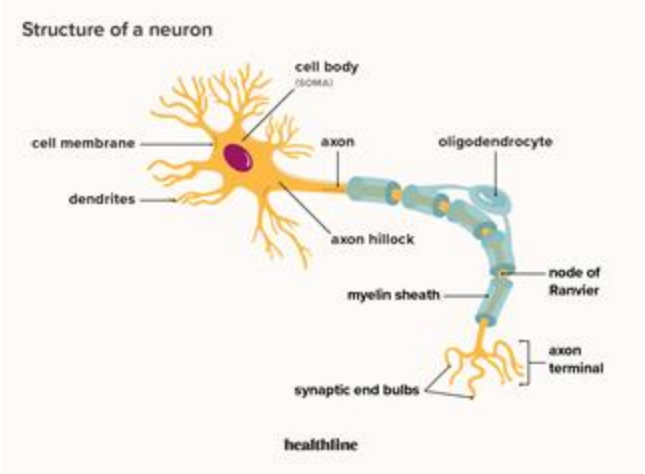
Final Overview Unit 1-11
BIO-311 Neuroscience

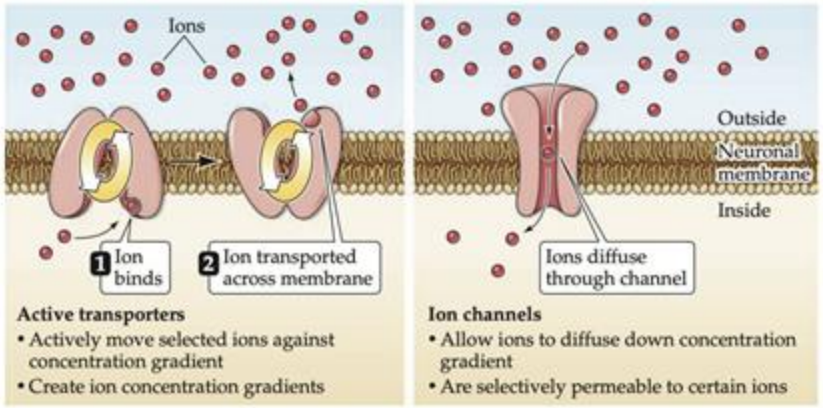
Unit 1 - Introduction to neuroscience and neuron basics

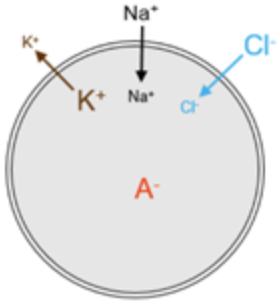
- Phospholipid bilayer permeability
- Ion concentrations — K^+ , Na^+ , Cl^- ATPase
- Equilibrium potential — Nernst Equation
- Resting membrane potential
- Passive membrane properties — RC circuit analogy

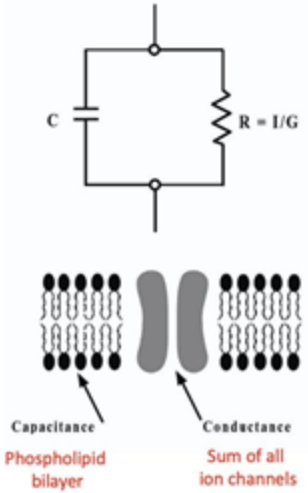
Unit 1

- Neurons
  - Axons and dendrites
  - Chemical and electrical synapses
- Glial Cells
  - Support and protect neurons
  - Astrocyte, Oligodendrocyte, Microglial cell





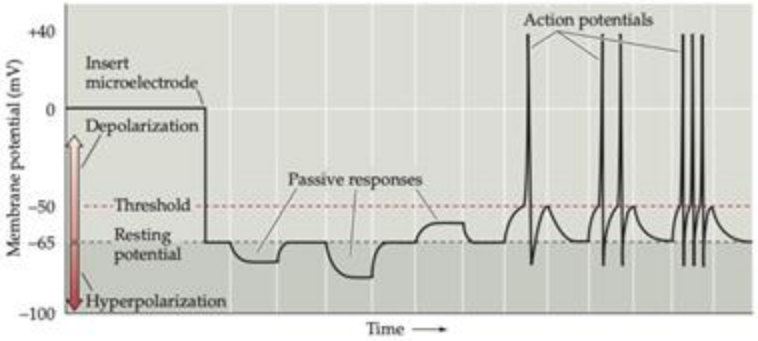


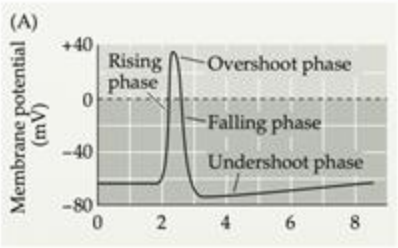


Unit 2 - Brain Anatomy & Action Potential

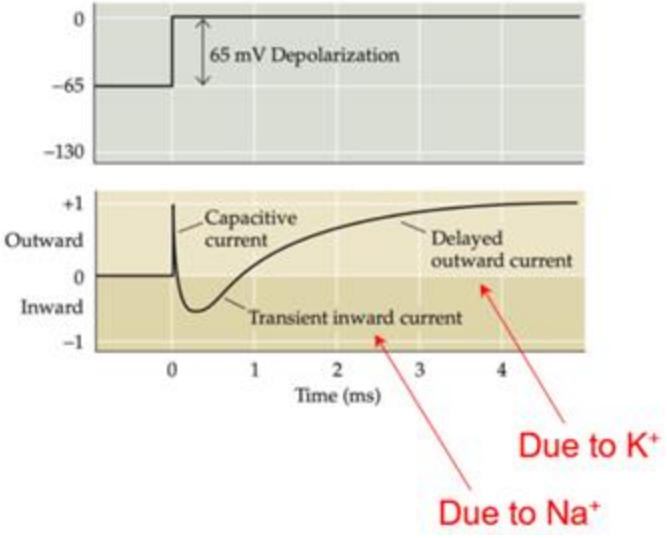
- Early & late currents, reconstruction of the action potential
- Experimental techniques: voltage clamp & current clamp
- The ionic basis: all-or-none voltage-gated Na^+ and K^+ channels
- Passive current and long-distance signal propagation
- Topology of Na^+ and K^+ channels

