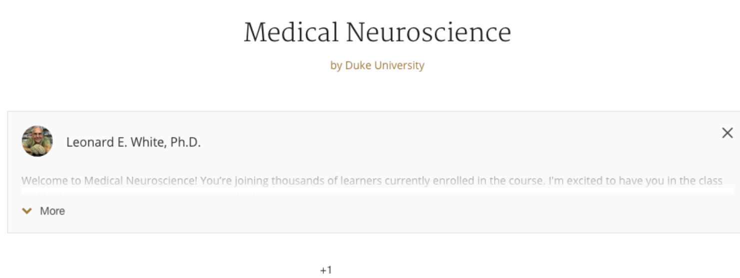
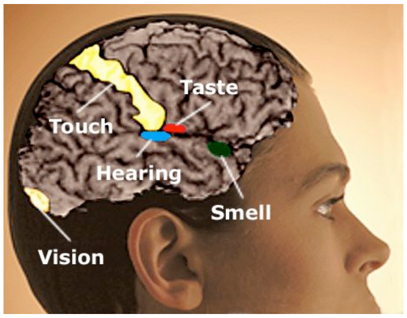
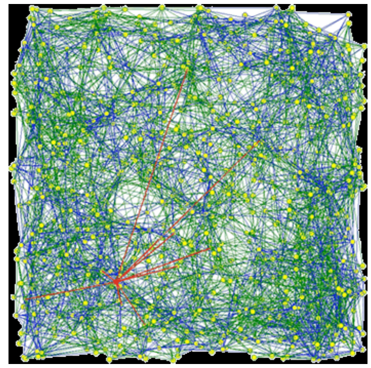
Engineer’s View of the Brain

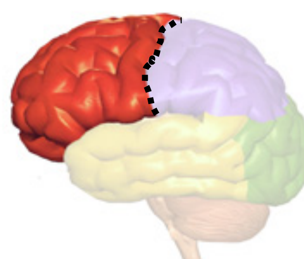
COURSERA







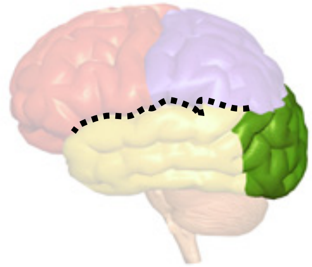
Lobes of the cerebrum



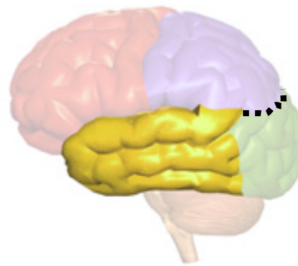
Frontal
- intellect
- personality
- skilled movement
- speech initiation

Parietal
- tactile sensation
- sensory combination & comprehension
- response to internal stimuli

Lobes of the cerebrum

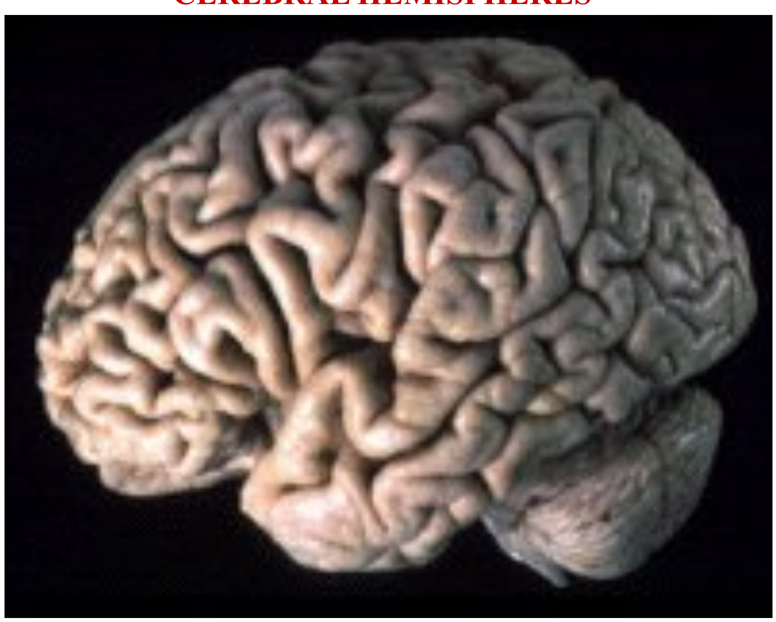


<u>Occipital</u>
• reading
• vision
• visual memory



<u>Temporal</u>
• auditory memory
• music appreciation
• some language & speech
• sense of smell

