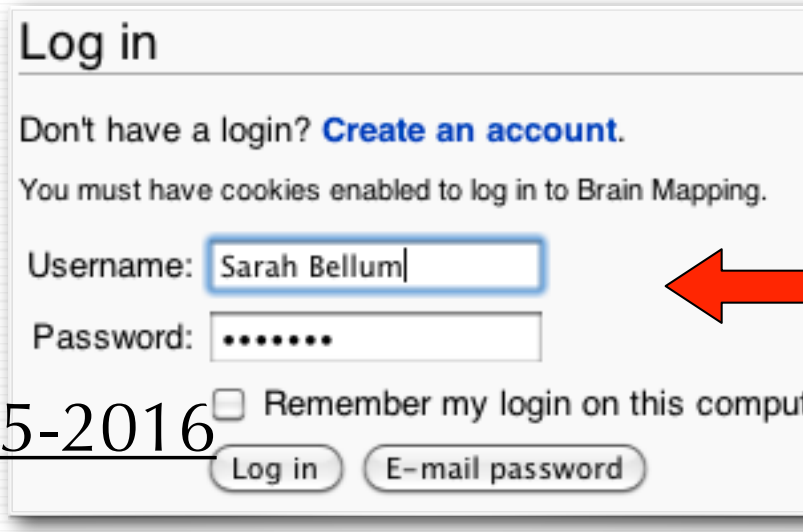
Organizational

- **Instructor contact**
  - mscohen@g.ucla.edu, 310-980-7453. Suite 17-369 NPI
  - Please include **NITP** in the subject line of emails
- **Sections and TAs**
  - We do NOT have a TA this year :-(
- **Wiki Web site**:
  - http://ccn.ucla.edu/wiki/index.php/Principles_of_Neuroimaging_-_2015-2016
- *Username:* NITP *Password:* 2007



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Organizational

- Problem Sets Due one week after assignment (usually)
  - Send via email to Mark (mscohen@g.ucla.edu)
- Journal Club
  - Contact:
    - Katherine Lawrence (katherine.E.Lawrence@ucla.edu) or
    - Janelle Liu (janelle.j.liu@ucla.edu)

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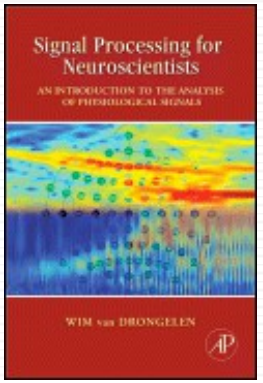
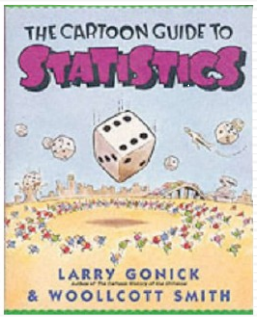
Requirements

Academic

Matlab 2014A* ..... Mac/Win (9163919)... 99





- MATLAB
- Signal Processing for Neuroscientists
- Cartoon Guide to Statistics (optional)
- Class List

Class List sign up [edit]

As soon as possible, please add yourself to the list of students in the class. Class List

- Pre-Requisites
  - Basic Statistics
  - Programming
  - Integral Calculus
  - Functional Neuroanatomy (concurrent is OK)

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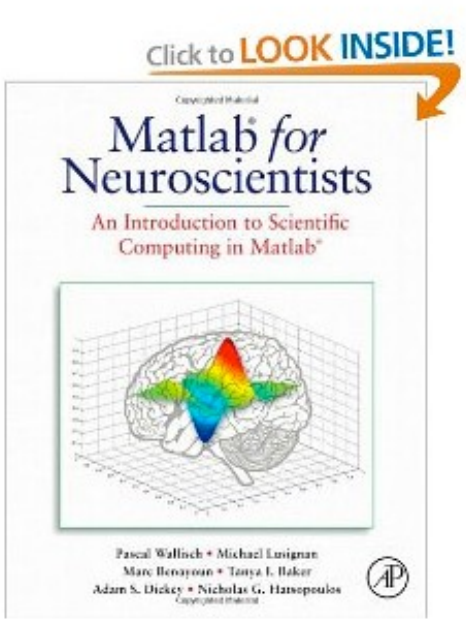
More reading



Matlab for Neuroscientists: An Introduction to Scientific Computing in Matlab [Hardcover]

Pascal Wallisch (Author), Michael Lusignan (Author), Marc Benayoun (Author), Tanya I. Baker (Author), Adam Seth Dickey (Author), Nicho Hatsopoulos (Author)

★★★★☆ (10 customer reviews) | Like (16)

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Concepts (M284A)

- Neural Signal Sources
- Digital Signal Processing
- Statistics
- Noise
- Electricity and Electronics
- Modeling
- Filters
- Sparsity
- Optics and Optical Imaging

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Grading

- Determined by Problem Sets, Midterm, Final and Participation
  - Participation 10%
  - Problem Sets 25%
  - Midterm 30%
  - Final 35%

- M284 is a required course for some students continuation in several Ph.D. programs, grading will be rigorous.