Unit 2

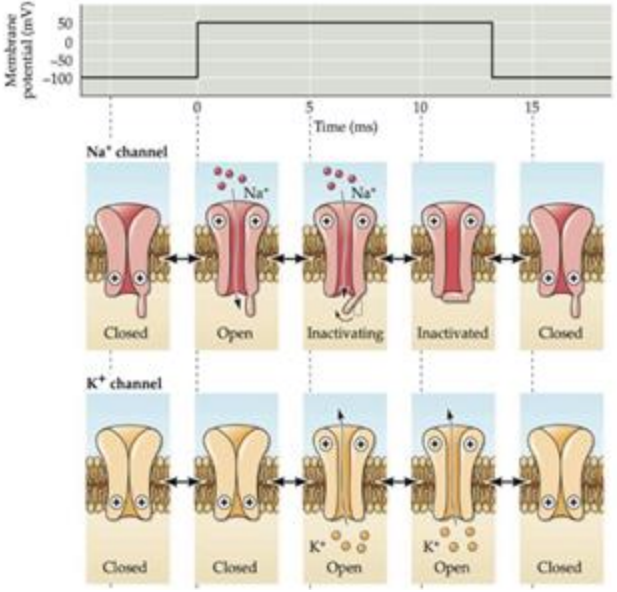




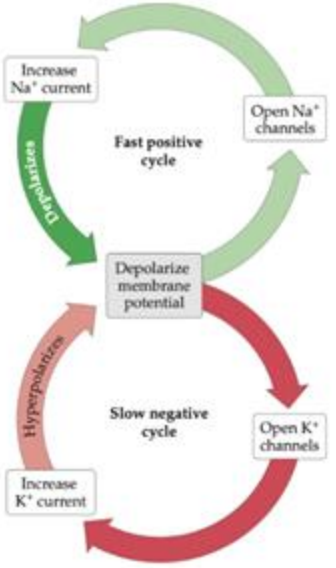
Inward Na+ current
Outward K+ current



4 ion channel properties



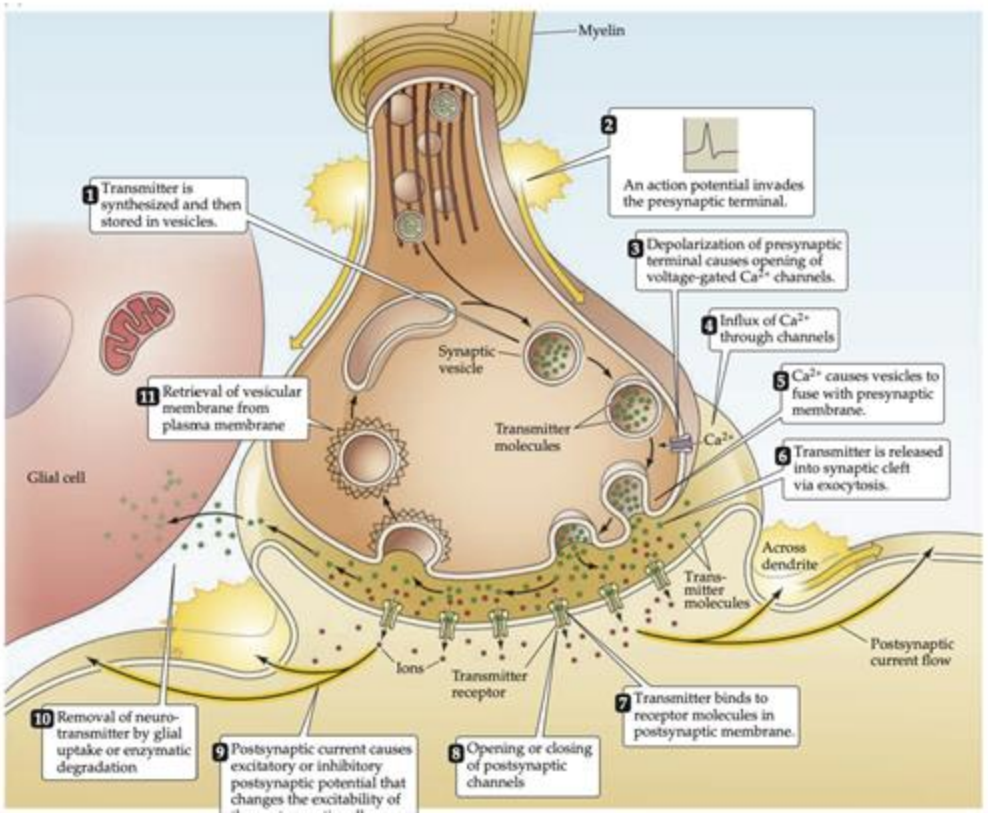
All-or-none nature of AP



Unit 3 - Synaptic Transmission & Neurotransmitters

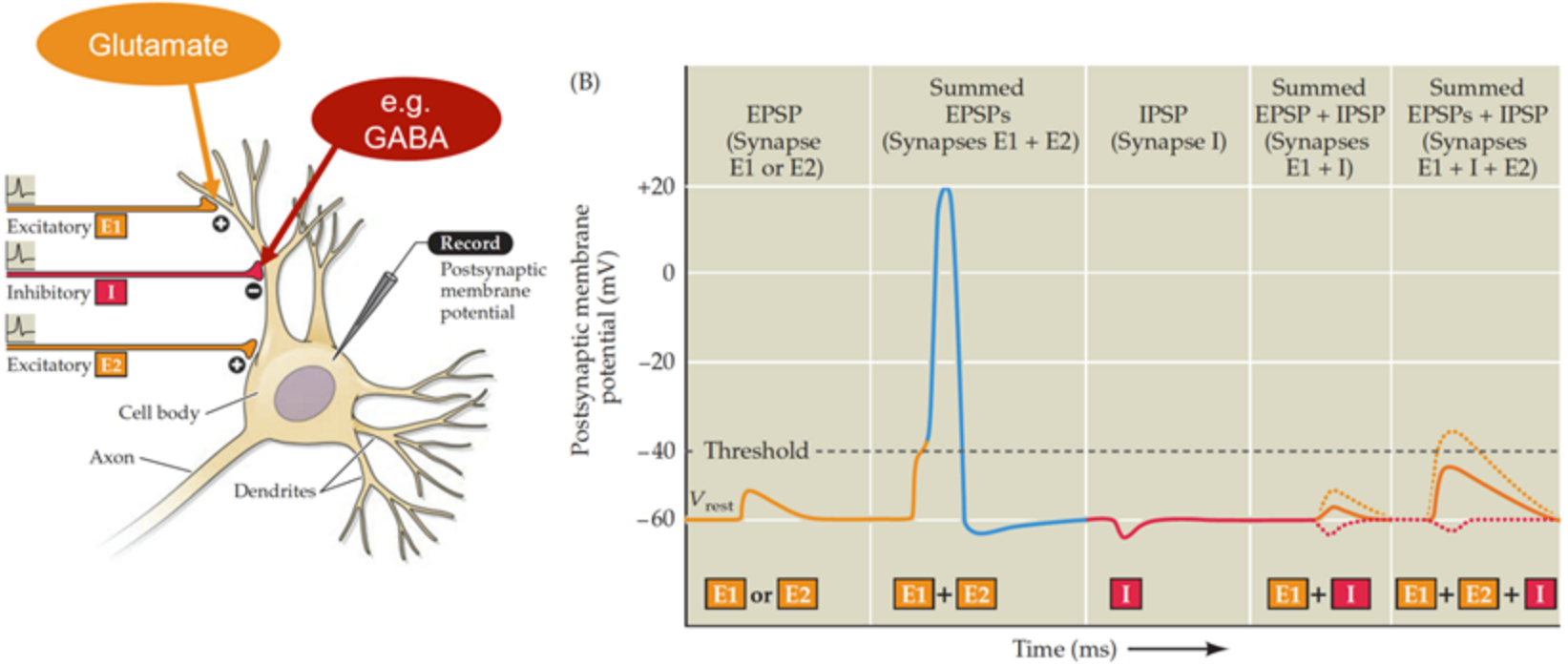
Chemical synapses

- Works by chemical signaling via neurotransmitters
- Ca^{2+} channels
  - Open when an action potential reaches the presynaptic terminal
  - Ca^{2+} cause the release of neurotransmitters into the synaptic cleft (exocytosis)
- Neurotransmitter causes ion channels to open/close in postsynaptic neuron
- This causes an action potential in the postsynaptic neuron