CEREBRAL HEMISPHERES

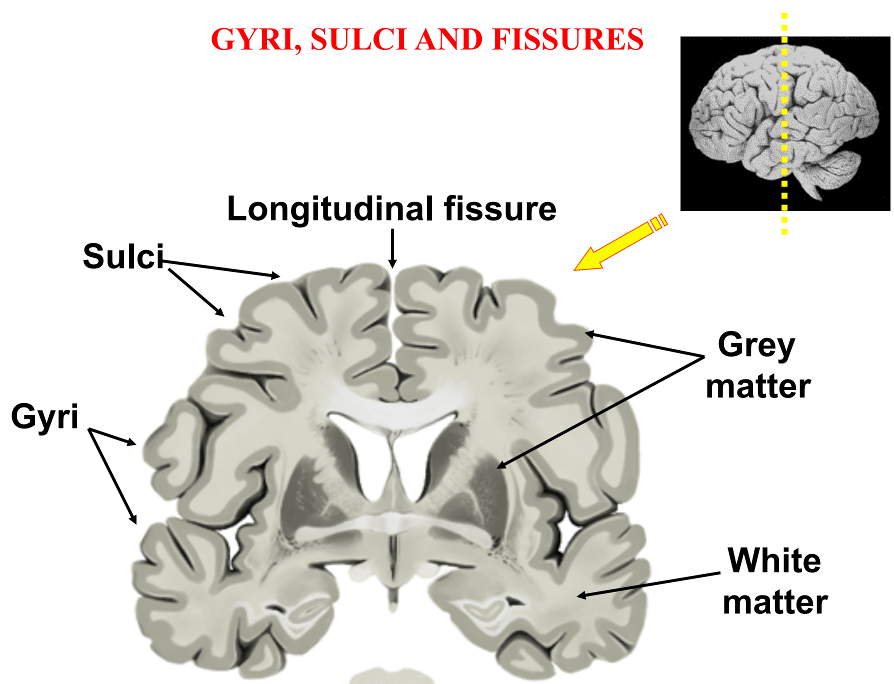


The hemispheres have gyri and sulci that increase their surface area.

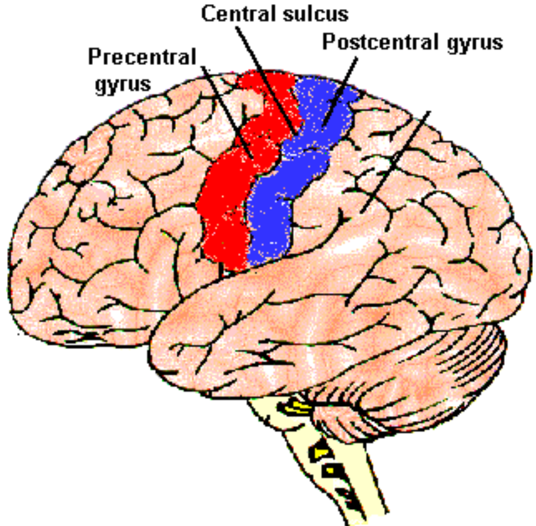
Terminology

- Efferent- effector neurons, carry nerve impulses away from the central nervous system
- Afferent-afferent axons, carry nerve impulses from receptors or sense organs towards the central nervous system.

GYRI, SULCI AND FISSURES



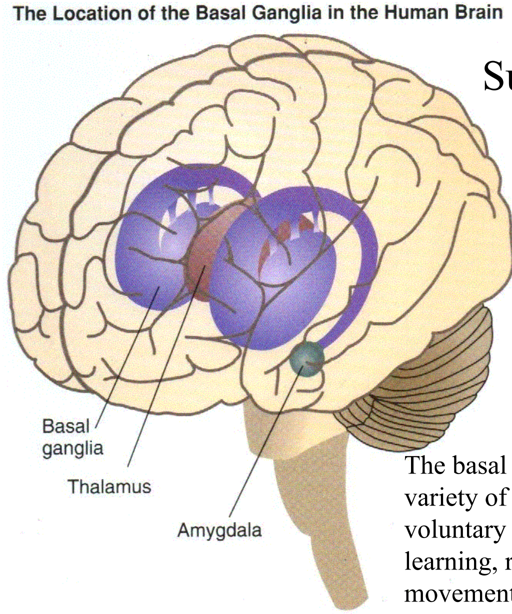
THE PRE AND POSTCENTRAL GYRI



The precentral gyrus is the primary motor cortex.
The postcentral gyrus is the primary sensory cortex.

The Location of the Basal Ganglia in the Human Brain

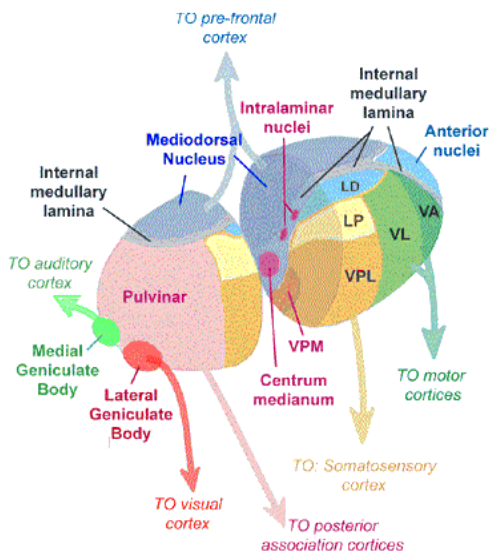
Sub cortical Structures)



The basal ganglia are associated with a variety of functions including: control of voluntary motor movements, procedural learning, routine behaviors, eye movements, cognition and emotion.

Substantia nigra , globus pallidus, subthalamic nucleus

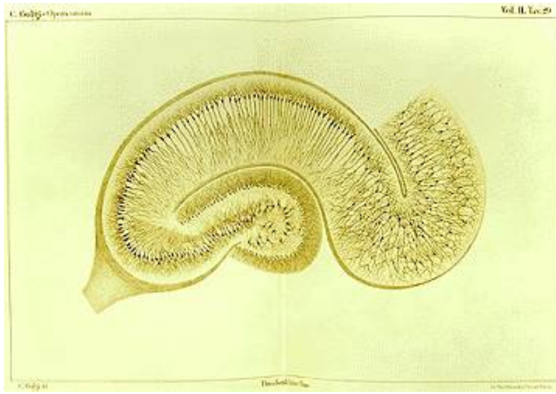
NUCLEI IN THE THALAMUS

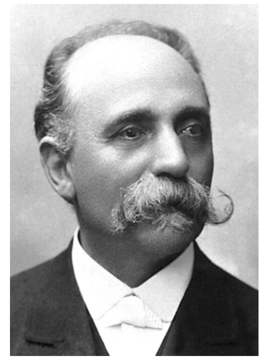


Axons from every sensory system (except smell) synapse here as the last relay site before the information reaches the cerebral cortex.