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UCLA

NeuroImaging Training Program

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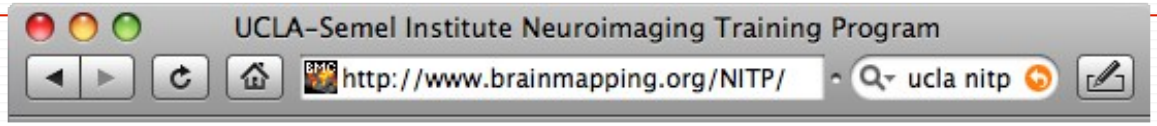
the UCLA Neuroimaging Training Program

- NIH-Sponsored Program Promoting Multidisciplinary Training

  Neuroscience, Statistics, Mathematics, Physics, Engineering Computer Sciences

- Six Graduate Fellowships (including non-US nationals)
- Annual Summer Advanced Fellowship
- *Only* Three Such Programs Funded

NeuroImaging Training Program



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How to Apply for Training

- NITP Will Prepare a Certificate for students completing the requirements. This does not depend on receipt of a fellowship.
- Requirements:
  - *M284A/B*
  - *Journal Club*
- Discuss with Home Department
- Contact Mark Cohen

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Neuronal Anatomy and Electrical Activity

Mark S. Cohen
UCLA Psychiatry, Neurology, Radiology, Psychology,
Biomedical Engineering, Biomedical Physics

Suite 17-369 NPI

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Topics

- anatomy of single neurons
- resting and action potentials
- transmission of signals
- chemical and electrical synapses
- information coding
- BOLD and unit activity
- EEG & SITE
- MR-visible effects

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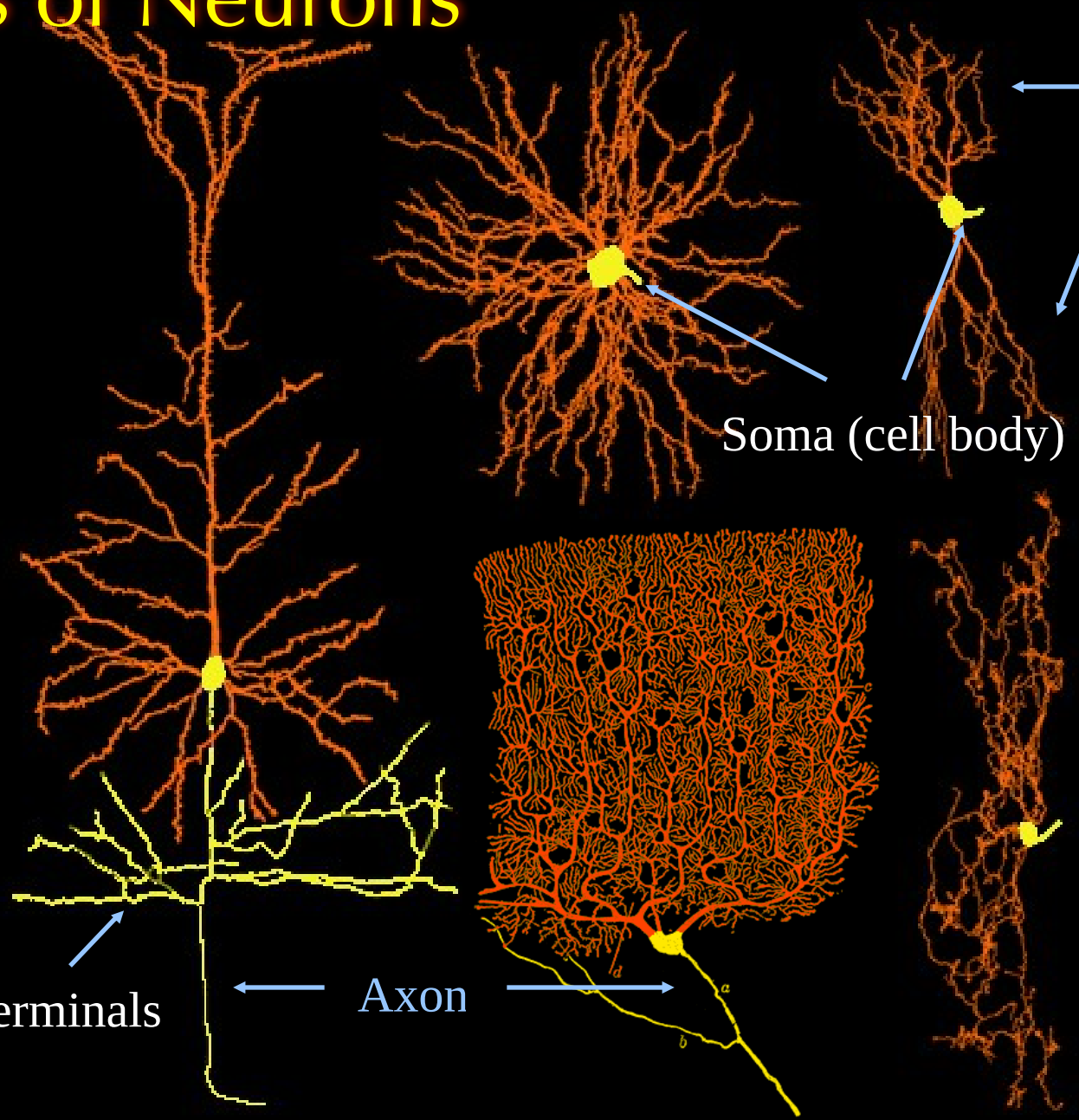
Types of Neurons