Unit 3 - Synaptic Transmission & Neurotransmitters

The dendritic summation of postsynaptic potentials



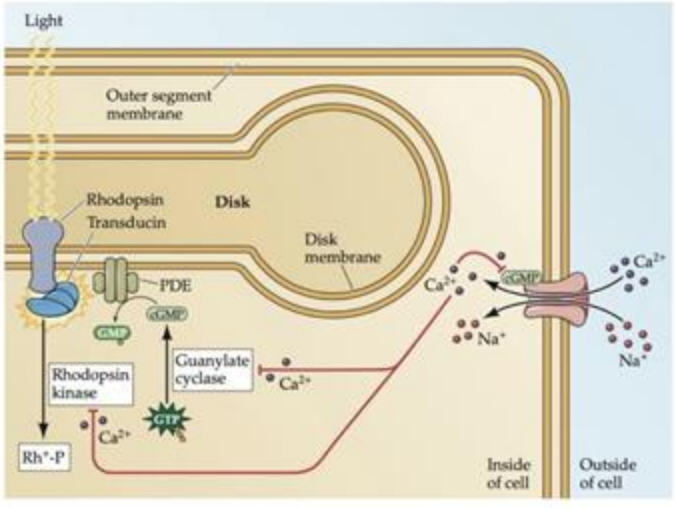
Unit 4 - The Eye & the Retina

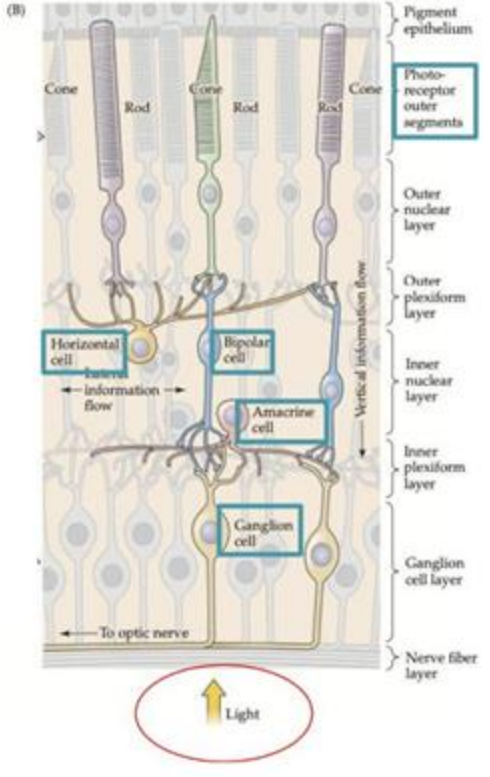
- The eye
- Photoreceptor cells; Primary sensory transduction in vision
- Scotopic (rod-based) and photopic (cone-based) vision; Rod and cones
- Color vision: S-, M- , L- cones; Color blindness
- Structure of the retina; Five major neuron types
- Concept of receptive field (in general) of a sensory neuron
- 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

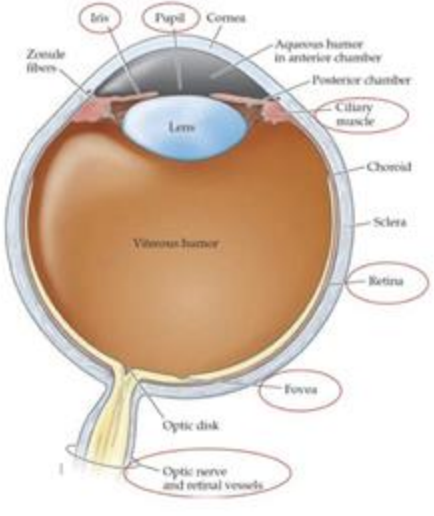
Unit 4

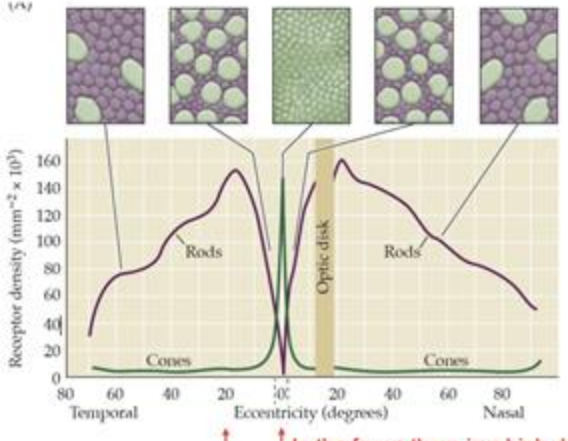
S-cones M-cones L-cones

Primates including humans:
Trichromatic color vision









Rod system:
- Low spatial resolution
- High light sensitivity

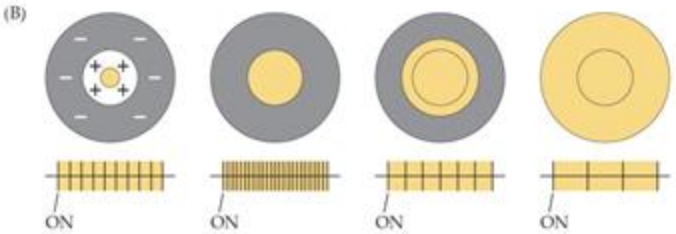
Cone system:
- High spatial resolution
- Lower light sensitive

In the fovea there is a high density of **cones**

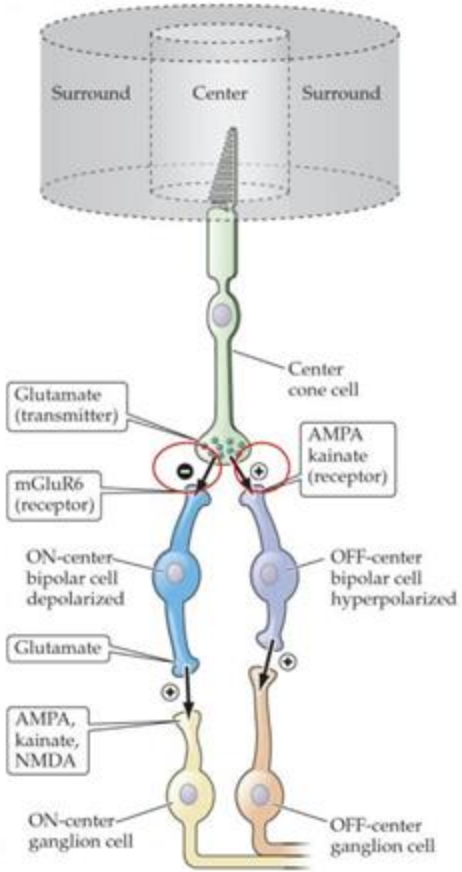
Unit 4

Processing of visual information

- ON and OFF bipolar cells and mechanisms
- Center-surround receptive field organization of ON-center and of OFF-center RGCs

