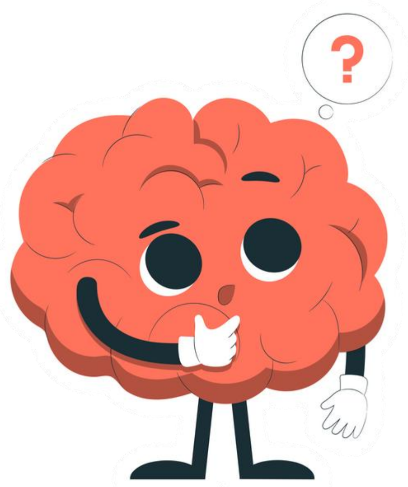
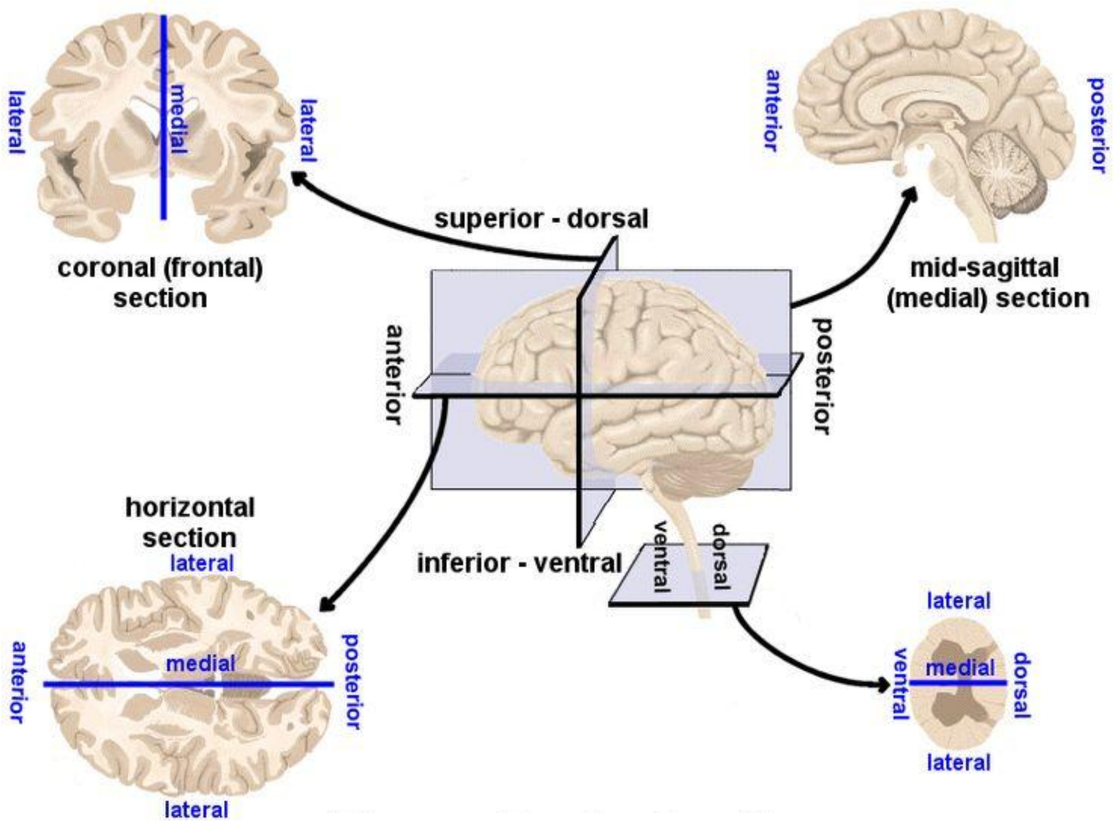
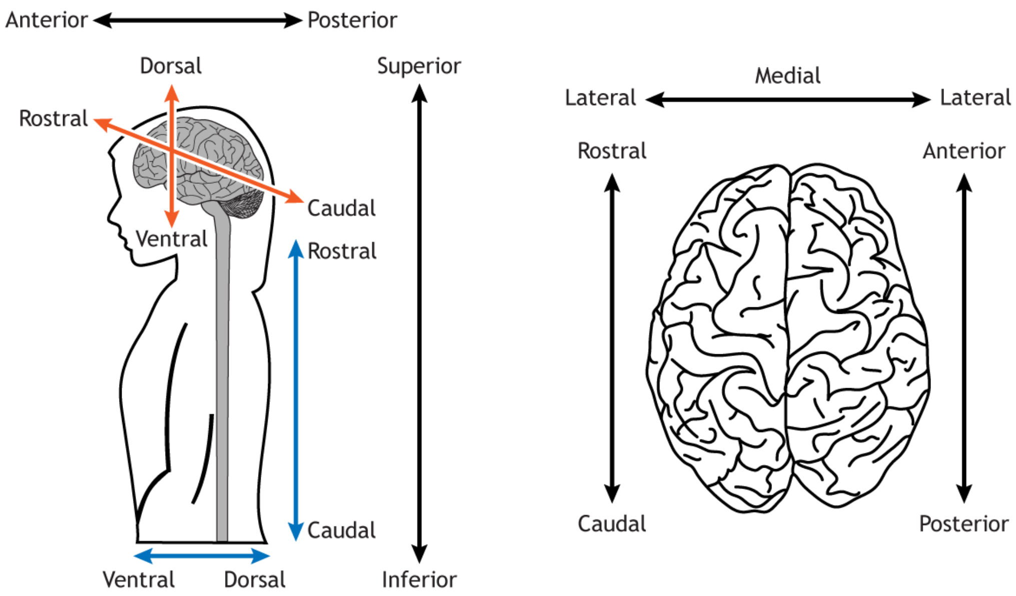
Final overview of BIO-311 Neuroscience 🎉

Units 1 to 13



Anatomical terminology



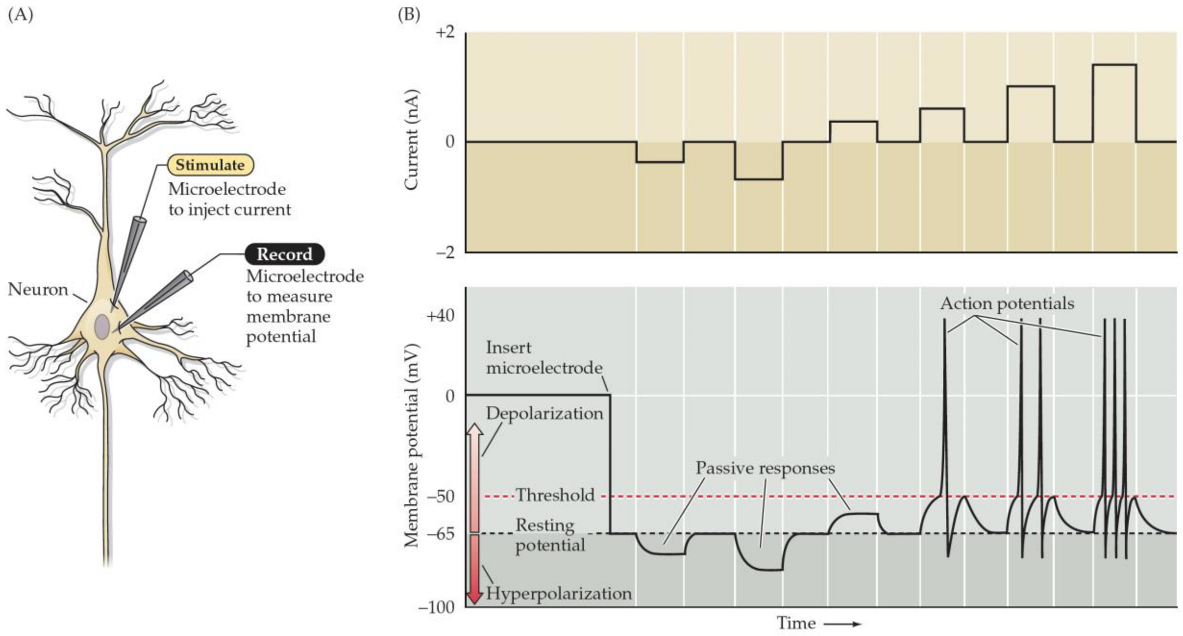


Unit 1 – Introduction to neuroscience and neuron basics

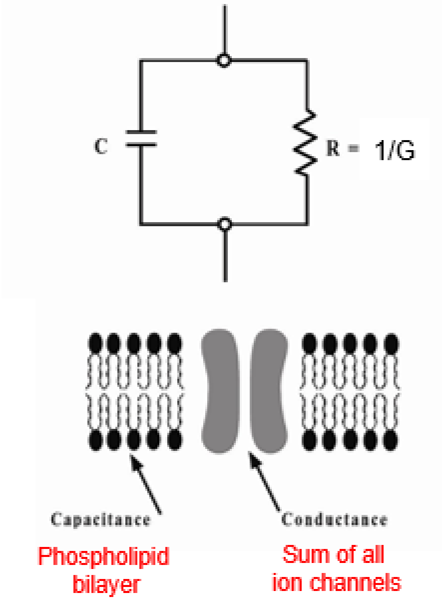
- Phospholipid bilayer permeability
- Ion concentrations — K+ , Na+ , Cl- ATPase
- Equilibrium potential — Nernst Equation
- Resting membrane potential
- Passive membrane properties — RC circuit analogy

Unit 1

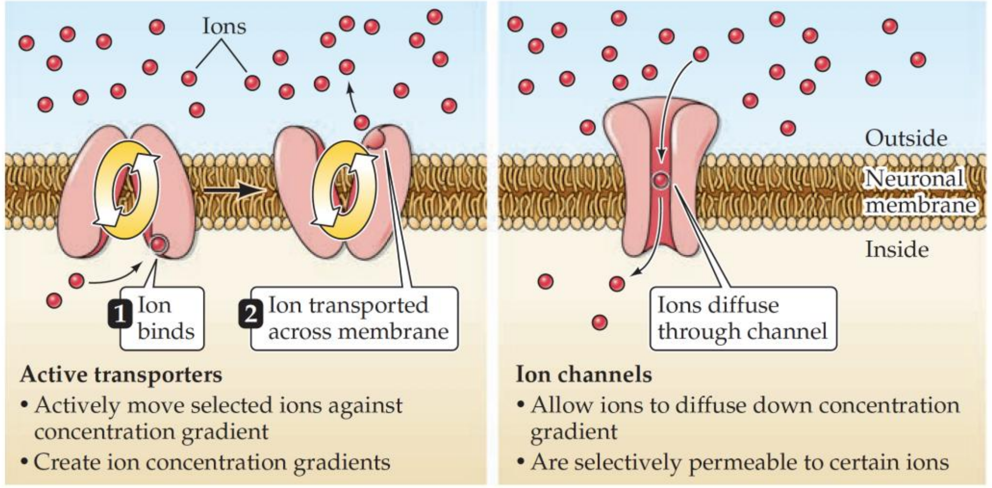
Resting membrane potential and response to current injection