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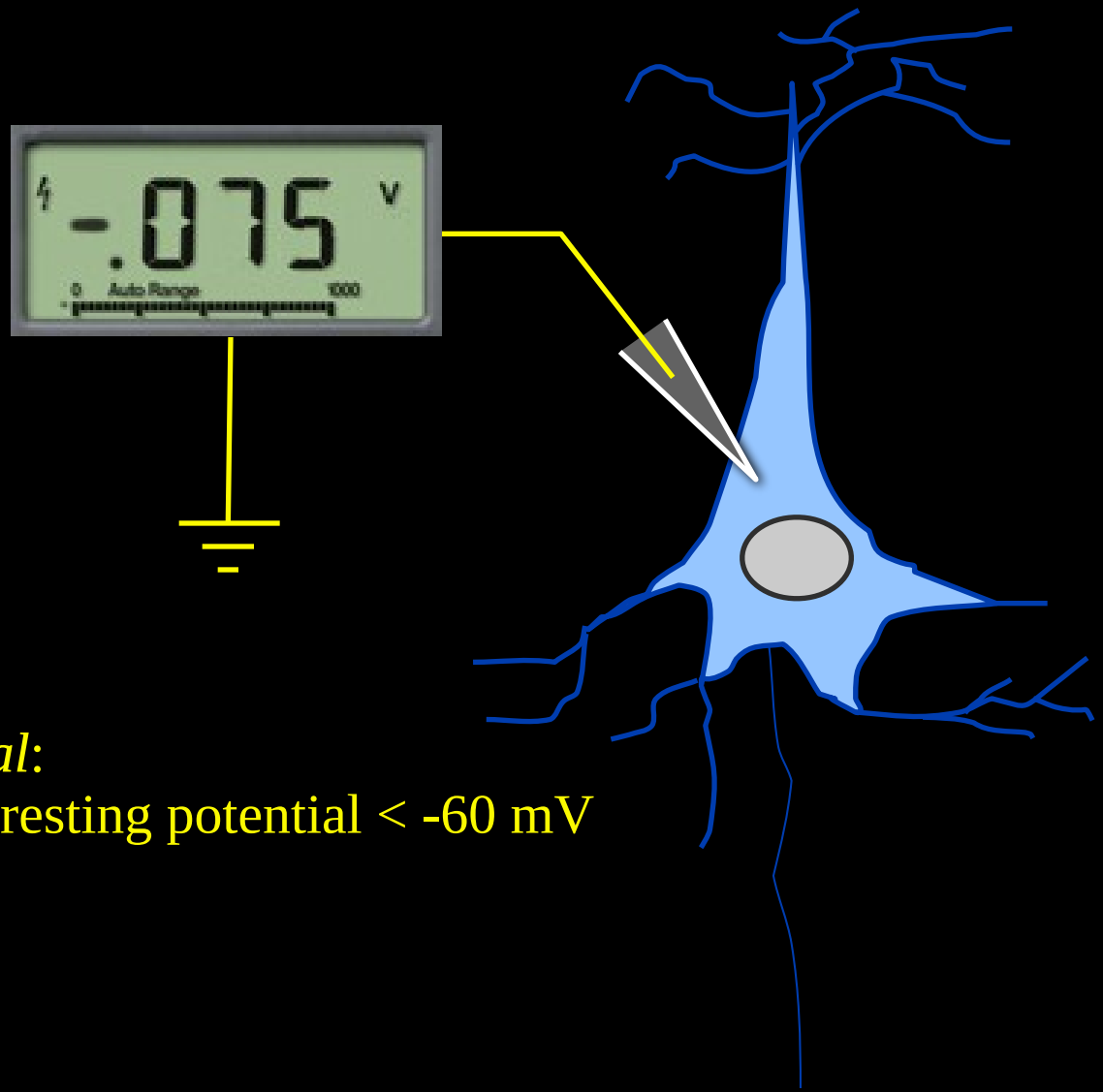
Resting Potential