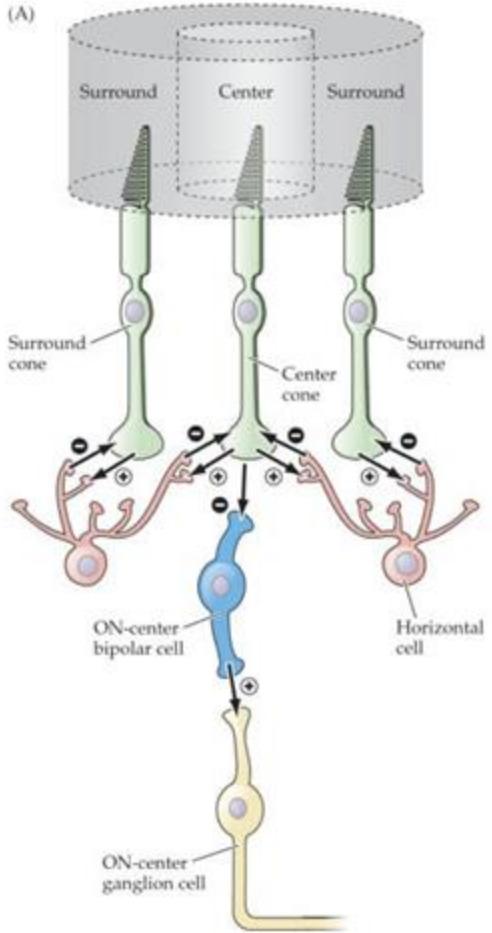


Luminance **contrast** is important



Mechanism of surround inhibition

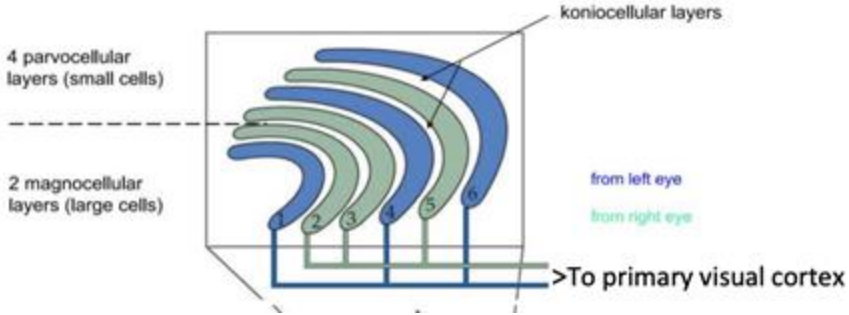
- Horizontal cells:
  - GABAergic -> hyperpolarisation
  - Since photoreceptors react through hyperpolarisation, horizontal cells **amplify** the signals normally
- When there is a large spot:
  - hyperpolarisation of photoreceptors
  - hyperpolarisation of horizontal cells
  - reduced GABA release
  - **reduced** sensitivity

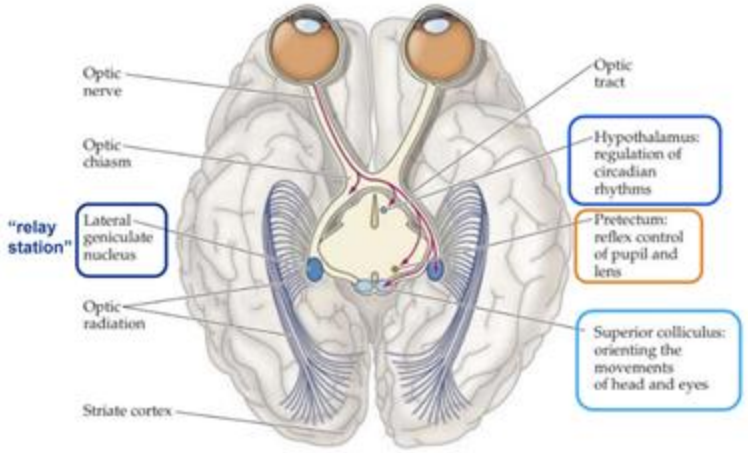


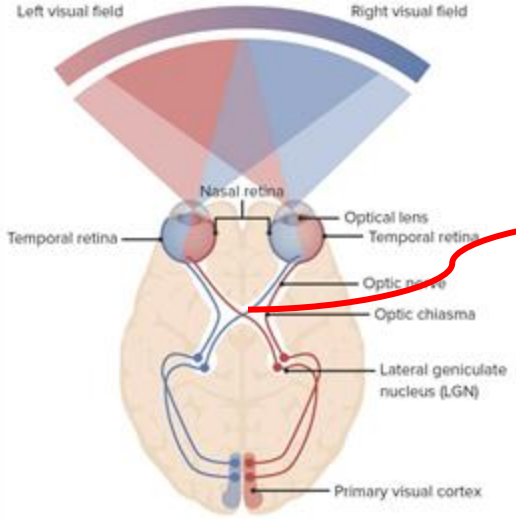
Unit 5 - Visions: Systems & Circuits

- 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 5

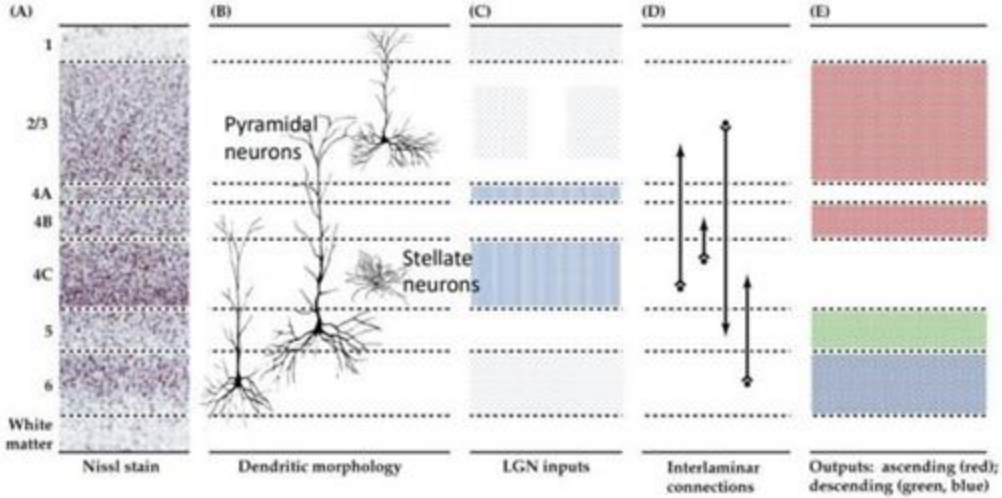


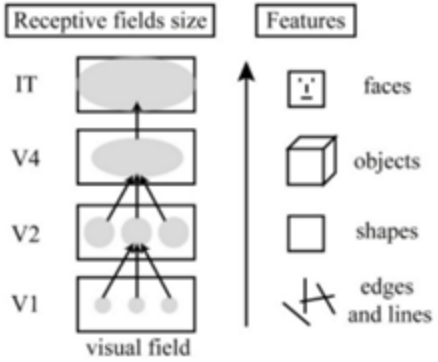


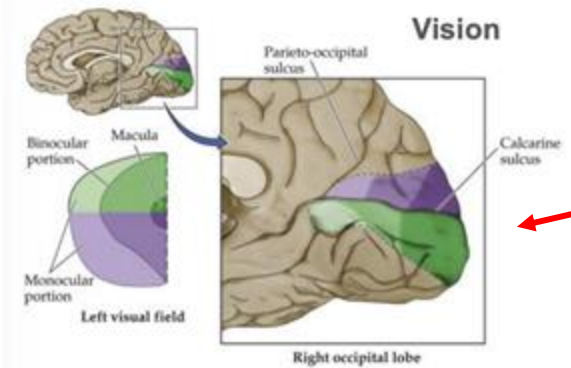


Side-Switching! Information from the left half of the visual world, whether it originates from the left or right eye, is represented in the right half of the brain, and vice versa.

Unit 5







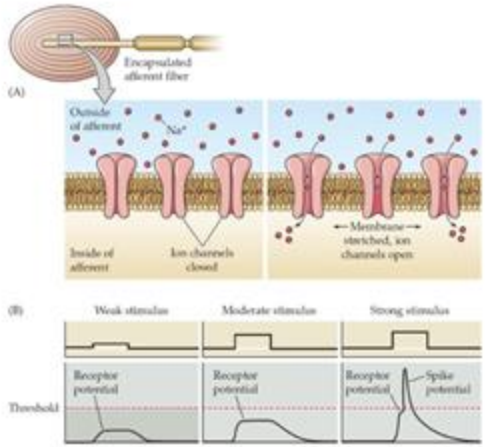
Cortical magnification: the dedicated brain surface area is proportional to the density of receptors

Unit 6 - Somatosensation

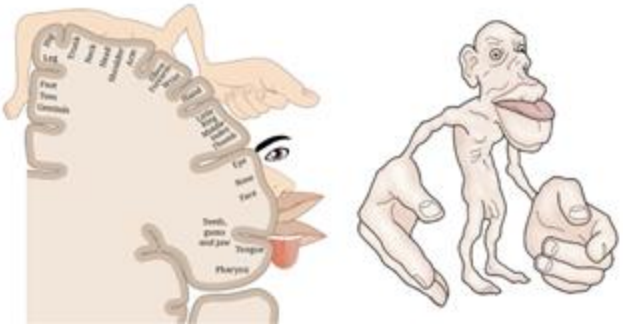
- Touch and proprioception
- Mechanoreceptors
- Touch receptor types
- Somatosensory receptive fields & tactile acuity
- Touch and proprioception neural pathways
- Somatotopy & homunculus
- Plasticity of the somatotopic map in the context of amputation

