-gated channels
“Action potentials”

- brief voltage-sensitive change in permeability
- fast change in Na+ permeability
- slower change in K+ permeability
Action potentials
• unidirectional conduction along axon membrane as self-replicating wave-front

Fig. 1.21. Impulse conduction in un-myelinated axons.
How to change permeability

3. Post-synaptic: receptors
Inter-neuronal communication

how does the action potential go from one cell to the next in the chain?
Neurotransmitter release & post synaptic reception

Fig. 1.23.  Impulse transmission at the synapse.
Synaptic transmission

Most neurons release only one type of neurotransmitter

Most synapses receive only one neurotransmitter
Synaptic integration
Synaptic integration

![Graph showing membrane potential over time with peaks labeled as AP, EPSP, and IPSP, along with thresholds and resting potentials.](image)
Synaptic integration
Action potential rate reflects summed potential at “spike initiation zone”

**Figure 7-13.**
Four types of firing patterns in the abdominal ganglion: R2, silent; R3, regular beating rhythm; R15, regular bursting rhythm; L10, irregular bursting rhythm. (Time and voltage calibrations for L10 are different from those for the other cells.)
Synaptic plasticity = Learning & memory
Long term synaptic potentiation – associative learning mechanism

Weak response

NMDA activation & protein synthesis

Strong response
Neural circuits: divergence, convergence and processing

A. Divergence

B. Convergence

C. Gating by interneurons

D. Gating by presynaptic inhibition
Neural circuits: pattern generation

E  Reverberating circuit

F  Rhythmic alternating activity
External and Internal Signals

Higher Centers

Neurohemal Organs

Other Motor Systems

Command and Modulatory Signals

Neuromodulators

Signals of CPG Activity

CPG

MNs

Muscles

Motor Behavior

Sensory Feedback

- a hind legs spontaneously walk some weeks after spinal section
- b brain stem section and electrical stimulation of locomotor region evokes normal walking pattern

mesencephalic locomotor region
Organisation of the Cerebral Cortex

- cortex forms the outer surface of the forebrain
- all “neocortex” has 6 distinct layers
- cortex covers the other sub-cortical forebrain structures.
• tight correspondence between cytoarchitecture and function
• BA areas are functionally specific
• but some functions are more finely grained than BA areas (e.g. in association areas, BA6, BA7, BA40, etc)
Localization of function

... and brain imaging