Typical:
-90 < resting potential < -60 mV

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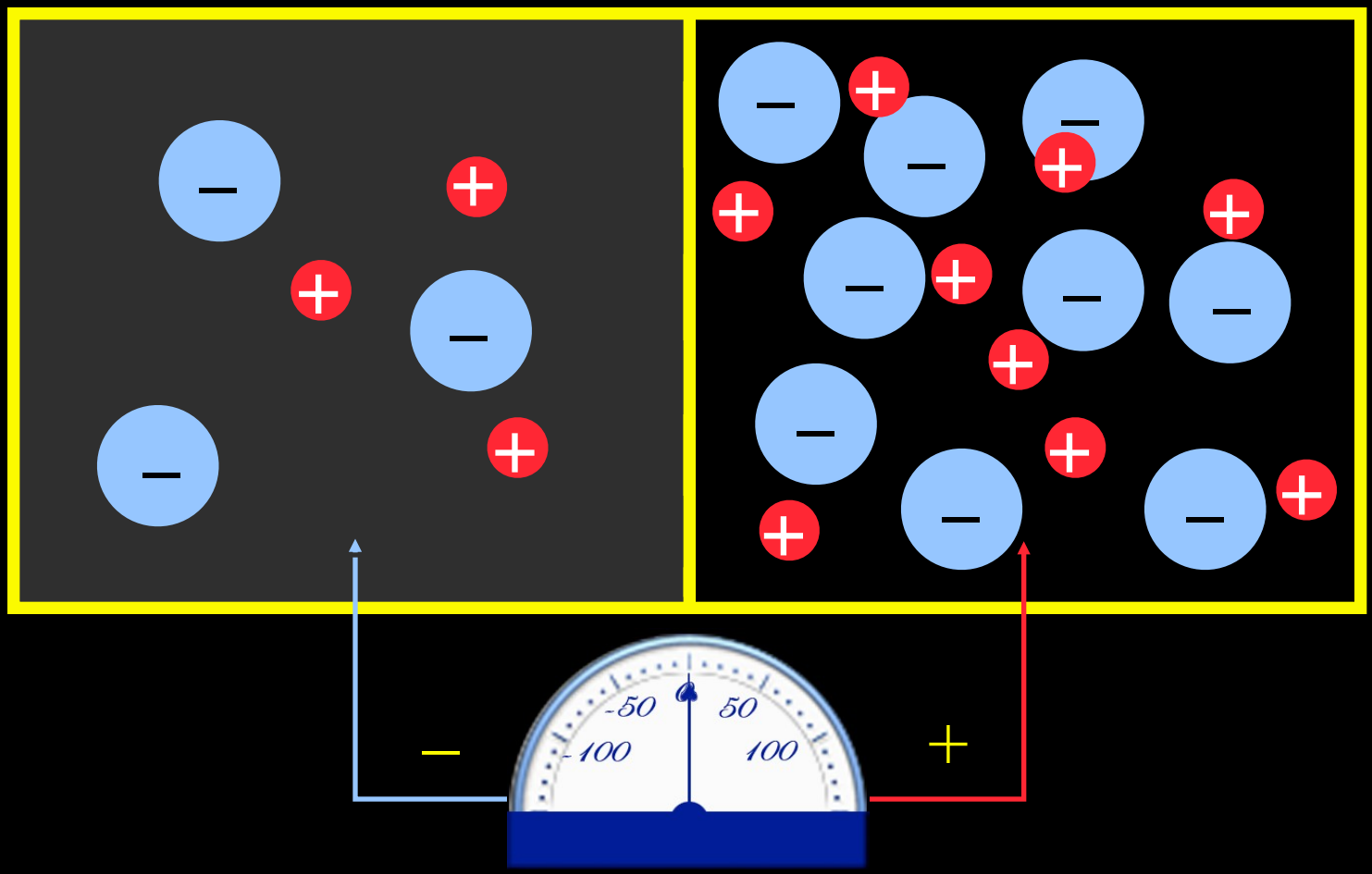
Development of the Membrane Potential