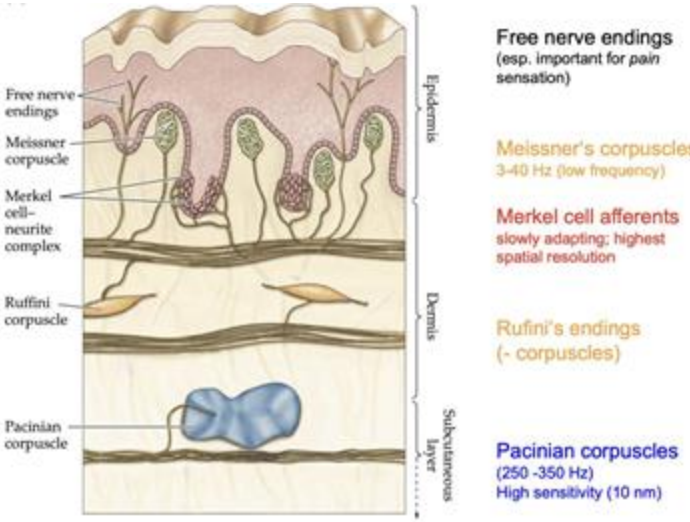
Unit 6

Mechanoreceptors

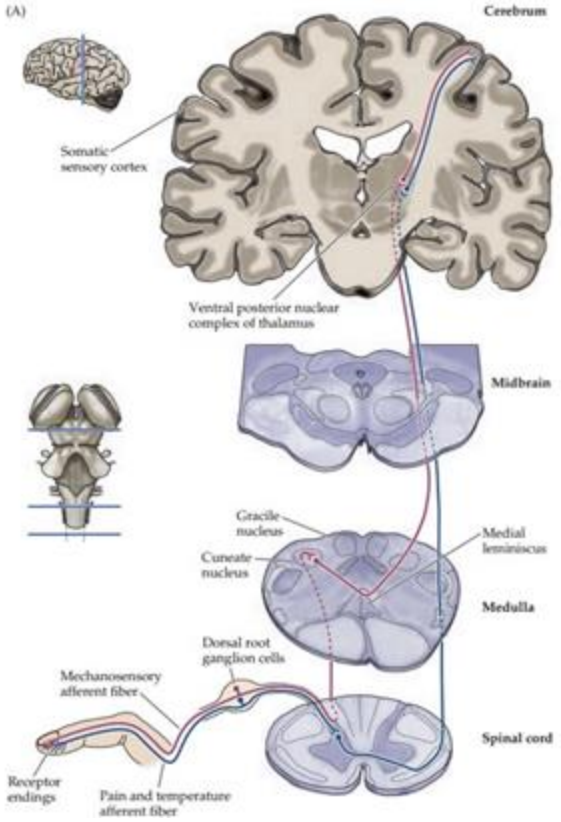


Somatotopy





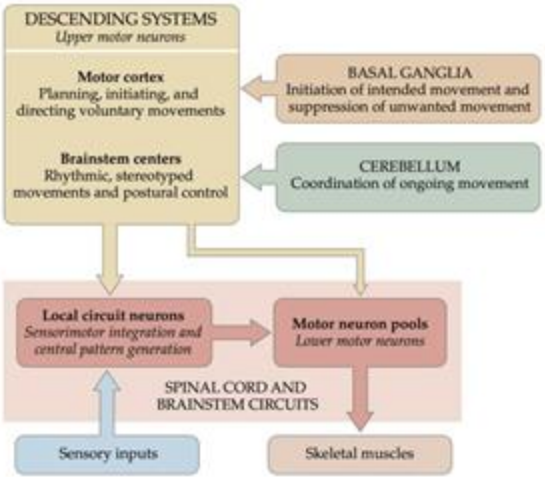
Dorsal column-medial lemniscus pathway

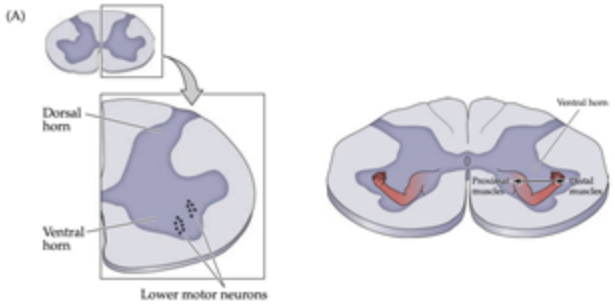


Unit 7 - Neural Control of Movement: spinal cord & cerebellum

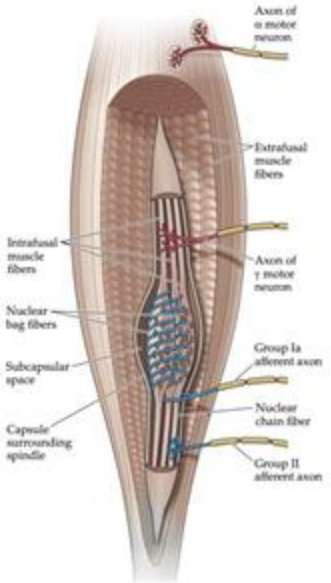
- Four main motor pathways: Upper motor neurons (cortex/brainstem); Basal Ganglia, Cerebellum, Spinal Cord
- Spinal cord - somatotopic organization (mediolateral and rostrocaudal)
- Henneman’s size principle
- Stretch reflex circuit function including roles of Group 1a sensory & alpha motor neurons
- 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