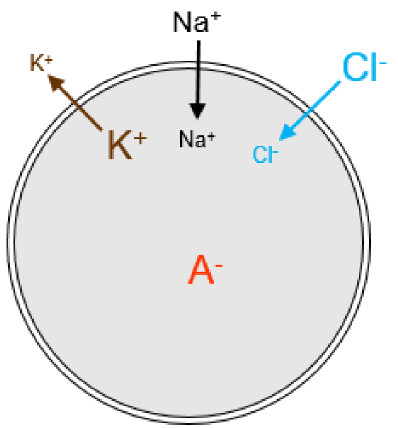


RC circuit analogy



Active and passive transport through lipid membrane



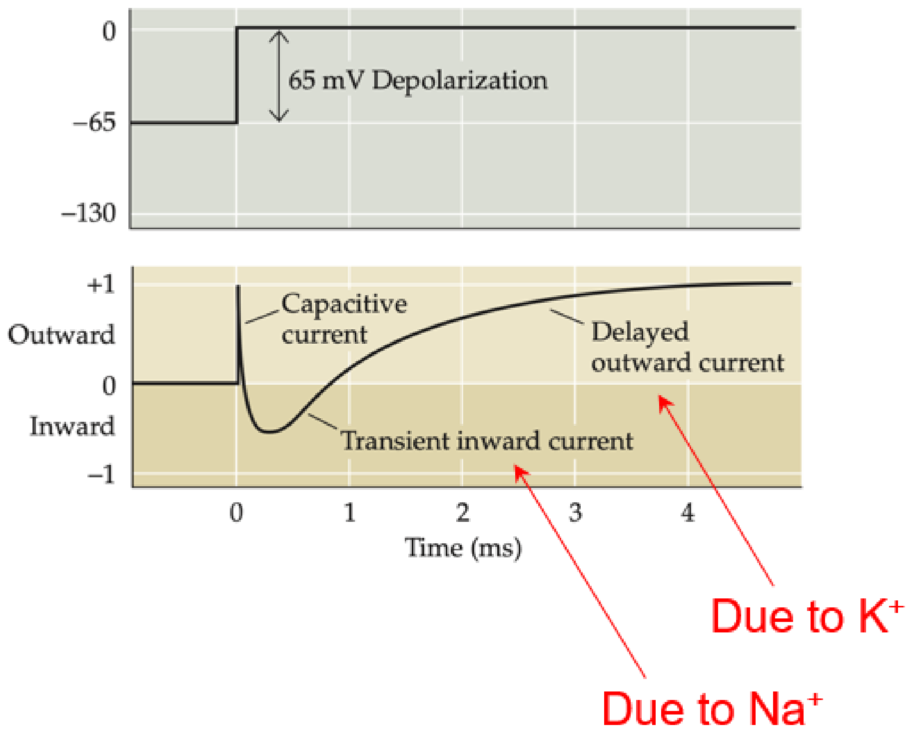


Unit 2 – Action potentials

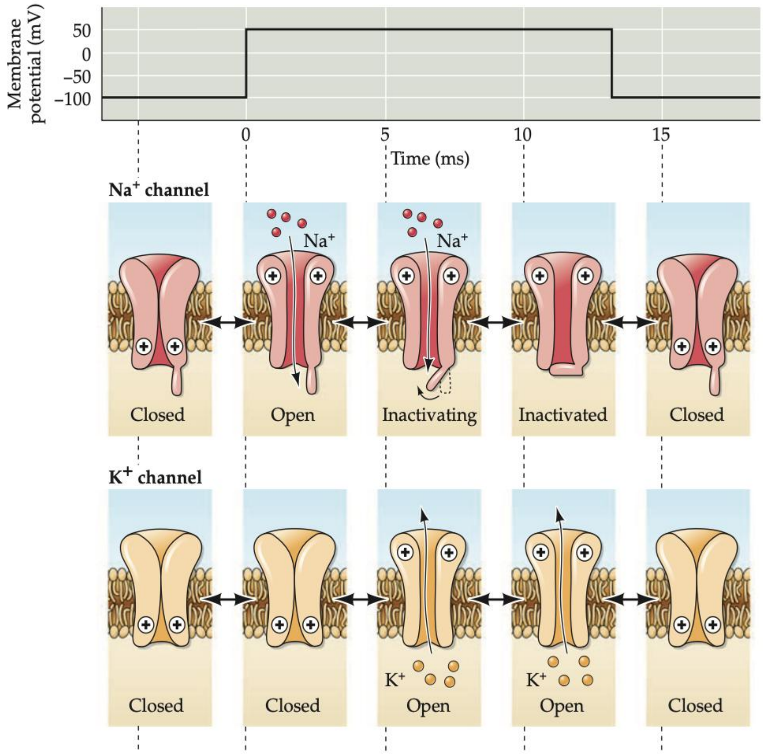
- Early & late currents, reconstruction of the action potential
- Experimental techniques: voltage clamp & current clamp
- The ionic basis: all-or-none voltage-gated Na^+ and K^+ channels
- Passive current and long-distance signal propagation
- Topology of Na^+ and K^+ channels

Unit 2

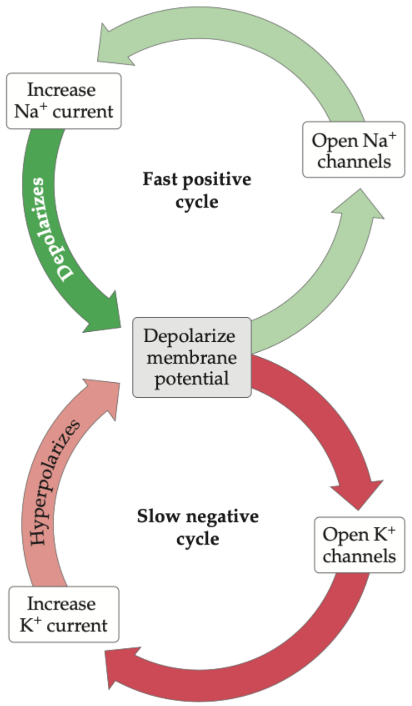
Inward Na+ current
Outward K+ current

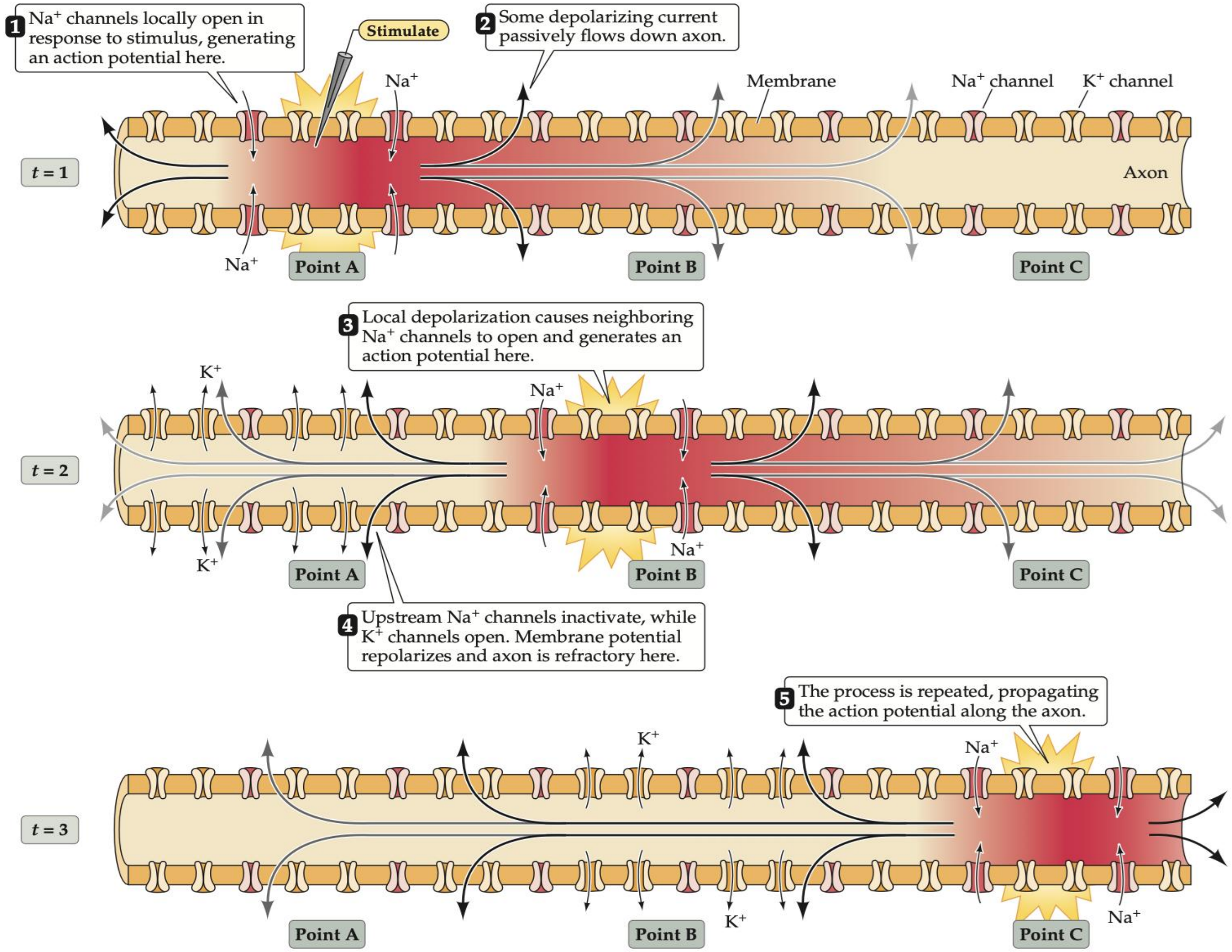


4 ion channel properties



All-or-none nature of AP





Long-distance signalling

- **Myelination**

- **Active current** in and out the cell
- **Passive current** along the axon

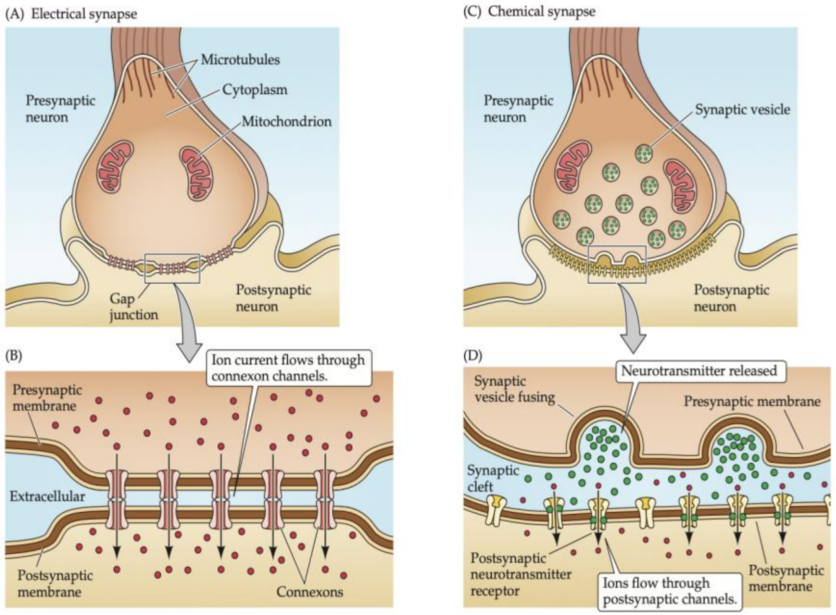
- **Refractory period** due to inactivation of Na+ channels

Unit 3 – Synaptic transmission and neurotransmitters

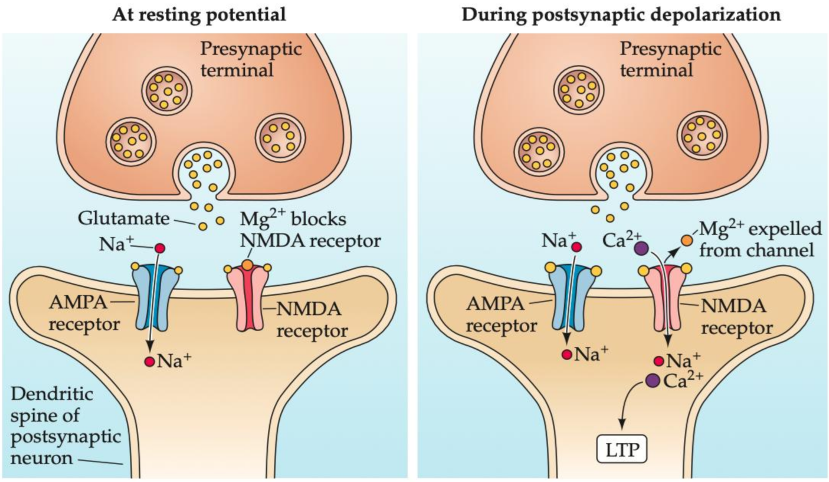
- Nerve terminal
- Quantized presynaptic transmission
- Ca2+ regulation of vesicle fusion; SNARE proteins, Synaptotagmin
- EPSP versus EPSC
- Glutamatergic receptors: roles and mechanisms for AMPA versus NMDA
- GABA as an inhibitory transmitter and IPSP
- Integration of excitatory and inhibitory synaptic inputs in the dendrite of neurons
- Gap junctions
- Neuromodulation