Virtual Brain Anatomy

http://www.youtube.com/watch?v=D1zkVBHPh5c&feature=c4-overview-vl&list=PLmGQgRI4QyEDCSPyYurmzj_zatY5BWz_r



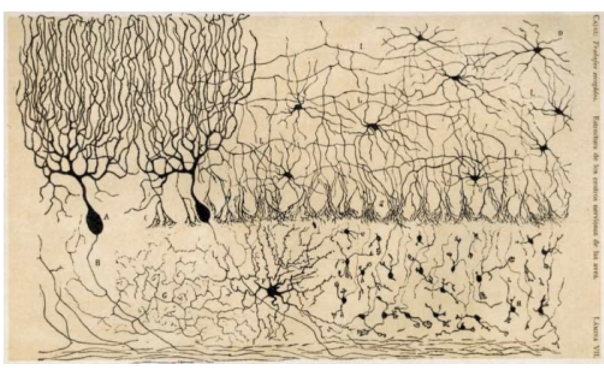


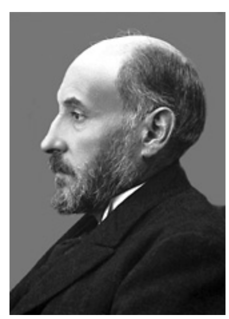
Italian physician, biologist, pathologist, scientist, who among had a number of discoveries but is best known for developing staining methods for the central nervous system.

Camillo Golgi

1843 –1926

“a forest of outstretched trees”





Spanish pathologist, specializing in neuroanatomy, particularly the histology of the central nervous system. Known for microanatomy support for the neuron theory and existence of dendritic spines.

Santiago Ramón y Cajal.

1852 –1934)

View of the Brain- 1880's

The reticulists, led by Golgi—thought the nervous system consisted of a diffuse network of continuous tissue, or reticulum, formed by the fused branches of dendrites and axons.

The neuronists, supported by the work of Cajal, countered that the nervous system was composed of distinct individual elements, or neurons.

The Nobel Prize in Physiology or Medicine 1906 was awarded jointly to Camillo Golgi and Santiago Ramón y Cajal "in recognition of their work on the structure of the nervous system"

"It may seem strange that, since I have always been opposed to the neuron theory – although acknowledging that its starting-point is to be found in my own work – I have chosen this question of the neuron as the subject of my lecture, and that it comes at a time when this doctrine is generally recognized to be going out of favour."

"My wish is that these new anatomical studies, on which this Institute, in such a high order of thought, has wished to draw the attention of the world, may represent a new element of progress for humanity."

Brain Facts

- Brain 1-2 kg – 2% of body weight
- Uses 20% of O_2, 25% of glucose, 15% of blood flow

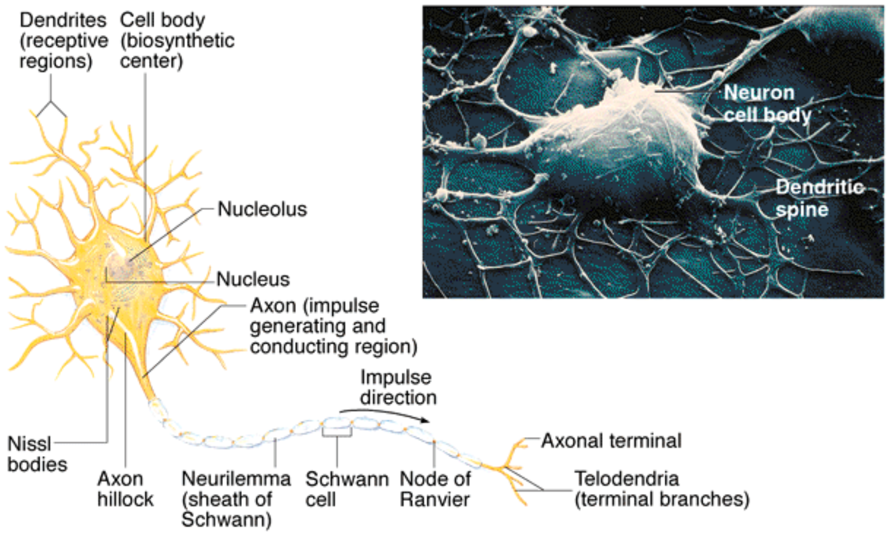
- Mass at birth is 20% of final value- growth of axons, myelination, glial cells
- Thickness of cortex- large part of what makes us human, 3 mm , 6 layers of cells
- Surface area of cortex 5 cm^2 for rat, 500 cm^2 for chimp (sheet of paper), 2000 cm^2 for human