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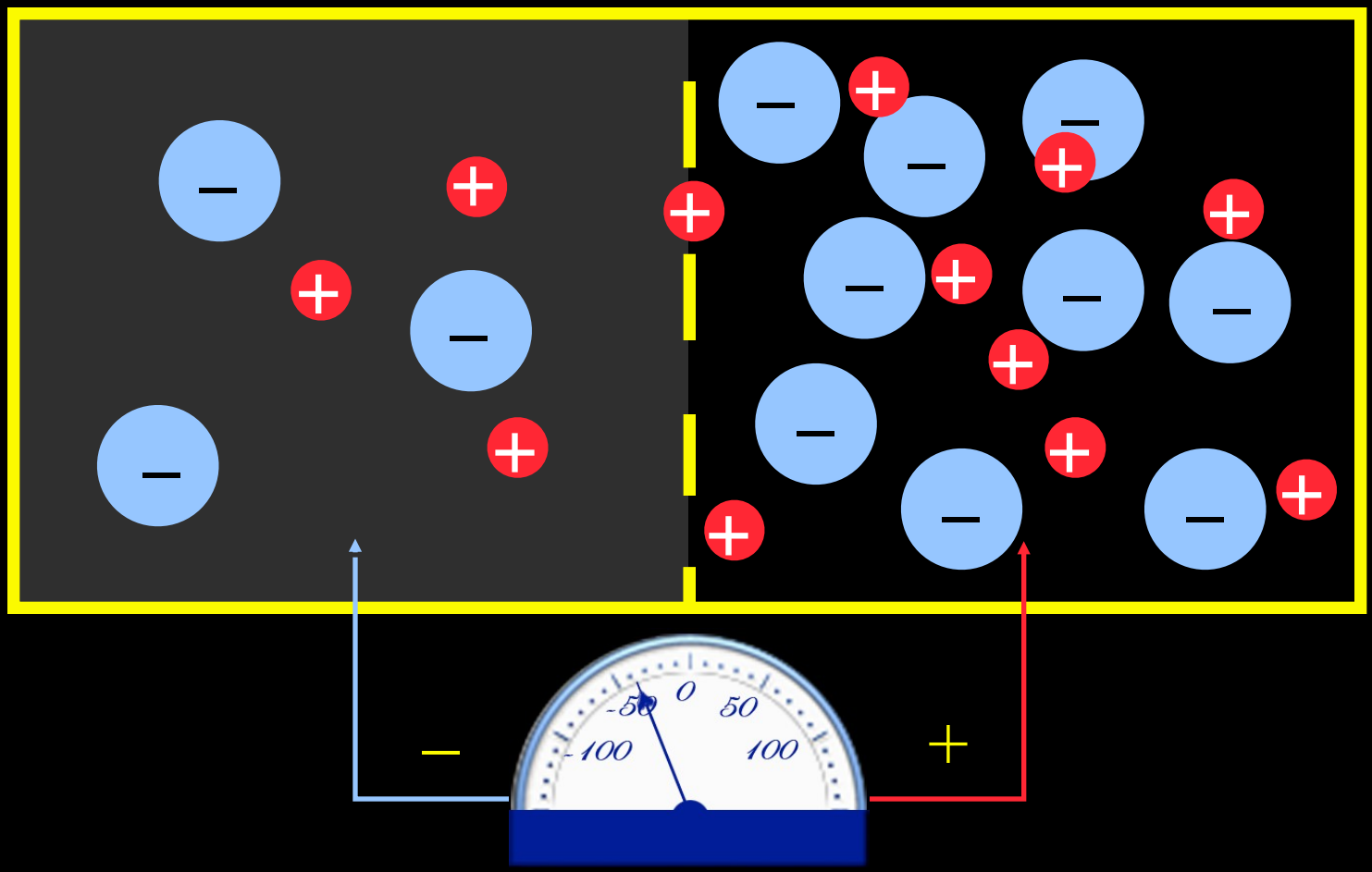
Development of the Membrane Potential