Unit 3

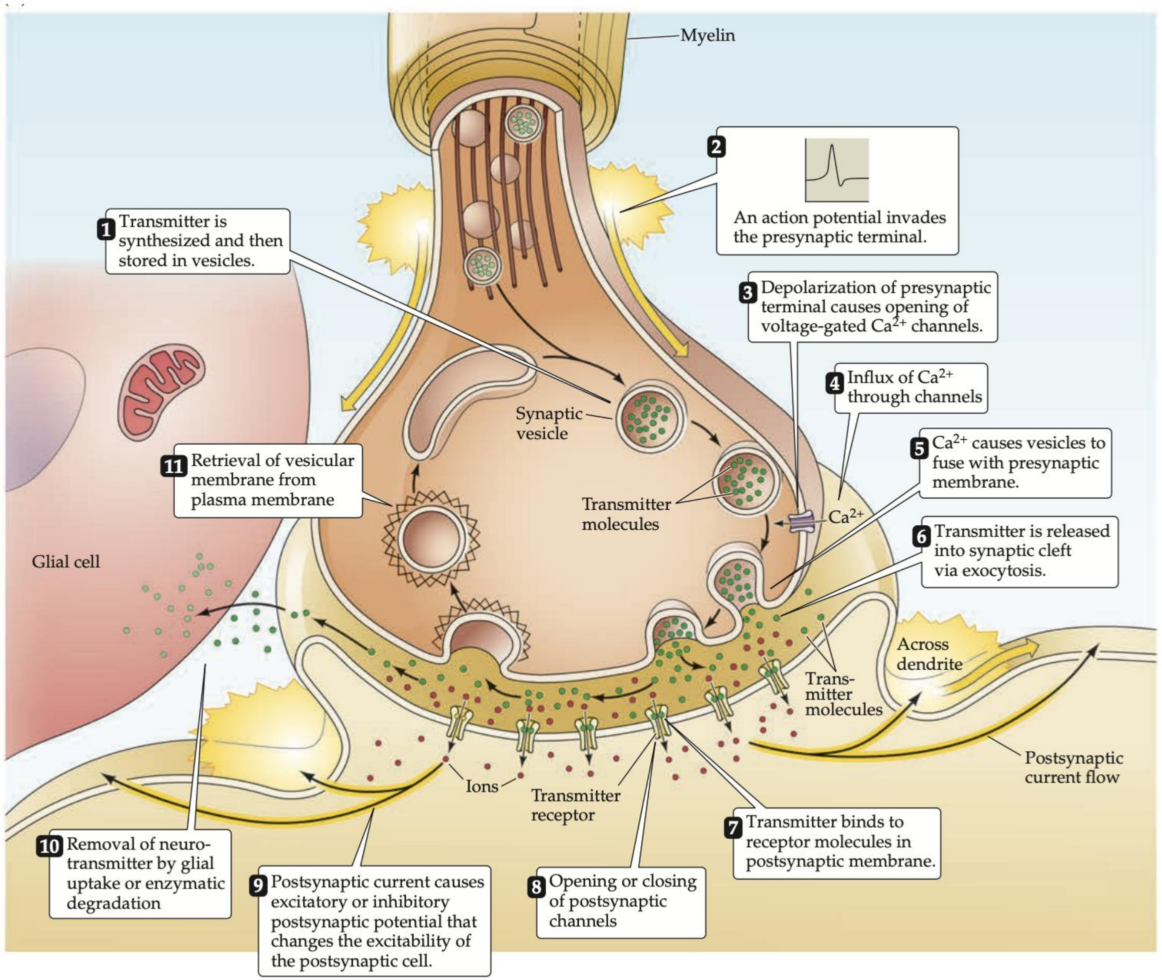
Electrical vs chemical synapses



Post-synaptic receptors and LTP



Synaptic transmission mechanism

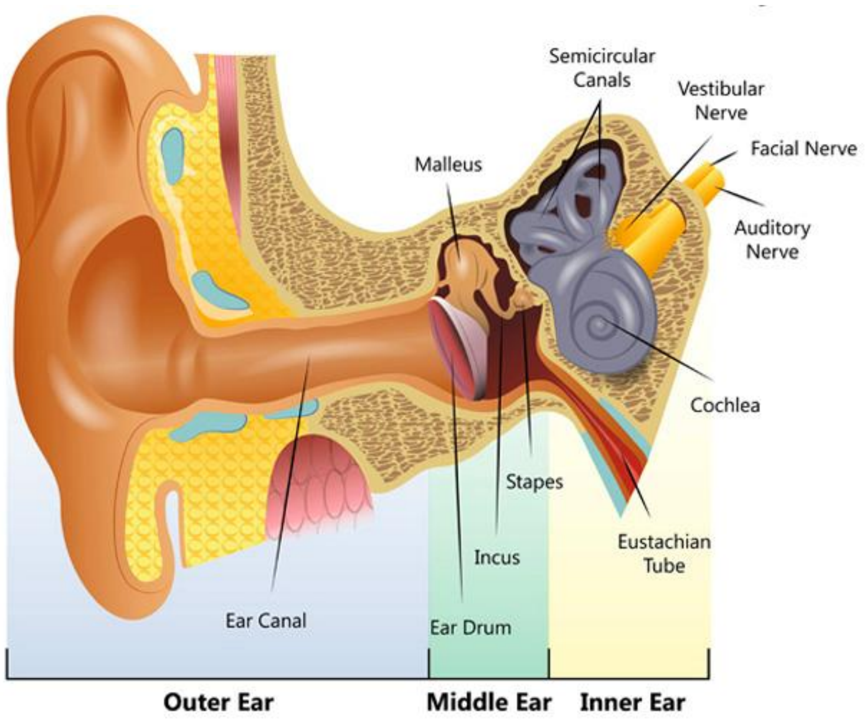


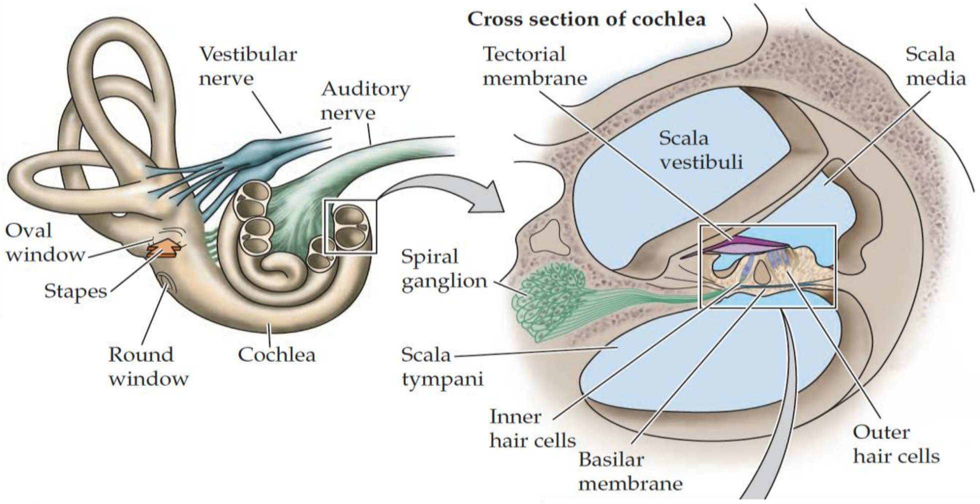
Unit 4 – Audition (hearing)

- What is a complex sound? A superposition of pure tones
- Anatomy of the ear and functional interpretation:
  - Outer, middle, and inner ear
  - Inner ear cochlea: mechanical signal → neural signal
  - Ionic basis of audio sensors (inner hair cells)
  - Outer hair cells: cochlear amplifiers
- The auditory pathway & auditory encoding:
  - Tonotopy preserved from cochlea to primary auditory cortex
  - Bilateral projections & parallel pathways
  - Strategy for localization: ITD & IID

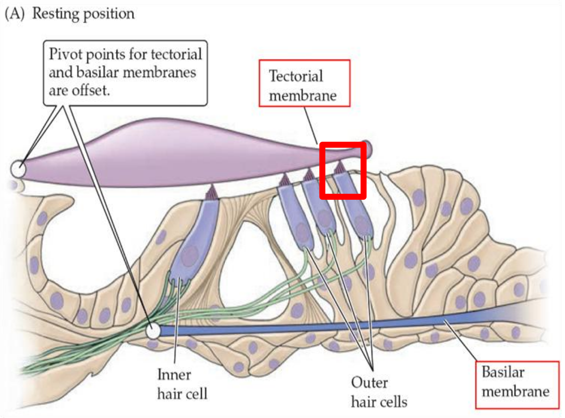
Unit 4

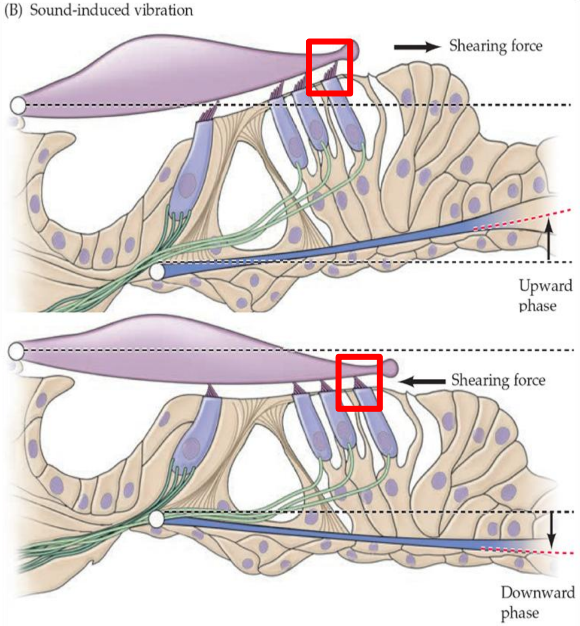
Anatomy of the hear

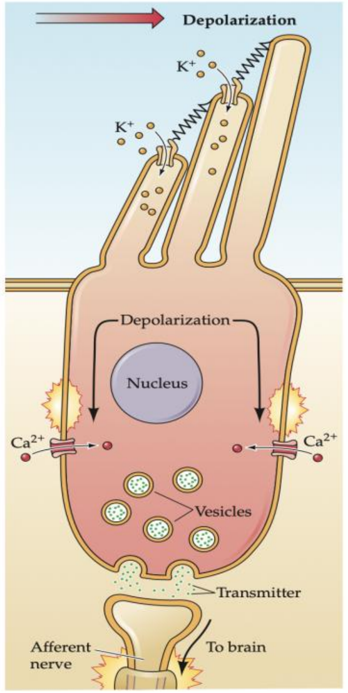




Primary auditory transduction





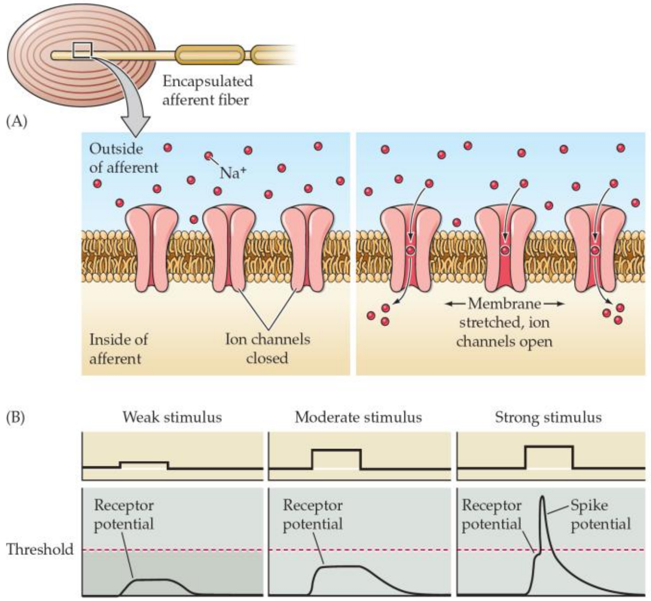


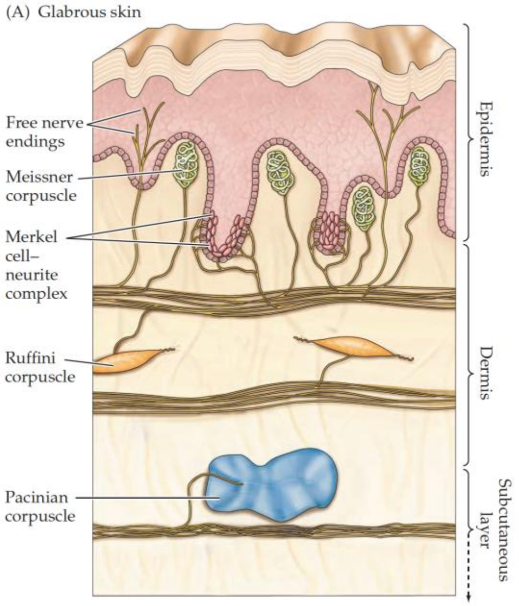
Unit 5 – The somatosensory system

- Touch and proprioception
- Mechanoreceptors
- Touch receptor types
- Somatosensory receptive fields & tactile acuity
- Touch and proprioception neural pathways
- Somatotopy & homunculus
- Plasticity of the somatotopic map in the context of amputation