Brain Facts

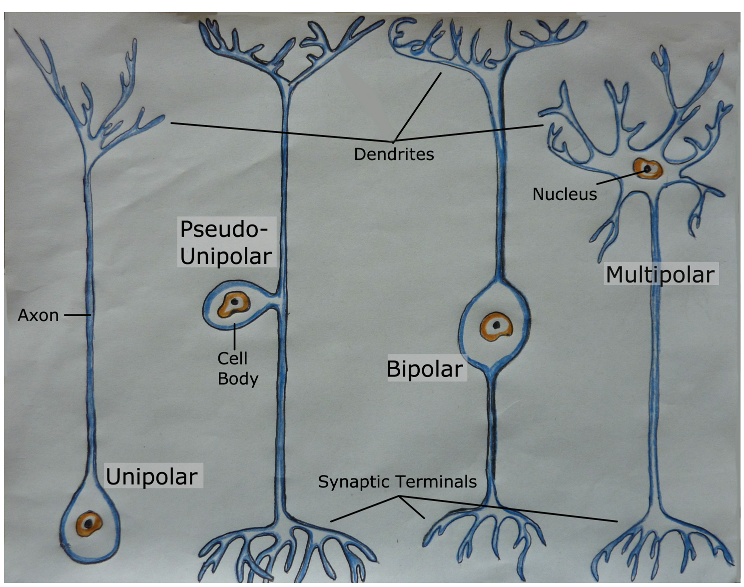
- Average number of neurons in the brain = 100 billion
- Average number of glial cells- 1-5 Trillion

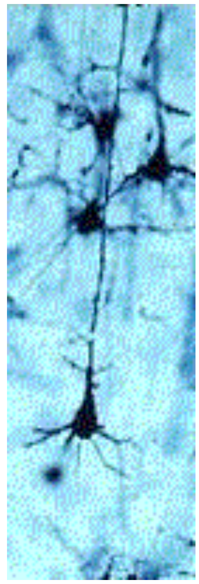
- Average number of neurons in the cortex – 10 billion
- Average number of synapses in cortex – 60-100 Trillion
- Average number of synapses per cortical neuron 10,000
- Average loss of neocortical neurons = 1 per second (86.5K per day) (4800 per class time)