Unit 7

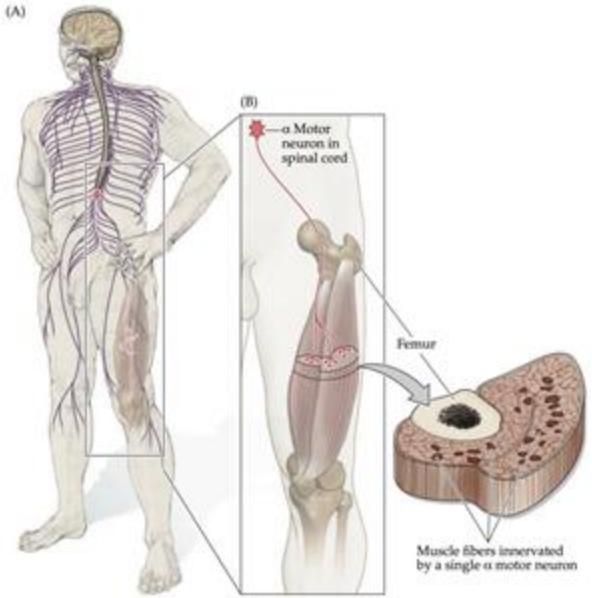




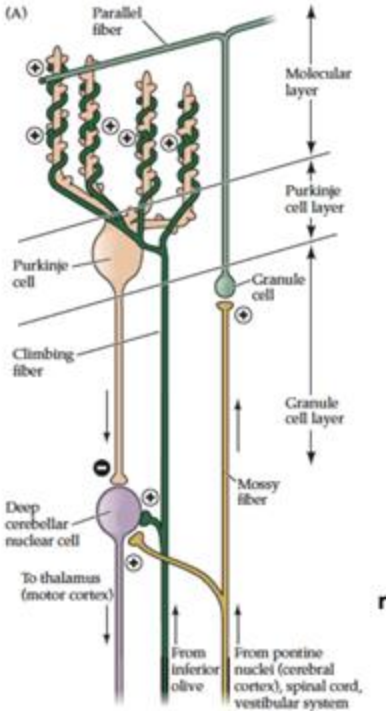
Muscle Spindle

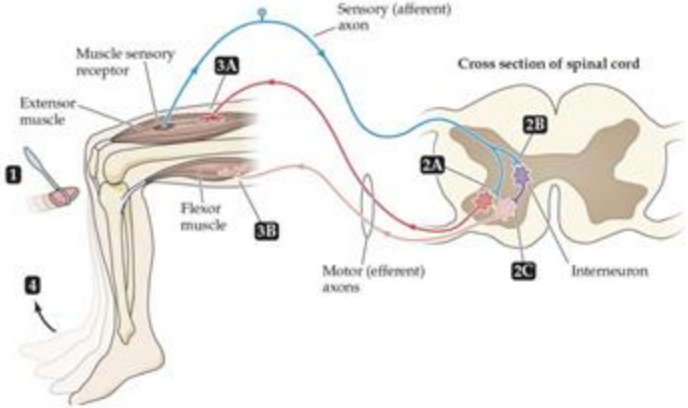


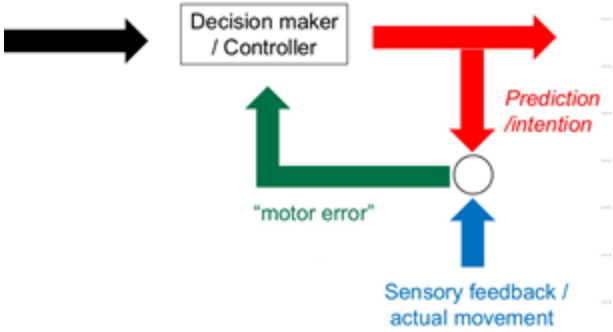
Motor Unit

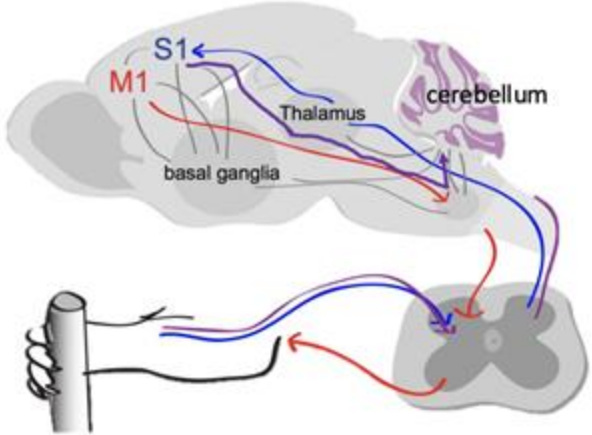


Unit 7

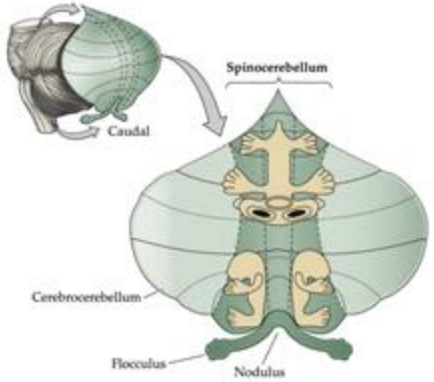








Topographic Map



Purkinje Neurons are the principle output of the cerebellar cortex!

Unit 8 - Motor systems: Cortex and Basal ganglia

Motor cortex

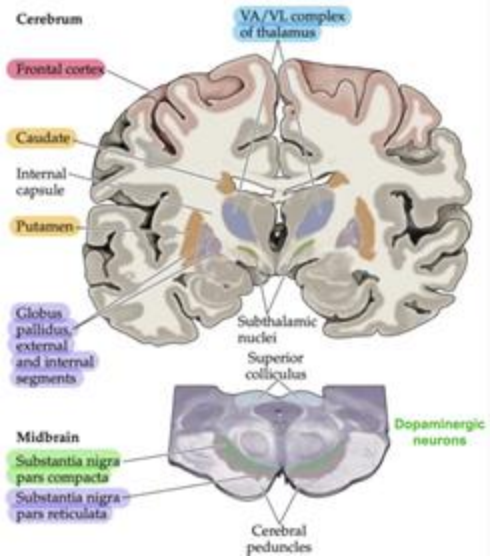
- Primary motor cortex (M1), output layer (L5), lateral corticospinal tract
- « Coding » of movement primitives in M1
- Principles and applications of a Brain-Machine Interface

Basal ganglia

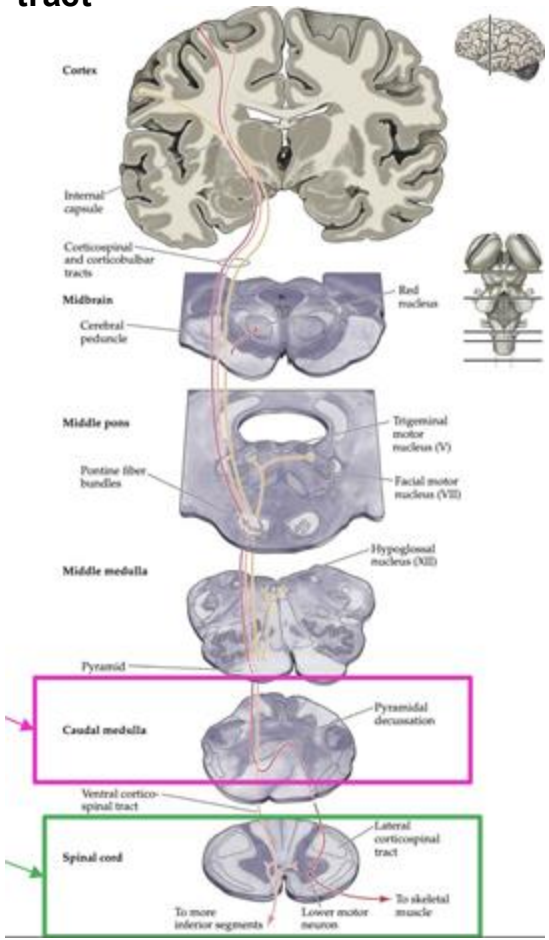
- Principal nuclei and their connectivity
- Medium spiny neurons (MSNs) in the striatum
- Direct and indirect pathways: modulation and role in action selection and movement
- Clinical cases of Parkinson’s and Hungtington’s disease

Unit 8

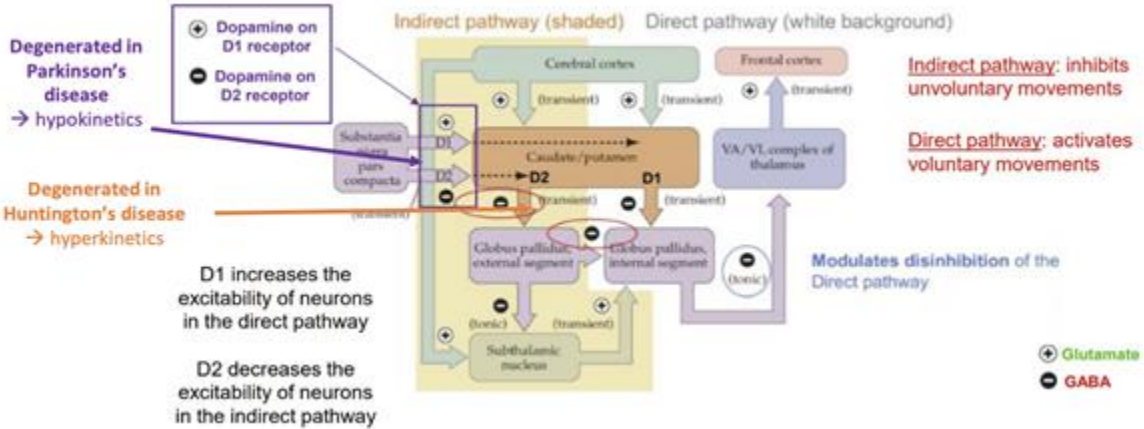
Basal ganglia (BG)