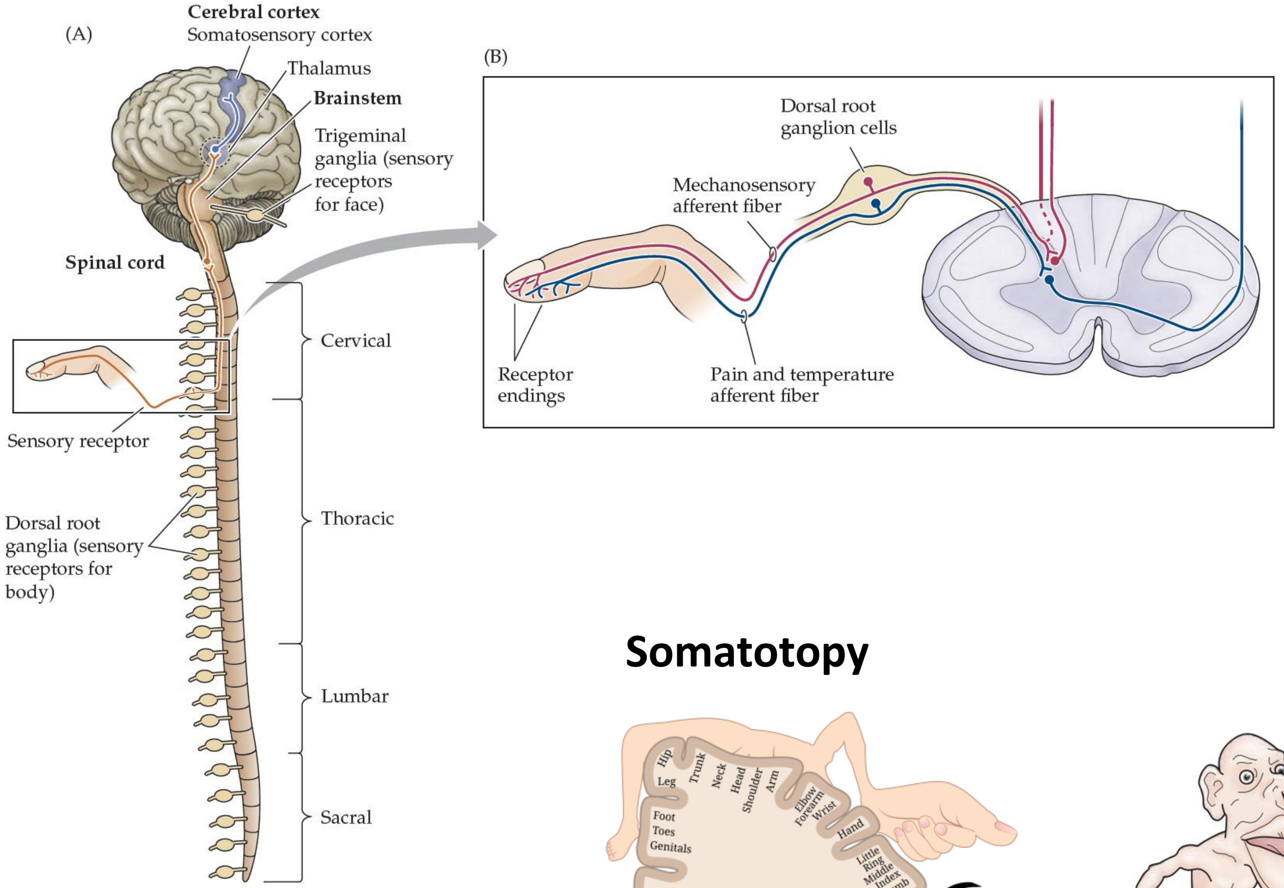
Unit 5

Mechanoreceptors

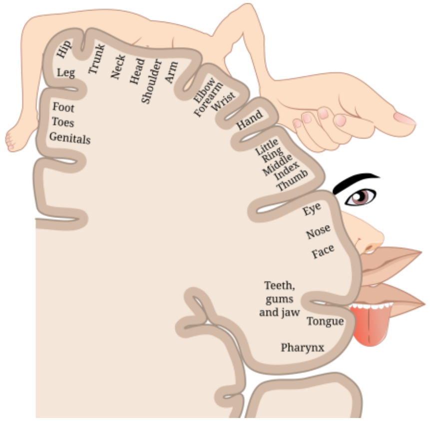


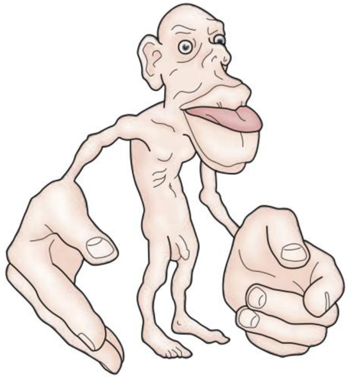


Touch and proprioception neural pathway



Somatotopy



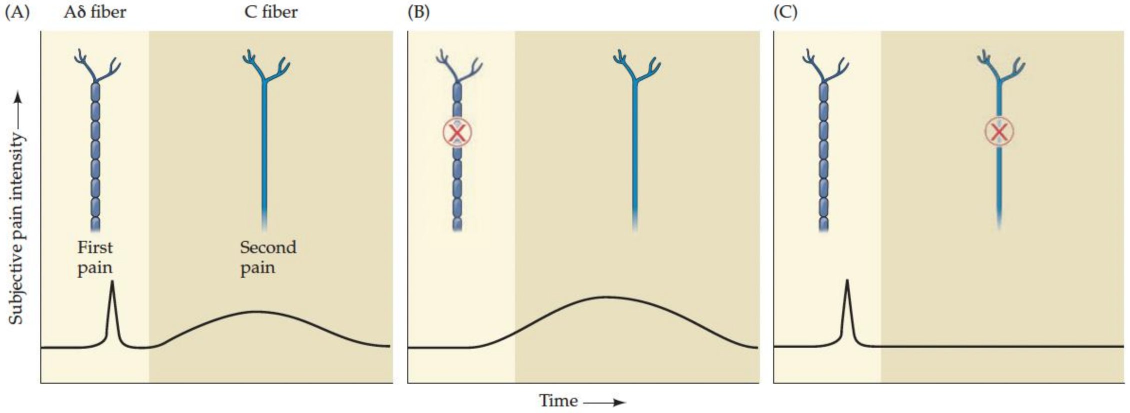


Unit 6 – Pain and the nociceptive system

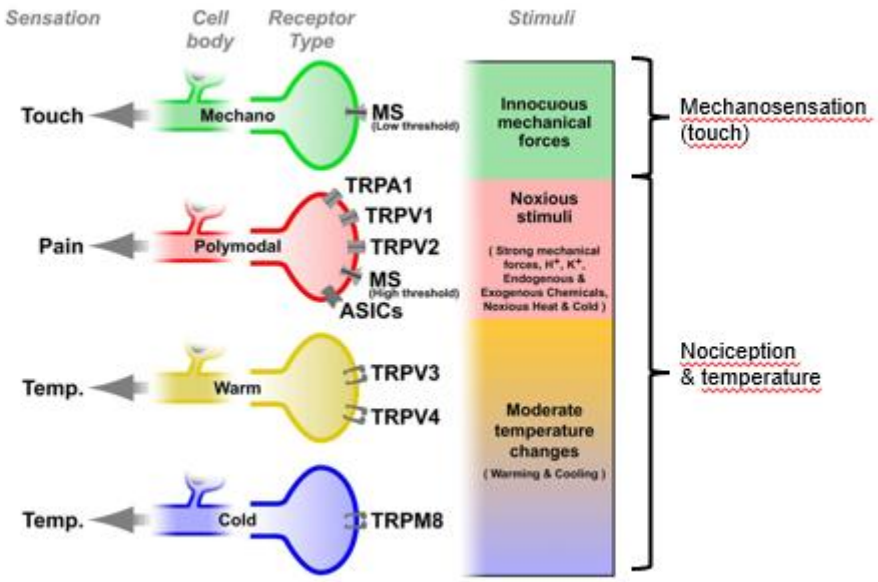
- Early and late pain
- Sensing through TRP ion channels (which stimuli, which ionic permeability)
- Principal anatomical organization (spinothalamic tract).
- Consequences for clinical diagnosis after spinal cord hemisection.
- Ascending pathways giving rise to two different perceptions of pain
- Descending control of pain and endogenous opioids
- Mechanisms behind Referred pain
- The gate theory of pain

Unit 6

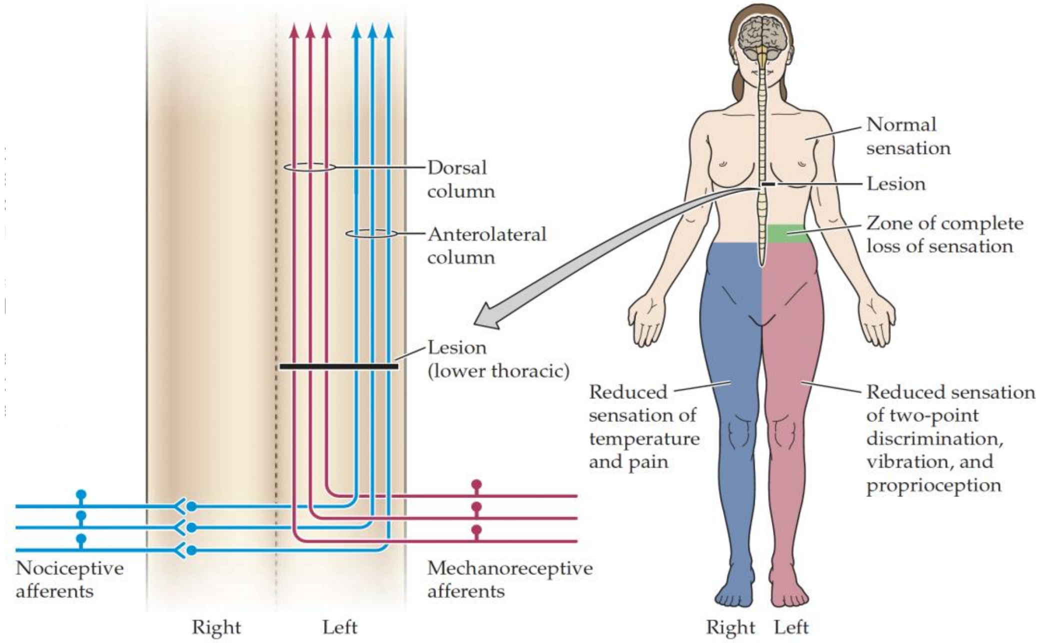
First and second pain



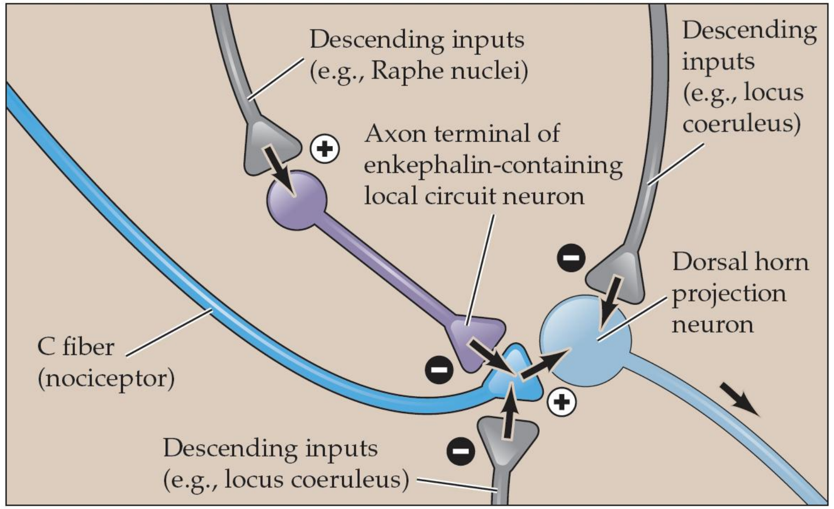
Pain receptors



Consequences of hemisection



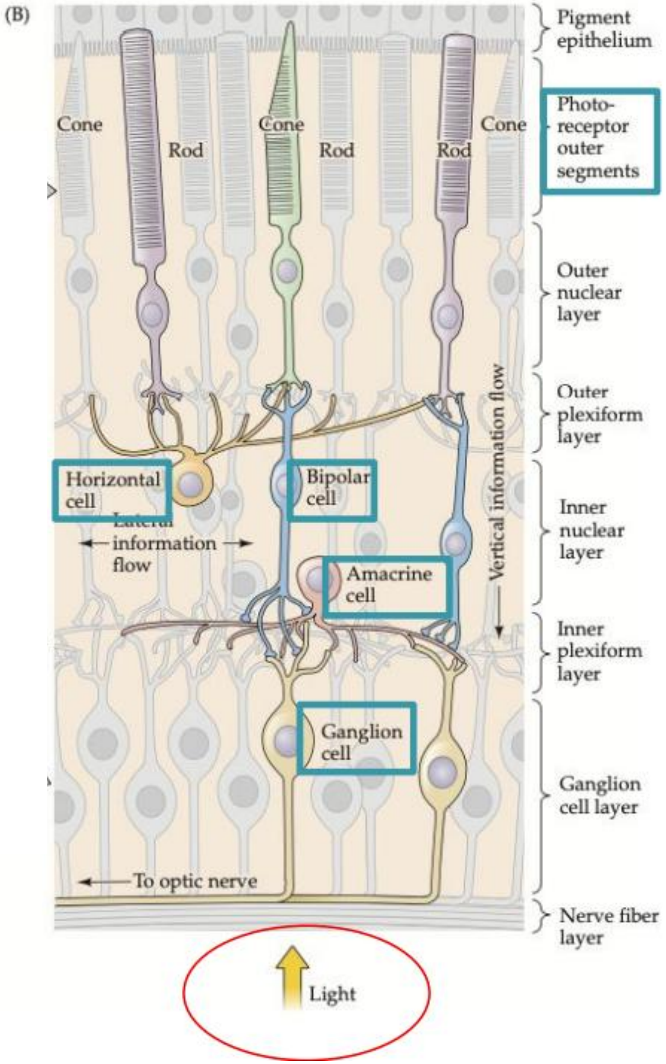
Descending control of pain



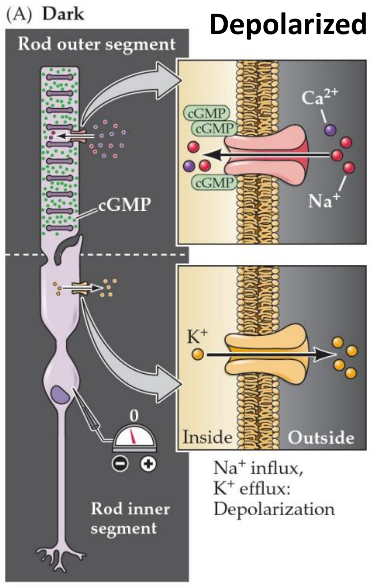
Unit 7 – Vision, the eye and retina

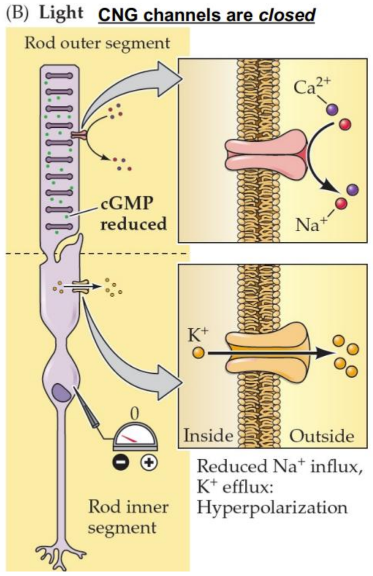
- The eye
- Photoreceptor cells; Primary sensory transduction in vision
- Scotopic (rod-based) and photopic (cone-based) vision; Rod and cones
- Color vision: S-, M- , L- cones; Color blindness
- Structure of the retina; Five major neuron types
- Concept of receptive field (in general) of a sensory neuron
- Blind spot and fovea
- Center-surround receptive field organization of ON-center and of OFF-center RGCs
- ON and OFF bipolar cells and mechanisms
- Light adaptation