Generalized Neuron- Basic Component

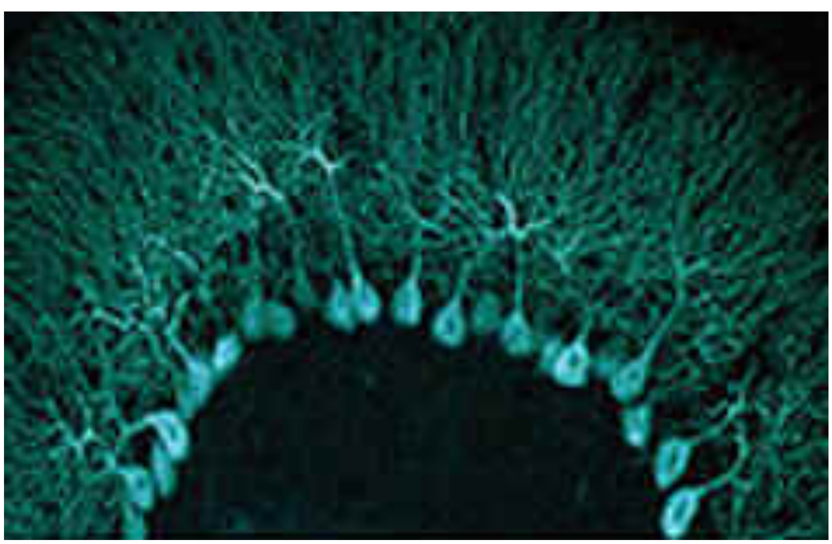


<u>Basic Neuronal Cell Types</u>

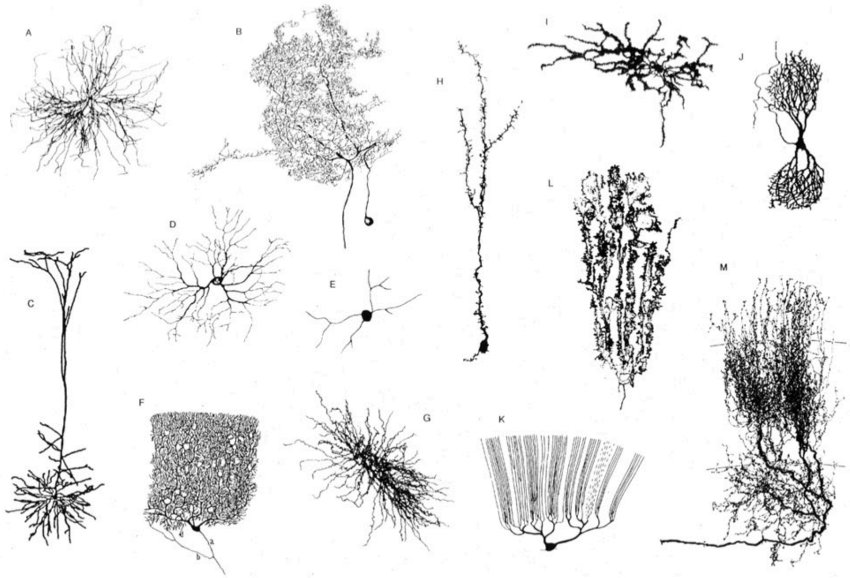




Multipolar neurons in the cerebral cortex

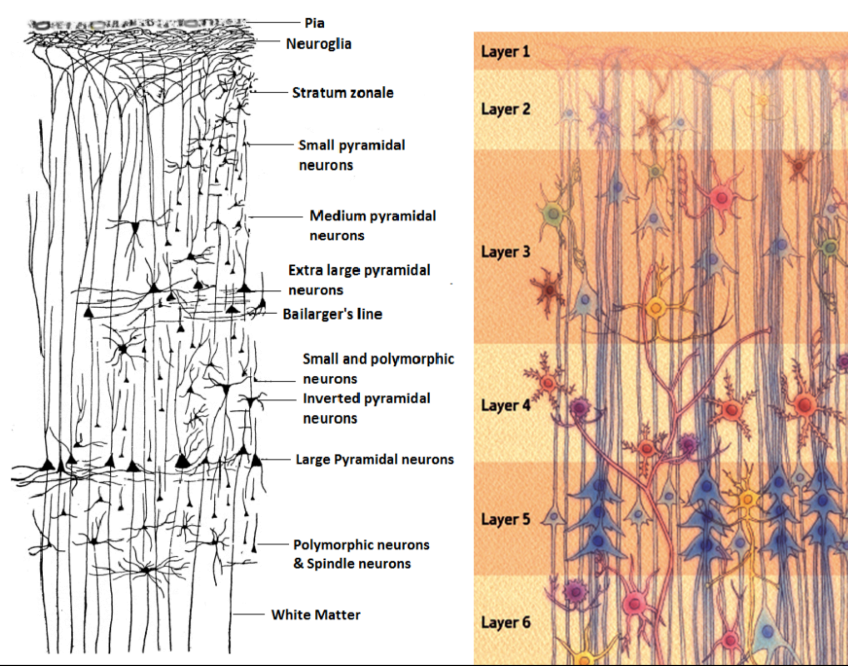


Special stain showing Purkinje neurons in the cerebellar cortex



https://www.janelia.org/lab/spruston-lab/research/cellular-diversity-hippocampus

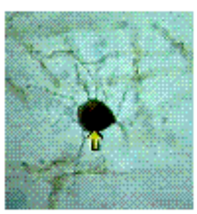
Histological Structrure of the Cerebral Cortex

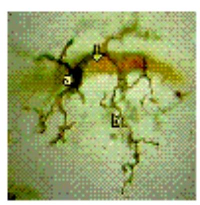


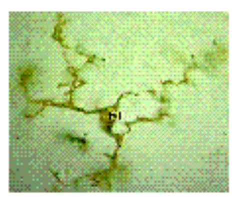
Glia

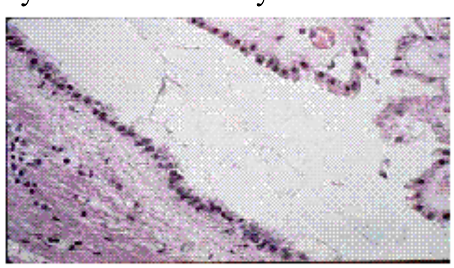
- outnumber neurons 10:1. 1/2 volume
- regulate chemical content
- envelop synaptic junction (restrict spread of neurotransmitters)
- control K concentration
- prevent spread of local currents
- Control myelination

CNS Neuroglia

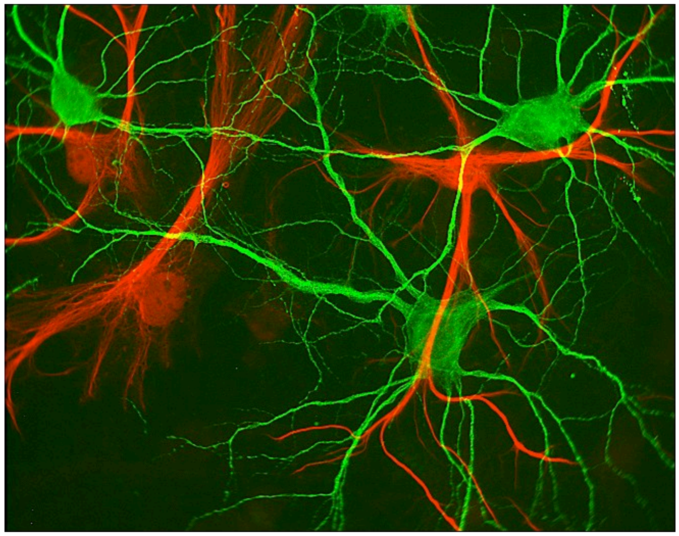

oligodendrocyte


astrocyte

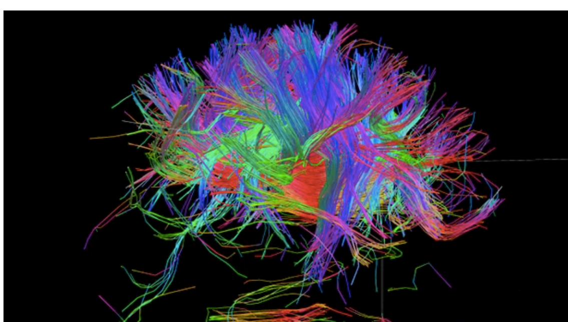

microglial cell


ependymal cells

GLIAL CELLS

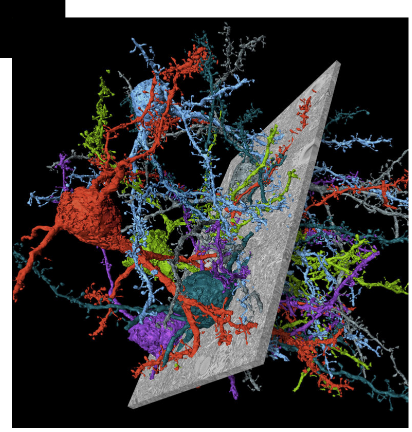


Astrocytes form a barrier between capillaries and neurons.