M1 and lateral corticospinal tract



Direct and Indirect pathways

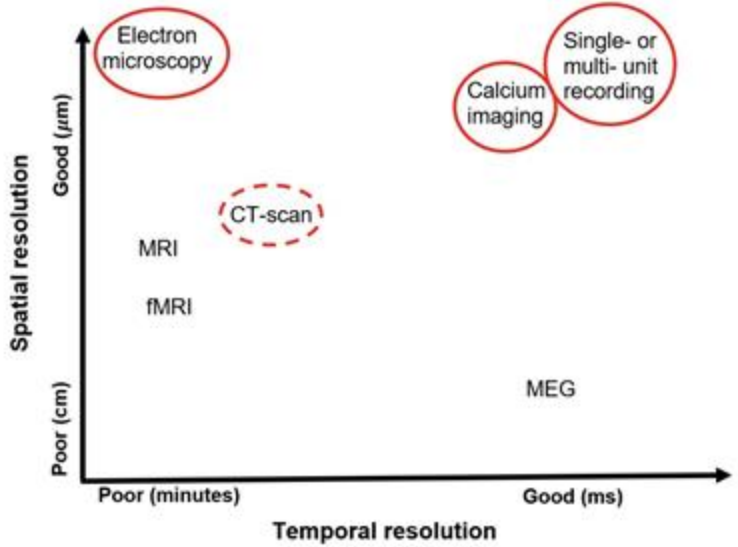


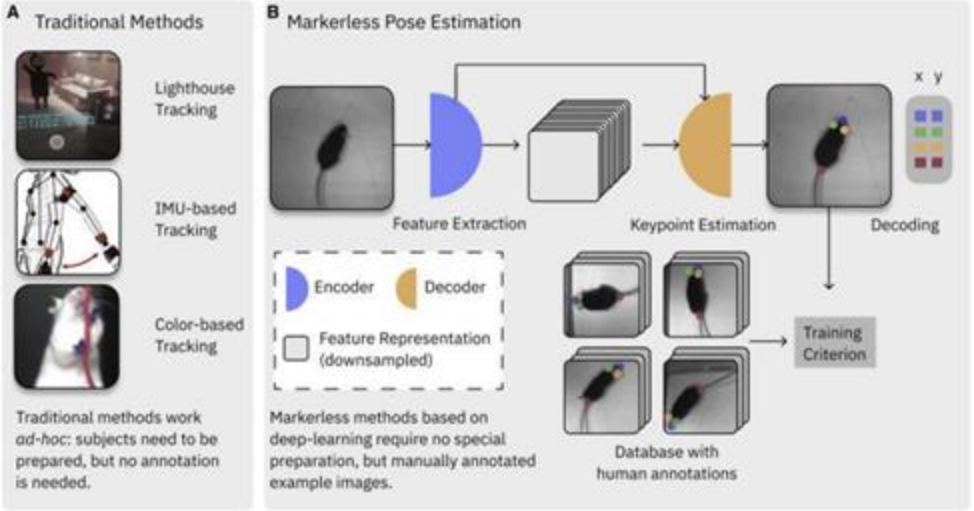
Unit 9 - Techniques in Neuroscience

- How things change during injury or disease can tell you about what the circuit does (examples: memory, motor system changes)
- Many ways to stimulate neurons and see changes in behavior: 3 shown → electrical stimulation, optogenetics, and TMS
- Electrical: Volta – driving all or none response, fast, can't control easily which neuron is stimulated
- Optogenetics – light gated ion channel/pumps, can target precise neurons
- TMS – non-invasive magnetic stimulation used in humans; changes single cell activity, but targets large areas
- Genetic tools for model organisms (optogenetics, gene knockouts, calcium imaging)
- Computer vision for behavioral monitoring
- Computational neuroscience to link neural dynamics to behavior

Unit 9

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. deep learning tracking, pose estimation, computer vision
✓ Perturbate neural activity → e.g. Electrical stimulation, Optogenetics (ChR2 & Halorhodopsin), TMS