Unit 7

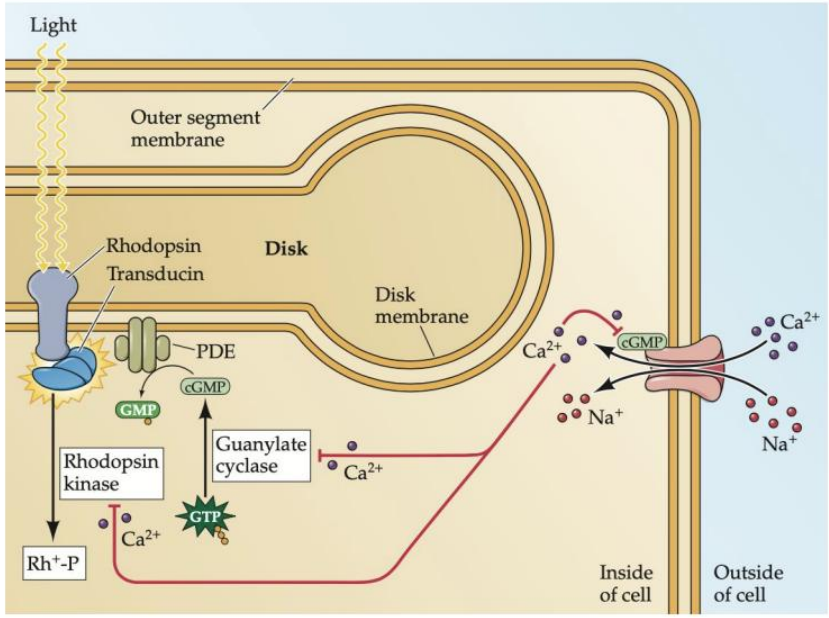


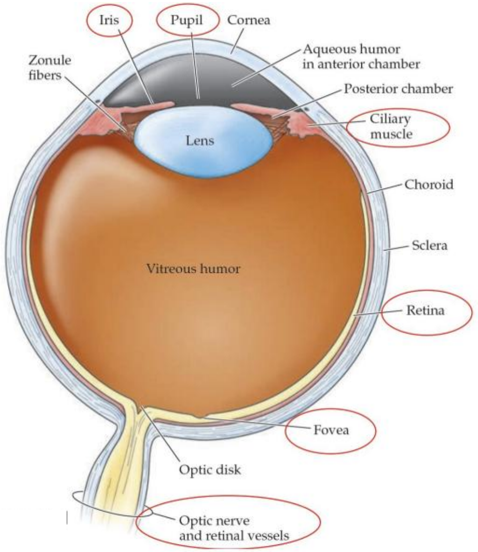
Depolarized





Hyperpolarized

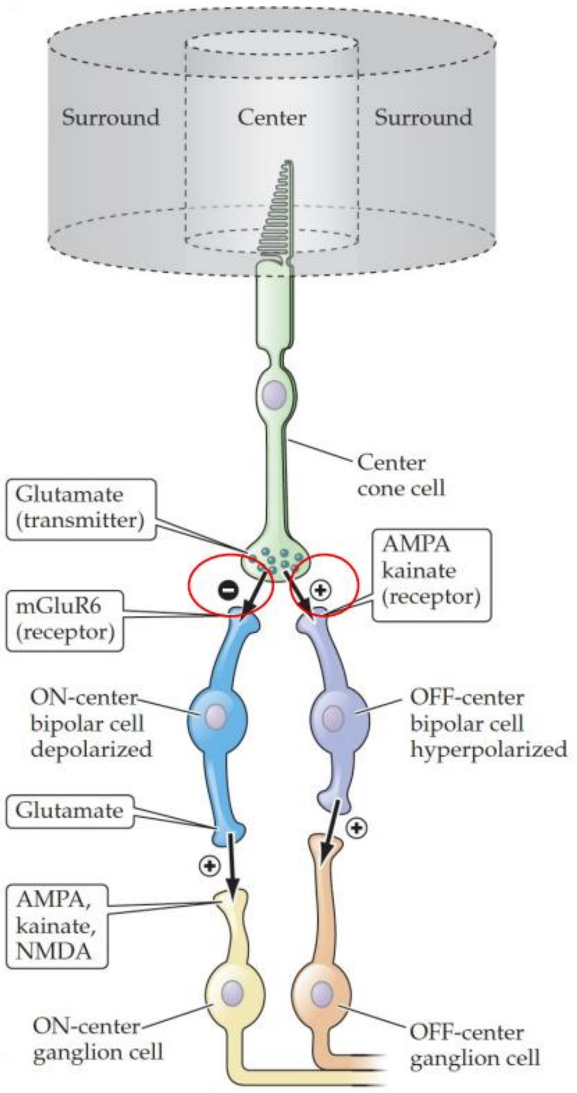


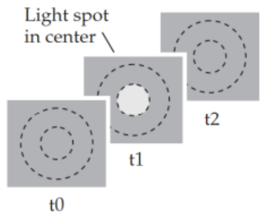


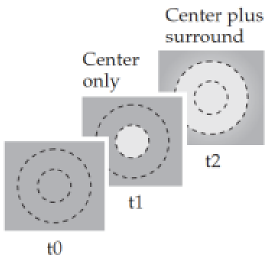
S-cones M-cones L-cones

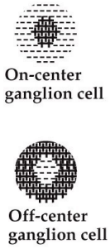
Primates including humans: Trichromatic color vision

Unit 7



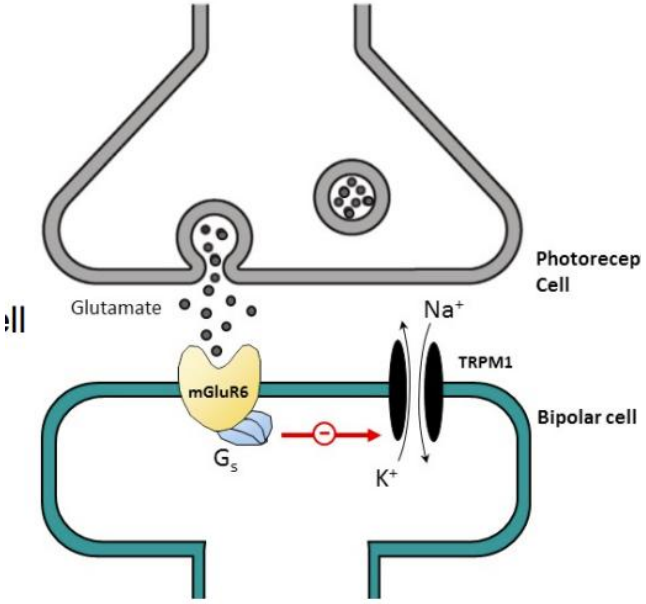




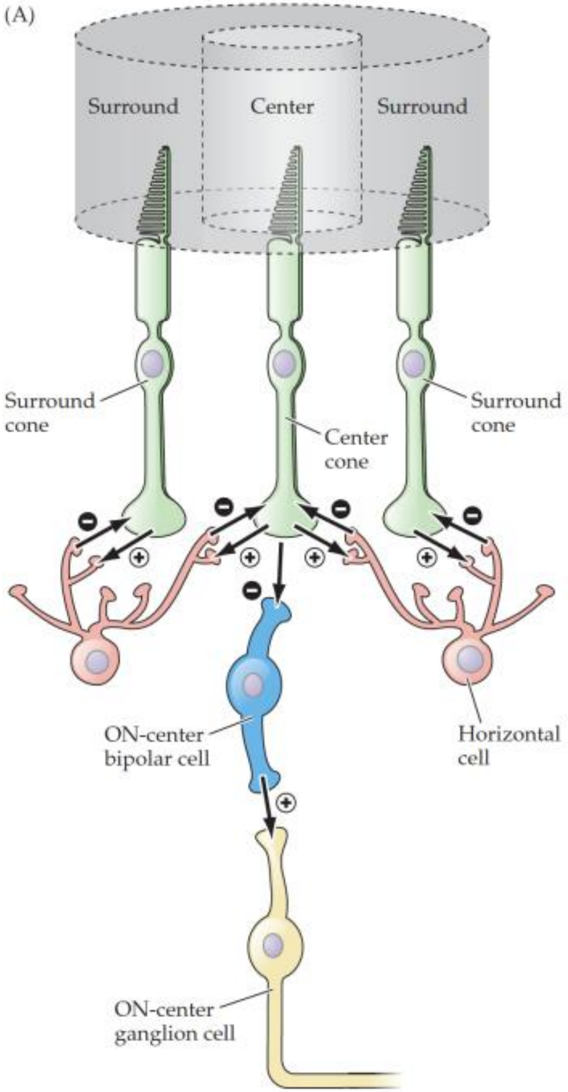


"ON-center":
↑ AP- frequency
in the center of the receptive field (RF)

"OFF center"
↓ AP-frequency
in the center of the RF



ON bipolar cell

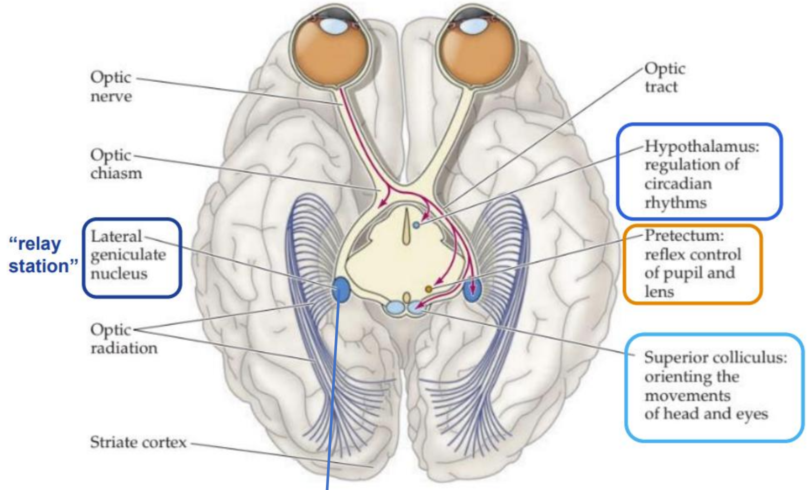


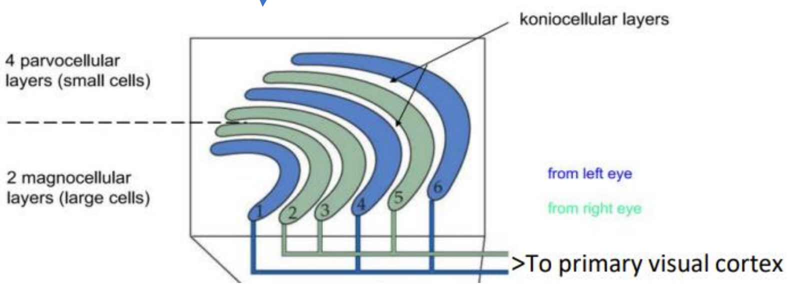
Unit 8 – Vision – Systems & Circuits

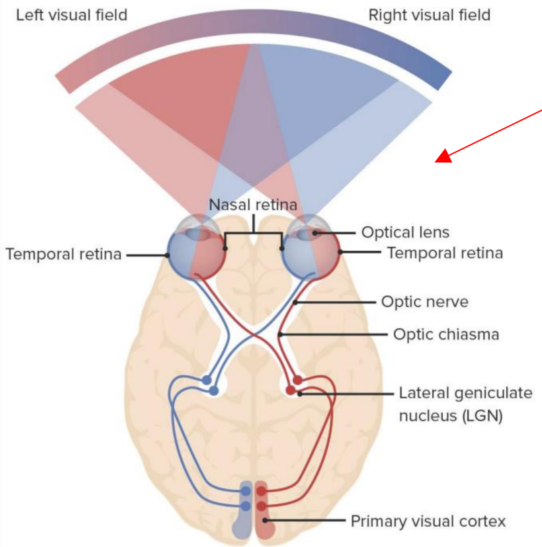
- Binocular vision
- The different targets of the retinal ganglion cells and their functions
- The retinogeniculostriate pathway (from the retina to V1)
- Lateral geniculate nucleus (LGN) organization
- Retinotopic map
- General layer organization of the primary visual cortex
- Columnar organization of V1 (orientation, ocular dominance)
- Receptive fields in the visual system