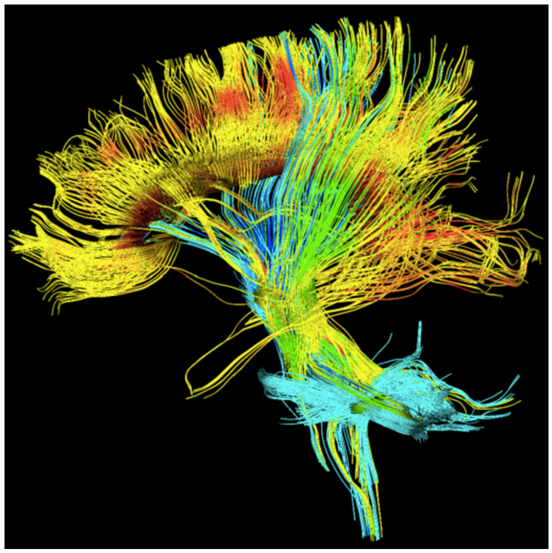


What is the wiring diagram?

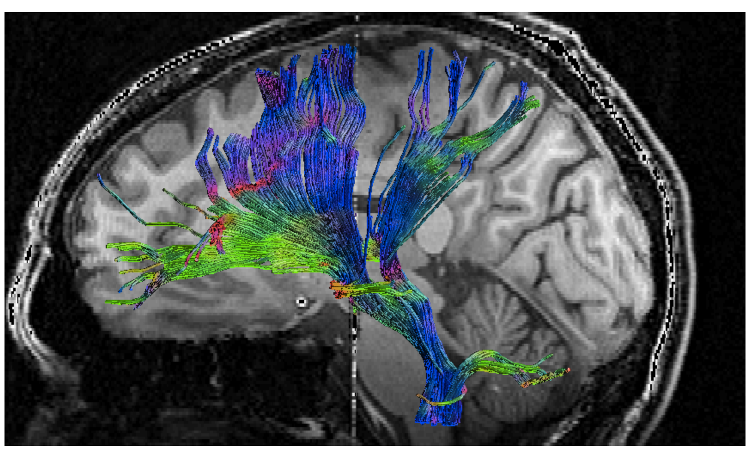
https://www.youtube.com/watch?v=nvXuq9jRWKE

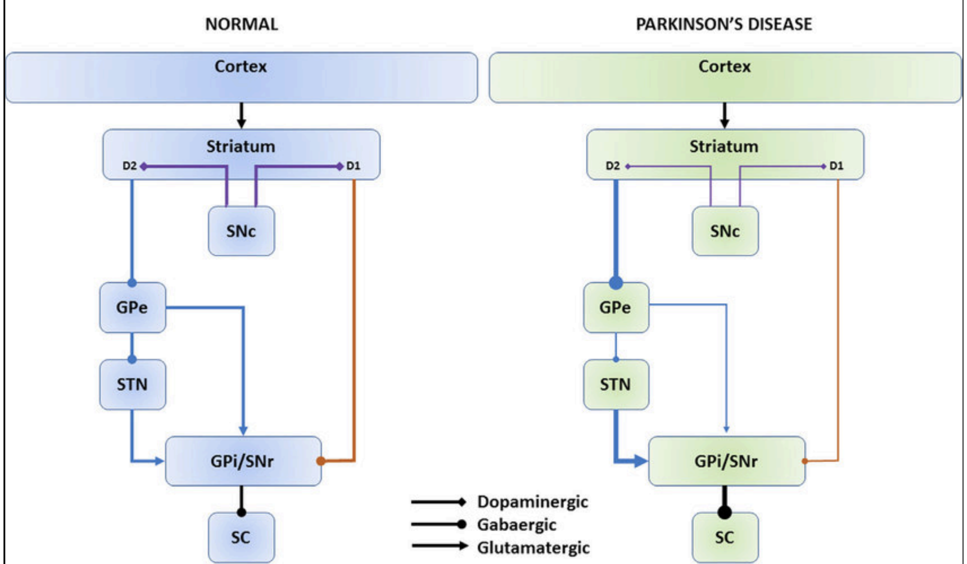


Diffusion Tensor Imaging – Tractography

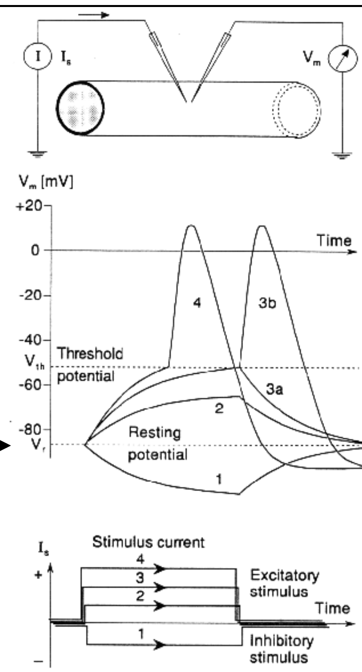


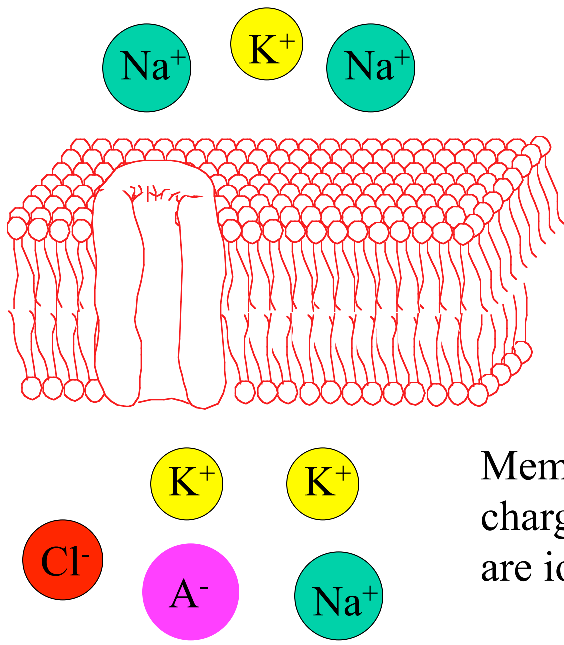
Diffusion Tensor Imaging – Tractography





Resting potential





Membrane separates charge- charge carriers are ions.