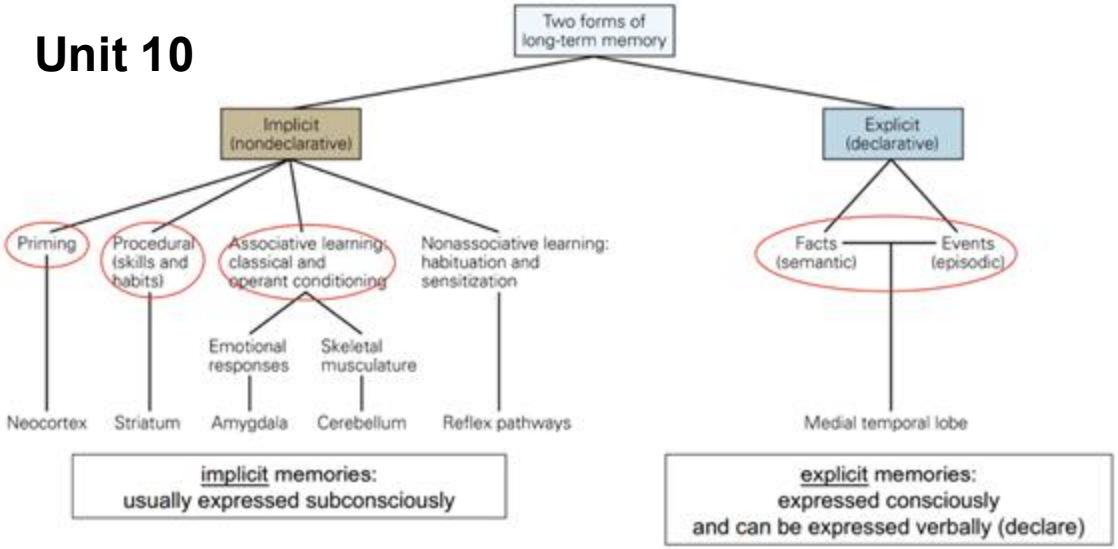


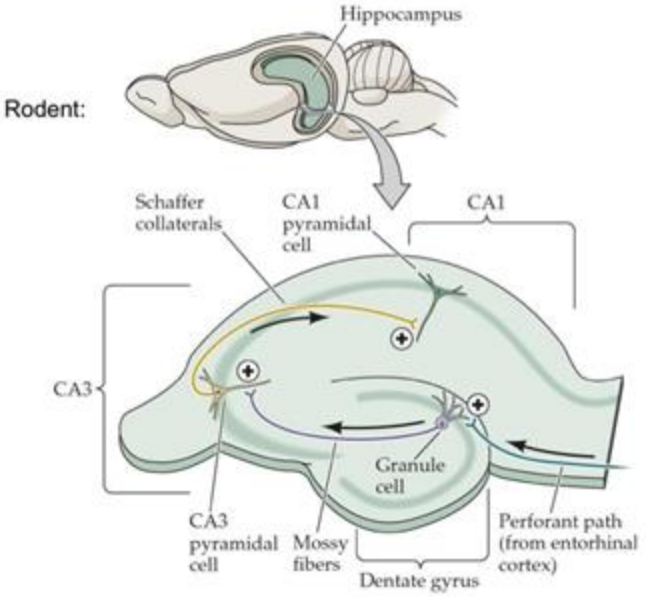


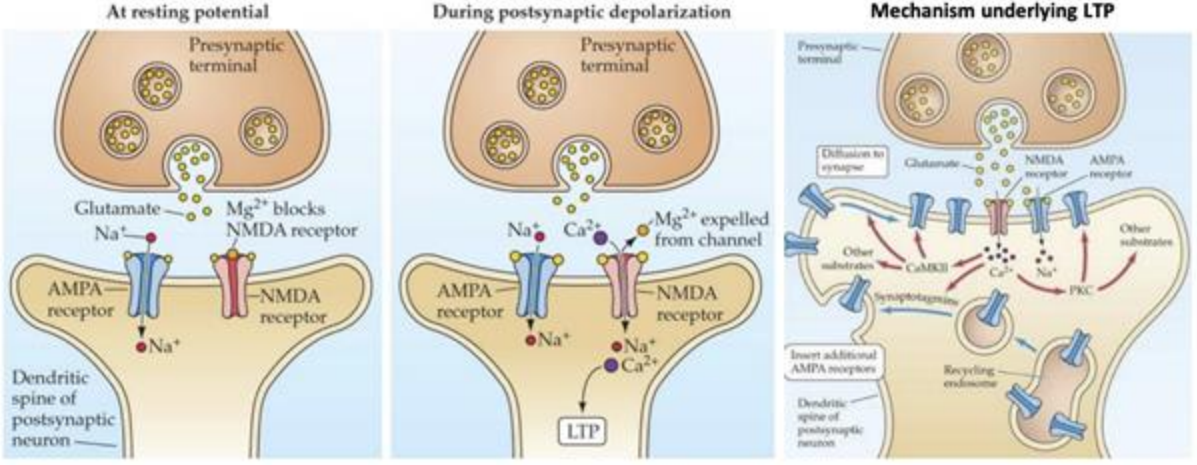
Unit 10 - Memory and cognitive maps of space

- 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 10







Association cortices

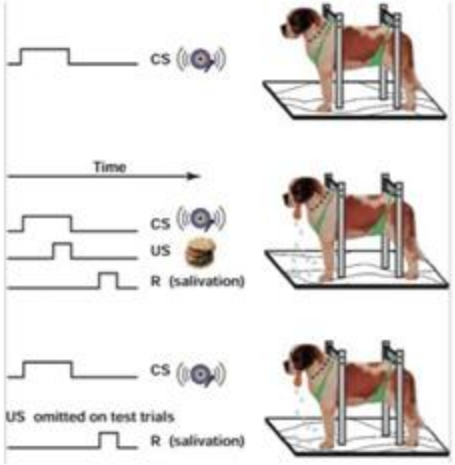
- **limbic** association cortex
- **parietal** association cortex
  - objects, self, spatial awareness
- **temporal** association cortex
  - declarative memory
  - identifying, naming objects
- **frontal** association cortex
  - planning of purposeful behaviours
  - short-term (‘working’) memory

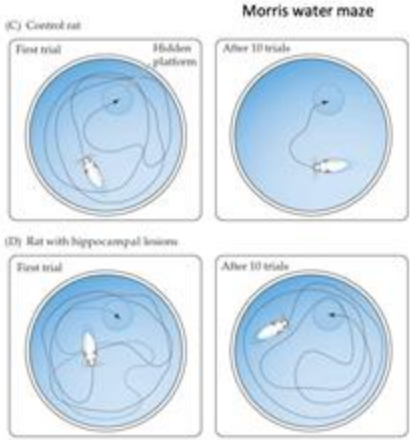
Unit 10

CS: conditioned stimulus

US: unconditioned stimulus

CR: conditioned response



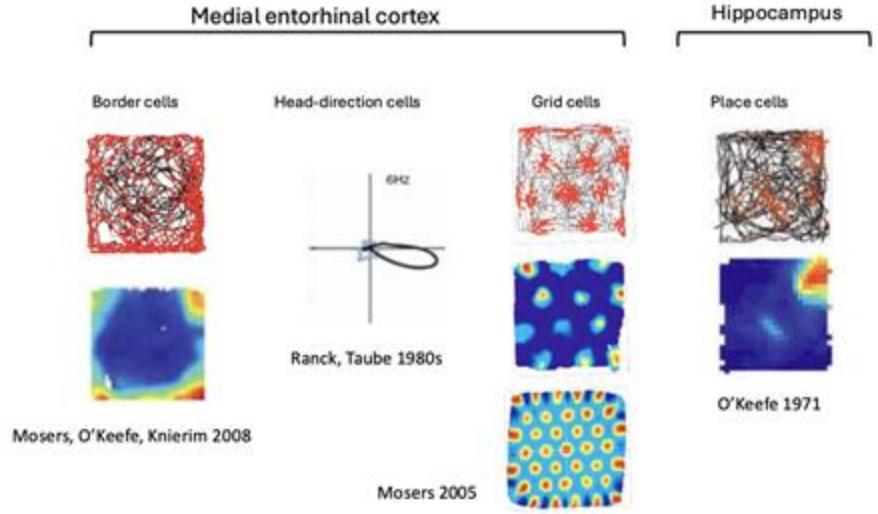


Classical (Pavlovian) conditioning:

- Drive animals to produce a **novel response** to a previously neutral stimulus
- A previously "neutral" stimulus (the **conditioned stimulus CS**)
  - gains control over e.g. a defensive / or appetitive reaction
  - when temporally paired with a strong **reinforcing (unconditioned) stimulus (US)**
  - such as **pain ('aversive') or food ('appetitive')**

Operant conditioning (instrumental learning):

- The outcome of the experiment depends on the behavior of the animal
- A "reinforcer" is **only** given upon a specific behavior of the animal e.g., a (hungry) rat learns to press one of two possible buttons to receive a food reward



Unit 11 - Disorders of the Nervous System

Motor and neurodegenerative Disorders

● ALS (Amyotrophic Lateral Sclerosis): Progressive loss of motor neurons → paralysis (fatal 2-5 years)

● Cerebellar Ataxia: Impaired motor coordination and learning (~4/100,000 affected)

● Alzheimer's Disease: Memory loss, plaques & tangles (affects ~50% of 85+ population)

Psychiatric Disorders

● Depression: Most common psychiatric disorder (10-25% lifetime prevalence). Increased blood flow in amygdala and prefrontal cortex.
-> Treatments to selectively block serotonin reuptake

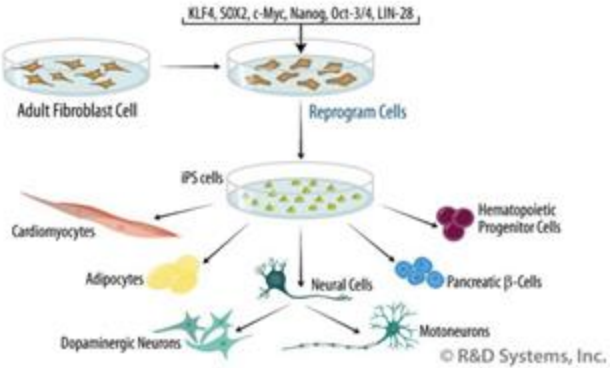
● Schizophrenia: 1% prevalence, with positive symptoms (delusions, hallucinations) and negative symptoms (apathy, diminished expression).
-> Dopamine receptor antagonists reduce psychotic symptoms

Unit 11 - Disorders of the Nervous System

Treatment Innovations

Bioengineering

- iPSC technology for patient-specific drug screening
- Cerebral organoids modeling brain development
- Brain-machine interfaces for motor restoration



Precision Psychiatry

- TMS (Transcranial Magnetic Stimulation) for personalized treatment, can modulate specific brain networks
- Shift from "one size fits all" to individualized approaches