Unit 8

Primary visual cortex
=
Striate cortex
=
V1
=
Brodmann area 17

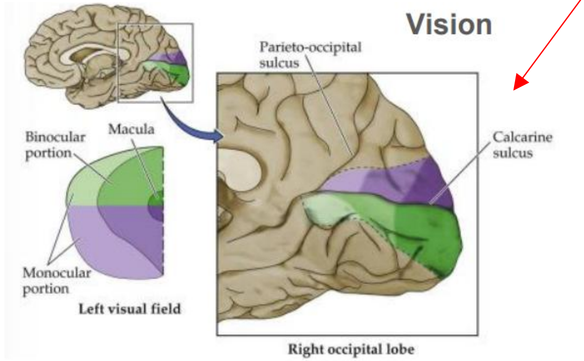




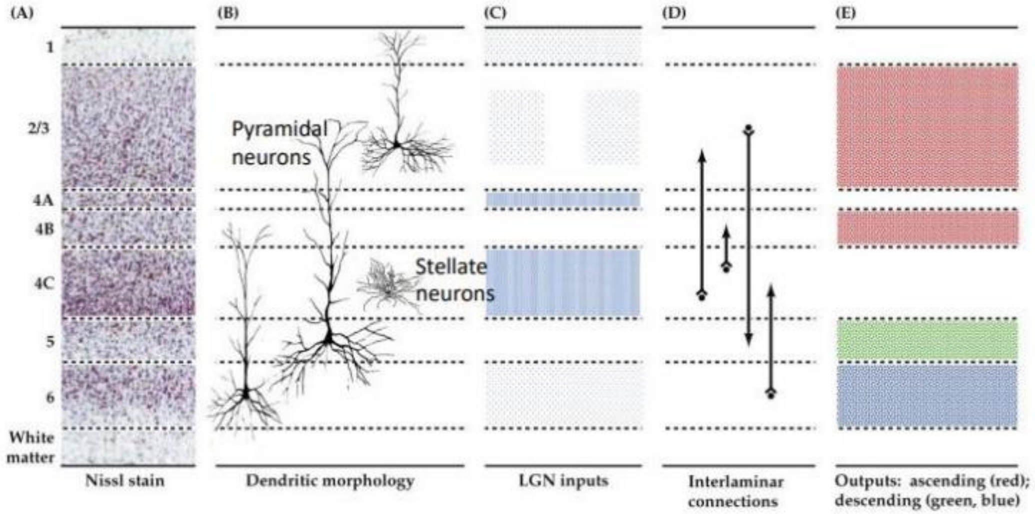


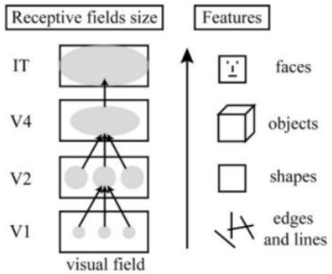
Side-Switching! Information from the left half of the visual world, whether it originates from the left or right eye, is represented in the right half of the brain, and vice versa.

Cortical magnification: the dedicated brain surface area is proportional to the density of receptors



Organization of the visual cortex



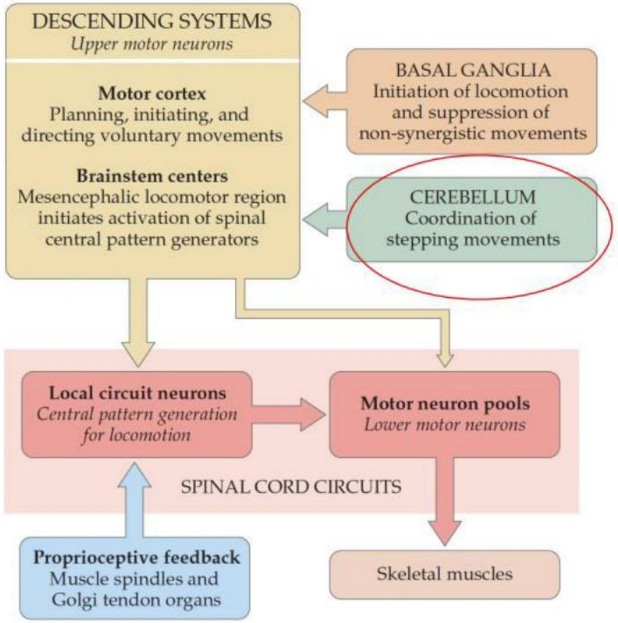


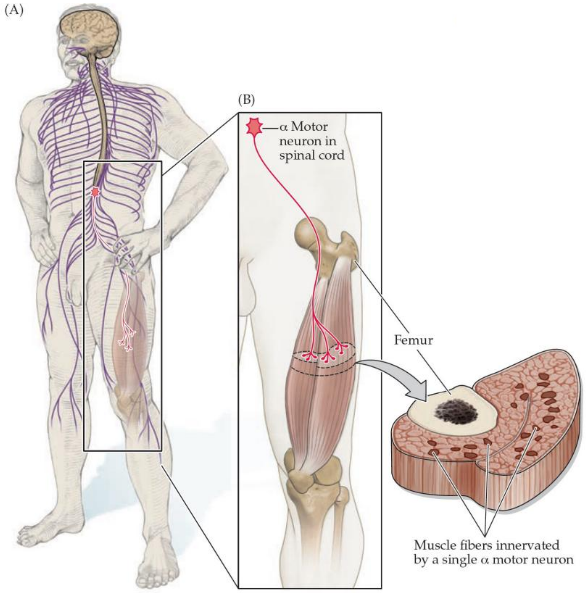
Receptive field of neurons in V1

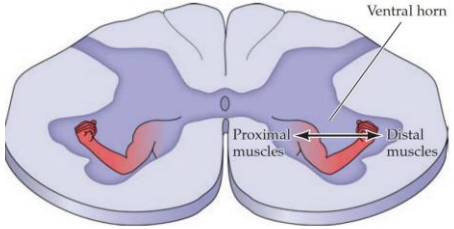
Unit 9 – Movement system: Spinal cord & Cerebellum

- Four main motor pathways: Upper motor neurons (*cortex/brainstem*); Basal Ganglia, Cerebellum, Spinal Cord
- Spinal cord - somatotopic organization (*mediolateral and rostrocaudal*)
- Henneman’s size principle
- Stretch reflex circuit function including roles of Group 1a sensory & alpha motor neurons
- Golgi tendon organ function including roles of Group 1b sensory, inhibitory, & motor neurons
- Flexion-crossed extension reflex and relevant components
- Rhythmic movements and how they arise from «central pattern generator» circuit
- Role and organization of cerebellum (input and output regions).
- Organization of the cerebellar circuit: granule cells, Purkinje cells, parallel fibers
- How cerebellar circuit computes and corrects motor errors (*examples in saccades and VOR*)

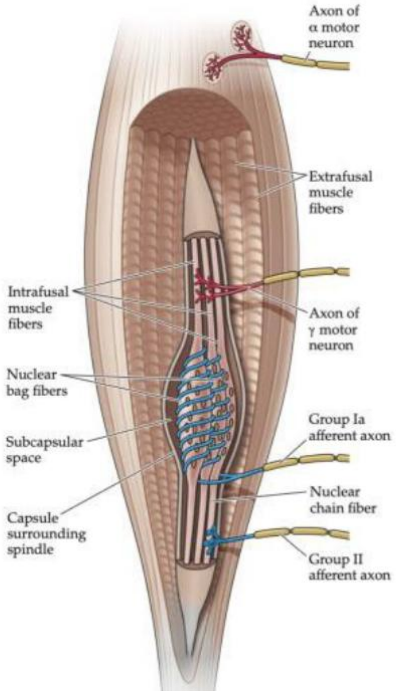
Unit 9



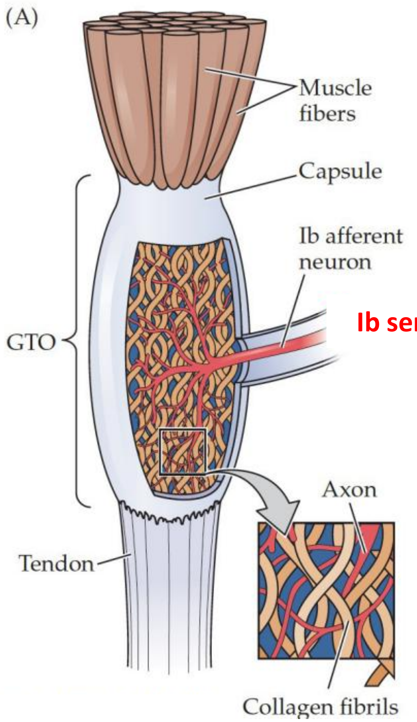




Muscle spindle

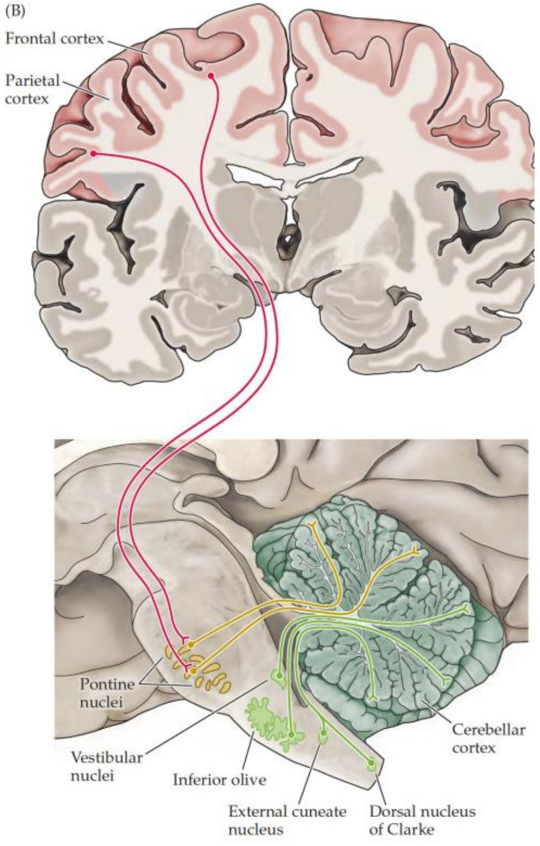


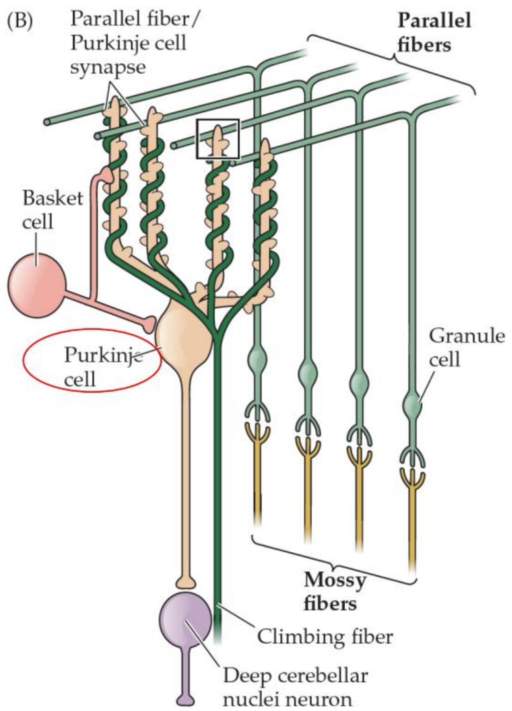
Golgi tendon organ (GTO)

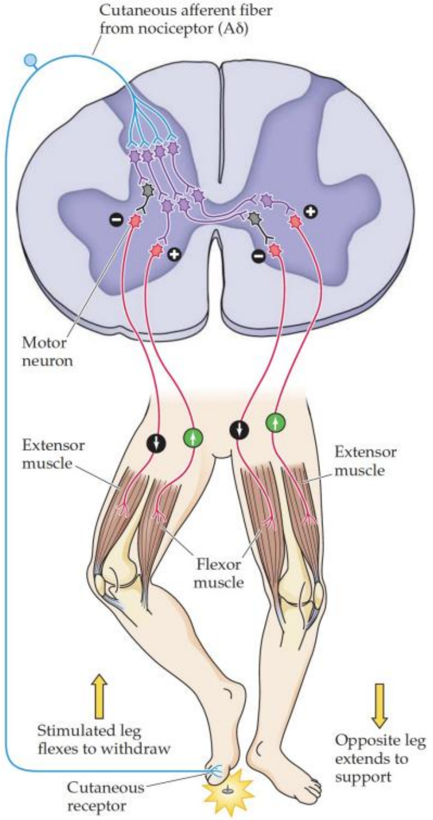


Ib sensor in GTO

Unit 9



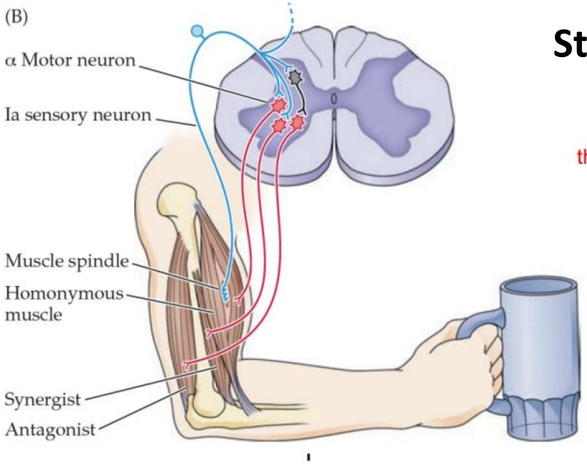




- A tack stimulates right foot
- Right foot is retracted (flexion)
- Left foot is extended (extension)

Note the role of **inhibition** here!