Thus the total flux is due to two components- one due to diffusion and the other due to an electric field

$$j_{total} = j_{diff} + j_{Efield}$$

$$J_{total} = J_{diff} + J_{Efield}$$

Substituting terms, we get

Diffusion

$$j_{total} = -D\left(\nabla C + \frac{zCF}{RT}\nabla\Phi\right)$$

drift

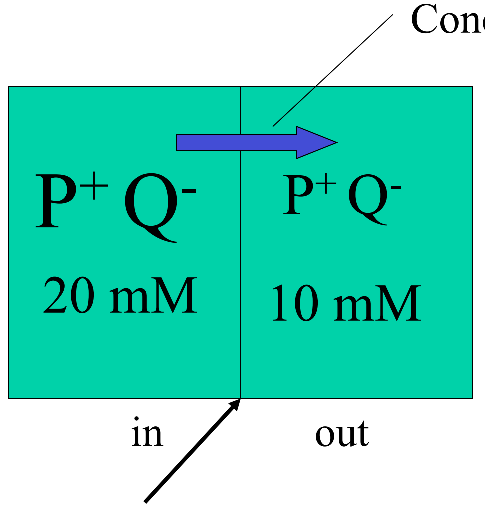
In terms of current density

$$J_{total} = -DzF\left(\nabla C + \frac{zCF}{RT}\nabla\Phi\right)$$

This is the Nernst-Planck Equation

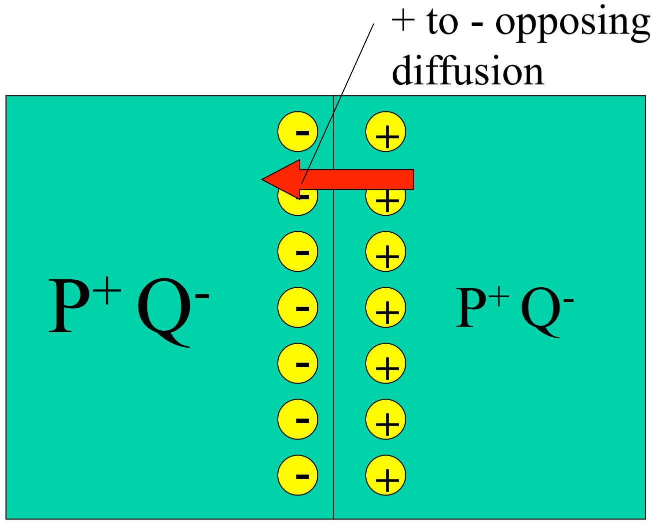
How do we relate to a cell

ion flow due to
Conc gradient

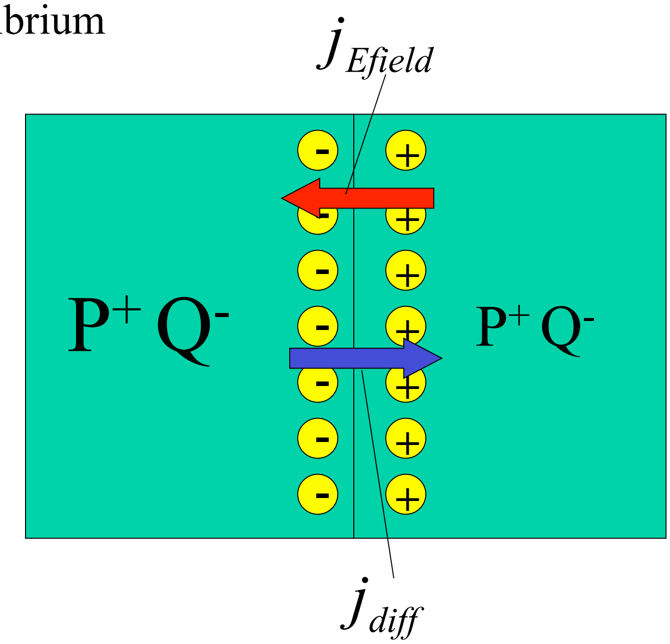


Membrane is permeable to P^+

Eventually a build up of charge...



Equilibrium



At Equilibrium

$$J_{total} = 0 = -DzF\left(\nabla C + \frac{zCF}{RT}\nabla\Phi\right)$$

or

$$\nabla C = -\frac{zCF}{RT}\nabla\Phi$$

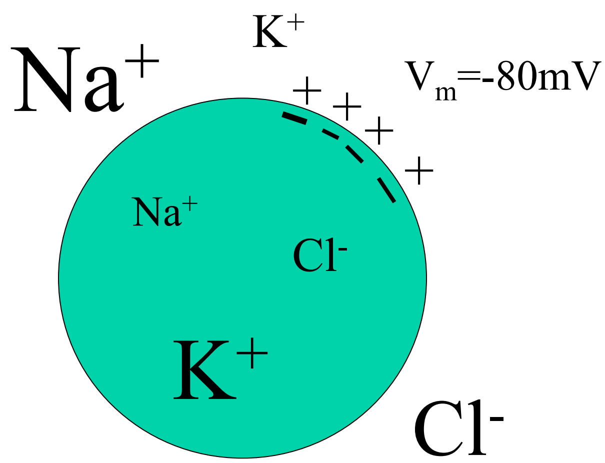
In one dimension across membrane

$$\frac{dC}{dx} = -\frac{zCF}{RT}\frac{d\Phi}{dx}$$

$$V_m = \frac{RT}{Fz}\ln\frac{[C]_{out}}{[C]_{in}}$$

Nernst Potential- an electrical measure of the strength of diffusion with which it is in equilibrium. RT/F typically 25-30mV.