Flexion-crossed extension reflex



Stretch reflex

Negative feedback loop involving the **intrafusal muscle** and **Ia sensors (spindle receptor)**

Unit 10 – Movement control: M1 & Basal Ganglia

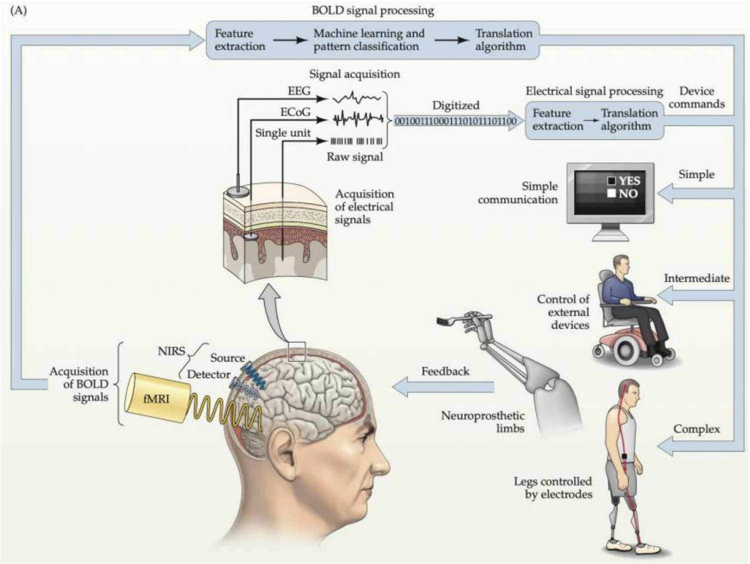
Motor cortex

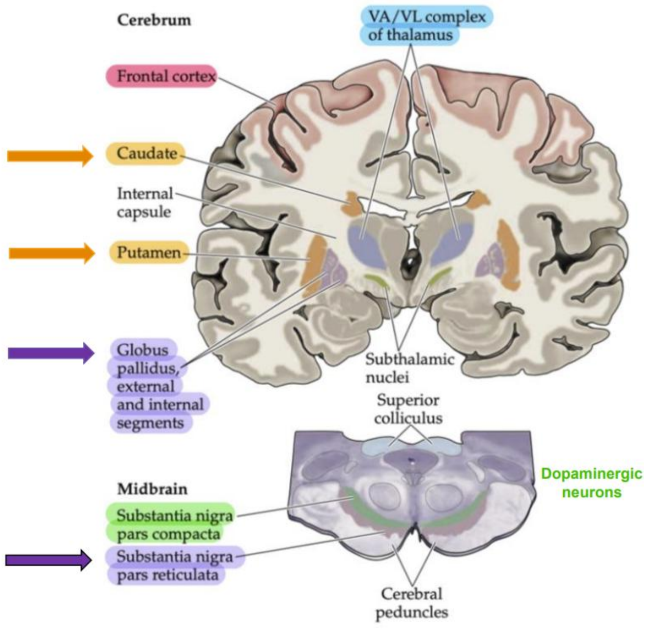
- Primary motor cortex (M1), output layer (L5), lateral corticospinal tract
- « Coding » of movement primitives in M1
- Principles and applications of a Brain-Machine Interface

Basal ganglia

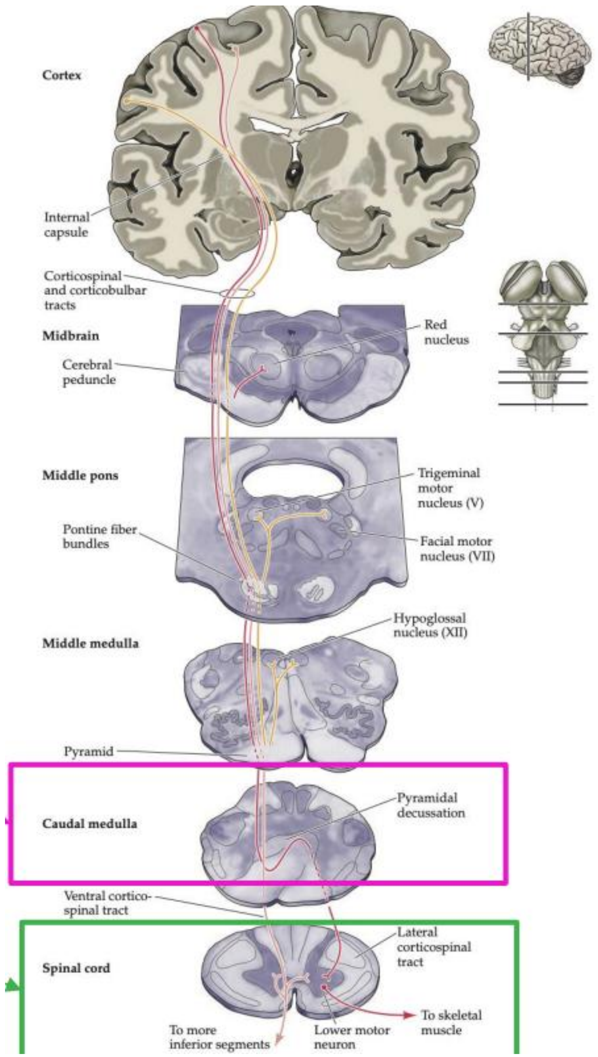
- Principal nuclei and their connectivity
- Medium spiny neurons (MSNs) in the striatum
- Direct and indirect pathways: modulation and role in action selection and movement
- Clinical cases of Parkinson’s and Hungtington’s disease

Unit 10



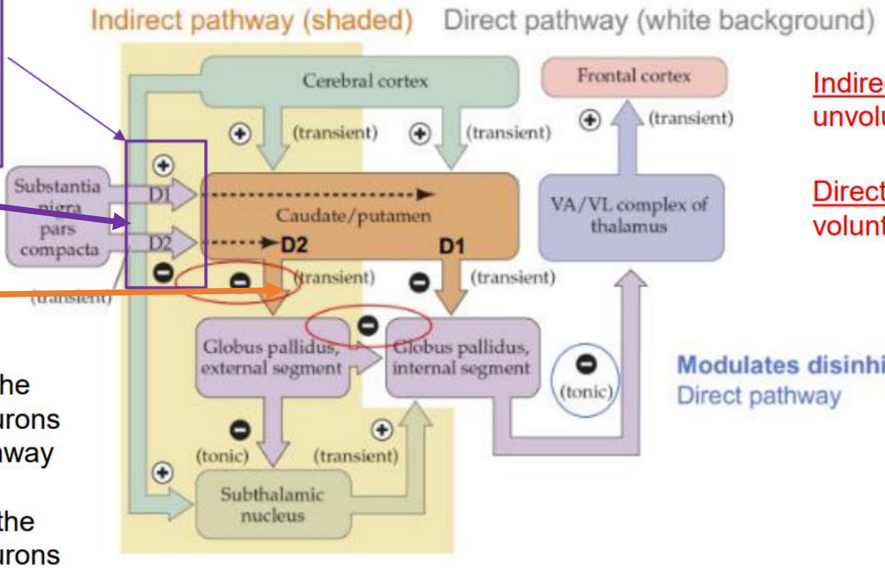


Neurons in the BG are **inhibitory** (*GABAergic*)



Degenerated in Parkinson's disease
→ hypokinetics

⊕ **Dopamine on D1 receptor**
⊖ **Dopamine on D2 receptor**



Degenerated in Huntington's disease
→ hyperkinetics

D1 increases the excitability of neurons in the direct pathway

D2 decreases the excitability of neurons in the indirect pathway

Indirect pathway: inhibits unvoluntary movements

Direct pathway: activates voluntary movements

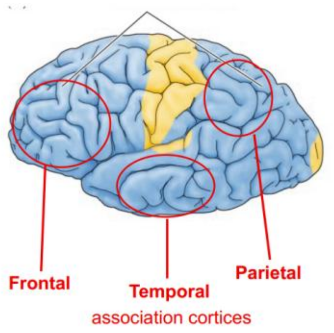
Modulates disinhibition of the Direct pathway

⊕ **Glutamate**
⊖ **GABA**

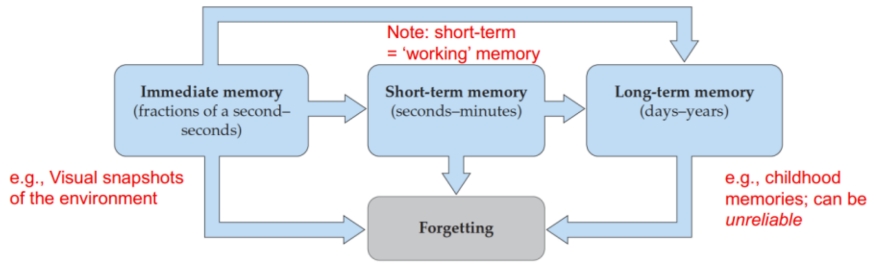
Unit 11 – Learning and memory

- Association cortices
- Memory: definitions in terms of time-scale and kinds (implicit, explicit, procedural, declarative)
- Role in and relationship between Prefrontal Cortex and short-term memory
- Explicit, episodic memories: role of hippocampus and temporal lobe
- What patient H.M. tells us about the locus and kinds of memory
- ‘Concept cells’ in temporal lobe and hippocampus in humans
- Long-term plasticity at excitatory synapses studied in hippocampus (which synapse; which fundamental mechanism)
- Role of the hippocampus for spatial navigation & spatial memory as studied in rodents
- Classical conditioning as a form of ‘implicit’ long-term memory; fear learning
- Alzheimer’s Disease and its putative underlying mechanisms

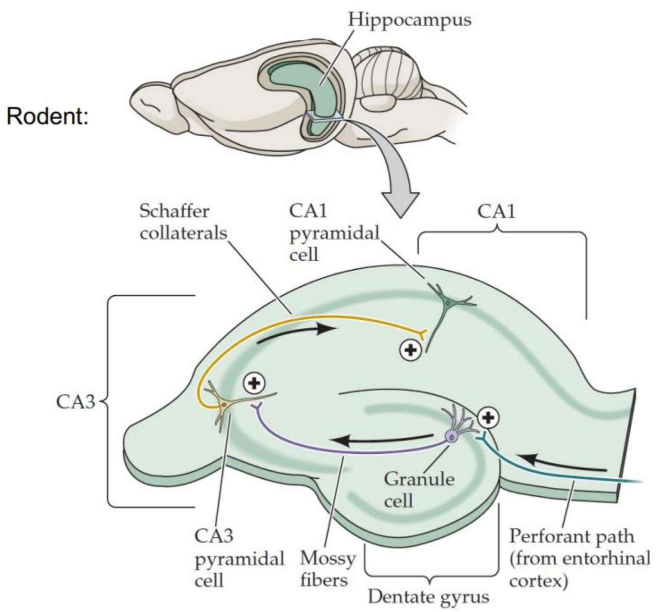
Unit 11



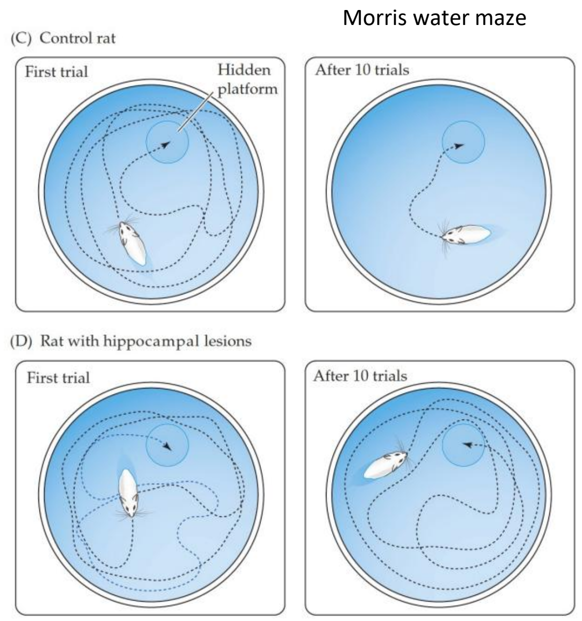
Frontal
Temporal
Parietal
association cortices



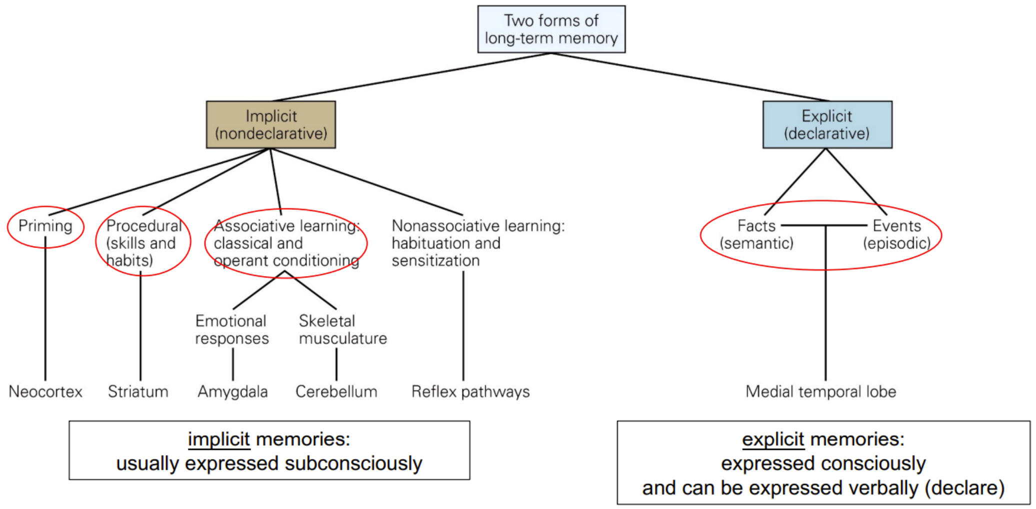
Note: short-term
= 'working' memory
Immediate memory
(fractions of a second–seconds)
Short-term memory
(seconds–minutes)
Long-term memory
(days–years)
Forgetting
e.g., Visual snapshots
of the environment
e.g., childhood
memories; can be
unreliable



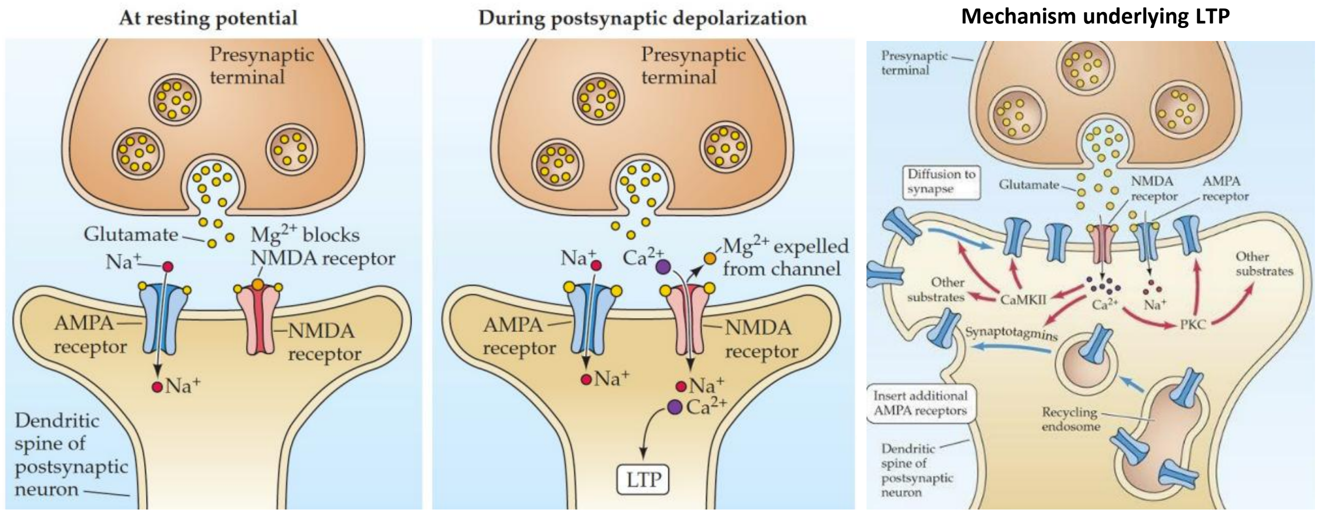
Rodent:
Hippocampus
Schaffer
collaterals
CA1
pyramidal
cell
CA1
CA3
Granule
cell
CA3
pyramidal
cell
Mossy
fibers
Dentate gyrus
Perforant path
(from entorhinal
cortex)



Morris water maze
(C) Control rat
First trial
Hidden
platform
After 10 trials
(D) Rat with hippocampal lesions
First trial
After 10 trials



Two forms of
long-term memory
Implicit
(nondeclarative)
Explicit
(declarative)
Priming
Procedural
(skills and
habits)
Associative learning:
classical and
operant conditioning
Nonassociative learning:
habituation and
sensitization
Emotional
responses
Skeletal
musculature
Facts
(semantic)
Events
(episodic)
Neocortex
Striatum
Amygdala
Cerebellum
Reflex pathways
Medial temporal lobe
implicit memories:
usually expressed subconsciously
explicit memories:
expressed consciously
and can be expressed verbally (declare)



At resting potential
Presynaptic
terminal
Glutamate
Na^+
Mg^{2+} blocks
NMDA receptor
AMPA
receptor
NMDA
receptor
Na^+
Dendritic
spine of
postsynaptic
neuron
During postsynaptic depolarization
Presynaptic
terminal
Na^+
Ca^{2+}
Mg^{2+} expelled
from channel
AMPA
receptor
NMDA
receptor
Na^+
Na^+
Ca^{2+}
LTP
Mechanism underlying LTP
Presynaptic
terminal
Diffusion to
synapse
Glutamate
NMDA
receptor
AMPA
receptor
Other
substrates
CaMKII
Ca^{2+}
Na^+
Other
substrates
PKC
Synaptotagmins
Insert additional
AMPA receptors
Recycling
endosome
Dendritic
spine of
postsynaptic
neuron

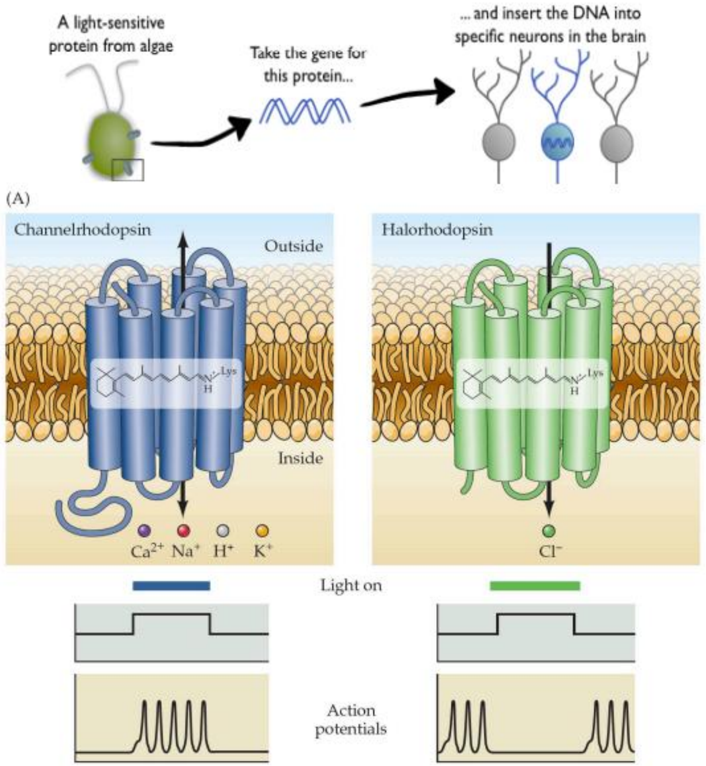
Unit 12 – Techniques in neuroscience

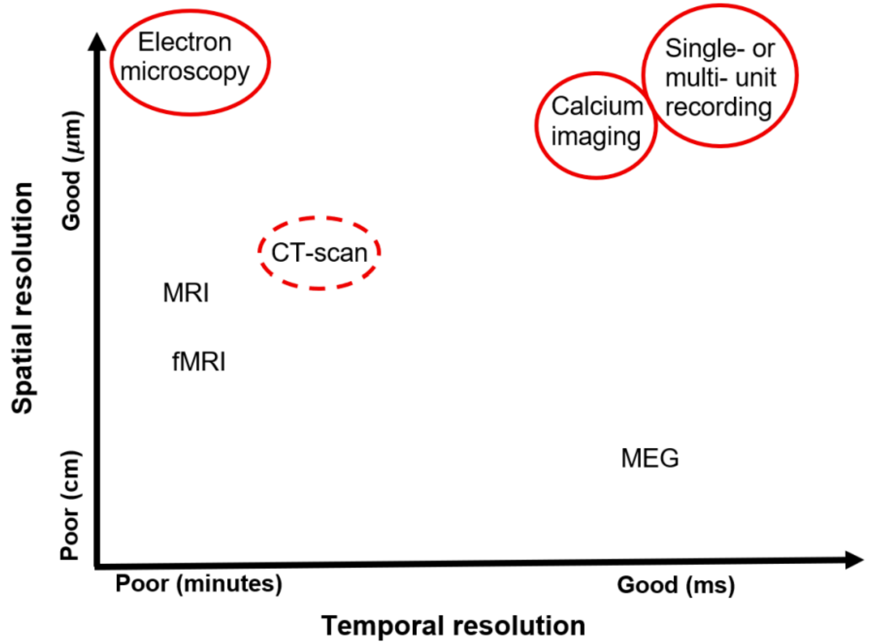
- CT and MRI scans permit coarse human brain mapping
- GFP enables measurements of neuron structure in living tissue
- Connectomics: how to obtain a synapse-resolution brain map in the fly
- Why to use optical rather than electrophysiological methods to record neurons. The mechanism by which the genetically encoded calcium indicator (GECI), “GCaMP” works
- Why to record neural activity in behaving animals. Why tethering is necessary sometimes
- fMRI and MEG are ways to record human brain activity non-invasively
- Behavior can be measured using markerless 3D and 2D pose estimation tools that leverage convolutional deep neural networks
- Neurons can be activated using optogenetics. For example, ChR2 is a nonspecific cation channel activated by blue light.
- How TMS works to activate human brain regions

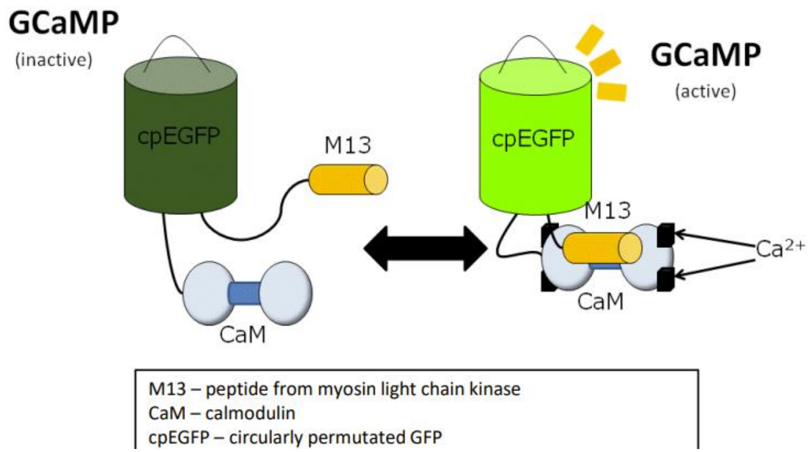
Unit 12

There are different things that we want to do in neurosciences:

- ✓ See brain structure and connectivity → e.g. microscopy
- ✓ Measure neural activity → e.g. electrophysiology, optical recordings
- ✓ Measure neural activity during behavior → e.g. fMRI
- ✓ Quantify behavior → e.g. pose estimation
- ✓ Perturbate neural activity → e.g. ChR2, TMS







Unit 13 – Neuroscience approaches, ethics, and sustainability

- What are the four most prominent goals of neuroscience?
- What is a model organism and what are examples of model organisms?
- Name the 6 model organisms (humans excluded) that are most commonly used in neuroscience
- How do these 6 model organisms compare with one another in terms of (i) ’modeling’ human brains, (ii) generating interesting, complex behaviors, (iii) being easy to study?
- What are some ethical concerns in neuroscience and why do we still perform these experiments anyway?

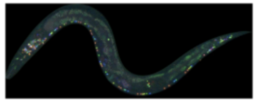
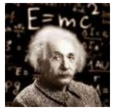
Unit 13

Fundamental understanding
(of the human or animal brain)

Medicine
(healing or prevention for healthy *human* brains)

"NeuroAI"
(building biologically-inspired artificial/robotic systems)

Bioengineering
(improving human capabilities)

		Similarity to humans (vertebrates/mammals)	Behavior complexity ('expressivity')	Tractability (ease of understanding)
	Worms (*C. elegans*)	Some genes/cells	Simple - crawling	Very high: transgenics, connectome
	Fly larvae (*D. melanogaster*)	More genes/cell types	Simple - crawling	Very high: transgenics, connectome
	Zebrafish larvae (*D. rerio*)	Vertebrates	Simple - swimming	High: transgenics, soon connectome
	Fly adults (*D. melanogaster*)	More genes/cell types some behaviors	Complex: walk, fly, fight, mate	High: transgenics, connectome
	Mice (*M. musculus*)	Many genes/cell types many behaviors	Complex: walk, fight, mate, care for young	Medium: transgenics, cells not ID across animals
	Macaque monkey	Most genes/cell types most behaviors	Very complex: Include language	Low
	Humans	Same	Very complex: include planning	Lowest

Best of luck for the exam,
you got this! 🎉