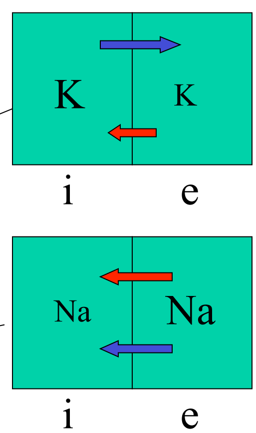
Consider an Realistic Cell



What are the flows (j's) if V_{rest}=-80mV

net outflux
$j_{diff} > j_{Efield}$

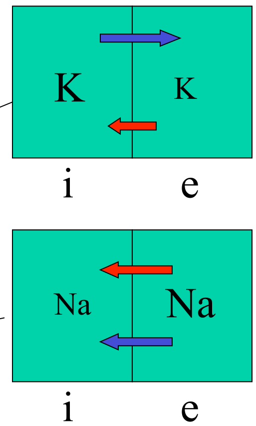
net influx
j_{diff} & j_{Efield}
point inward



E_K=-104mV

E_{Na}=+85.3mV

What are the flows (j's) if V_{rest}=-80mV



E_K=-104mV

E_{Na}=+85.3mV

net outflux

$j_{diff} > j_{Efield}$

net influx

j_{diff} & j_{Efield}

point inward

Neither Nernst Potential is in equilibrium with the rest potential.

We can have another kind of equilibrium

$$\sum_p j_p = 0$$

The Goldman Equation was developed to consider this type of equilibrium. It is based on the Nernst Planck Equation, but under certain conditions.

Let's look at the total current $J = J_K + J_{Na} + J_{Cl}$

From Goldman eqn we can write the following

$$J = \frac{V_m F^2 P_K}{RT}\left(\frac{w - ye^{V_m F/RT}}{1 - e^{V_m F/RT}}\right)$$

where

$$w = \left[K\right]_e + \frac{P_{Na}}{P_K}\left[Na\right]_e + \frac{P_{Cl}}{P_K}\left[Cl\right]_i$$

$$y = \left[K\right]_i + \frac{P_{Na}}{P_K}\left[Na\right]_i + \frac{P_{Cl}}{P_K}\left[Cl\right]_e$$

At Equilibrium: net current J=0

$$J = \frac{V_m F^2 P_K}{RT}\left(\frac{w - ye^{V_m F/RT}}{1 - e^{V_m F/RT}}\right) = 0$$

or

$$w - ye^{V_m F/RT} = 0 \Rightarrow e^{V_m F/RT} = \frac{w}{y}$$

$$V_m = \frac{RT}{F}\ln\frac{w}{y}$$

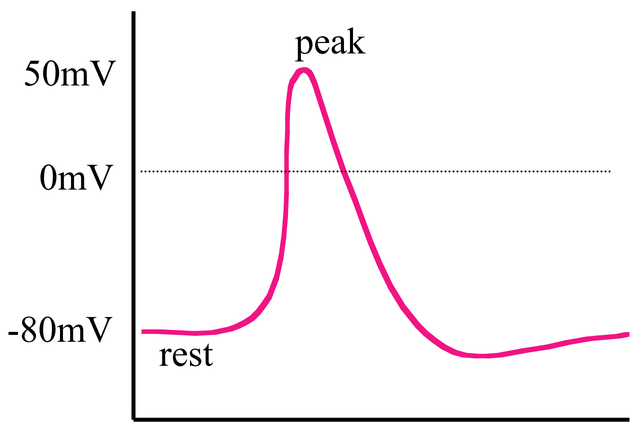
Goldman Eqn for rest (equil) potential

From Goldman Eqn- Equilbrium is a weighted average of all the Nernst Potentials. The weights are the permeabilities.

Under rest conditions, what permeability is greatest? Na? K?

$$P_K >> P_{Na}$$

How do we know this? $V_{m\_rest} \approx E_K$



What's true about permeabilities at peak?

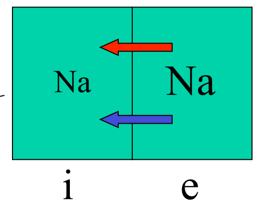
$P_{Na} >> P_K$ since $V_{m\_peak} \approx E_{Na}$

Recall that at rest (V_m=-80mV)

net influx

j_{diff} & j_{Efield}

point inward



E_{Na}=+50.2mV

Everything is primed for Na to enter the cell at rest!

Let's define $(V_m - E_{Na})$ as the driving force for Na

At rest, the driving force is negative signifying an inward current

To get the current density, $J_{Na,}$ we need multiply driving force by? g_{Na} Conductance per unit area

Units?

g_{Na} has units S/cm^2 ,is positive, and varies during action potential

$$J_{Na} = g_{Na}(V_m - E_{Na})$$

Improved model of excitable membrane