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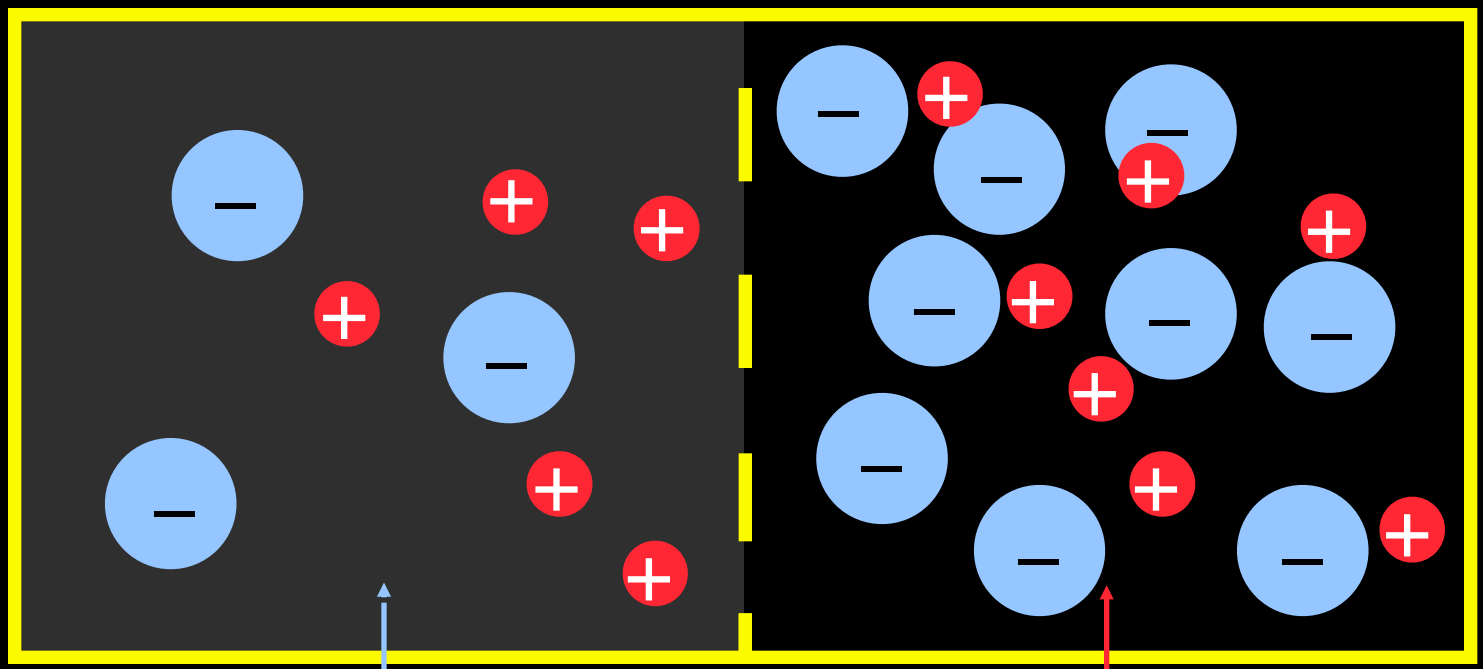
Development of the Membrane Potential



$$E = \frac{RT}{F} \ln \frac{[C_{inside}]}{[C_{outside}]}$$

Nernst Potential:

$$\approx 27\text{mV} \ln \frac{[C_{inside}]}{[C_{outside}]}$$

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Observed Ion Concentrations

Nernst Potential @37°C

[Na+] 460 mM ⋯⋯→ [Na+] 50 mM

+60 mV

$$E = \frac{RT}{F} \ln \left(\frac{p_A [A]_{out} \; p_B [B]_{out} \; p_y [x]_{in} \; p_y [y]_{in}}{p_A [A]_{in} \; p_B [B]_{in} \; p_x [x]_{out} \; p_y [y]_{out}} \right) V$$

A,B are cations

x,y are anions

–75 mV

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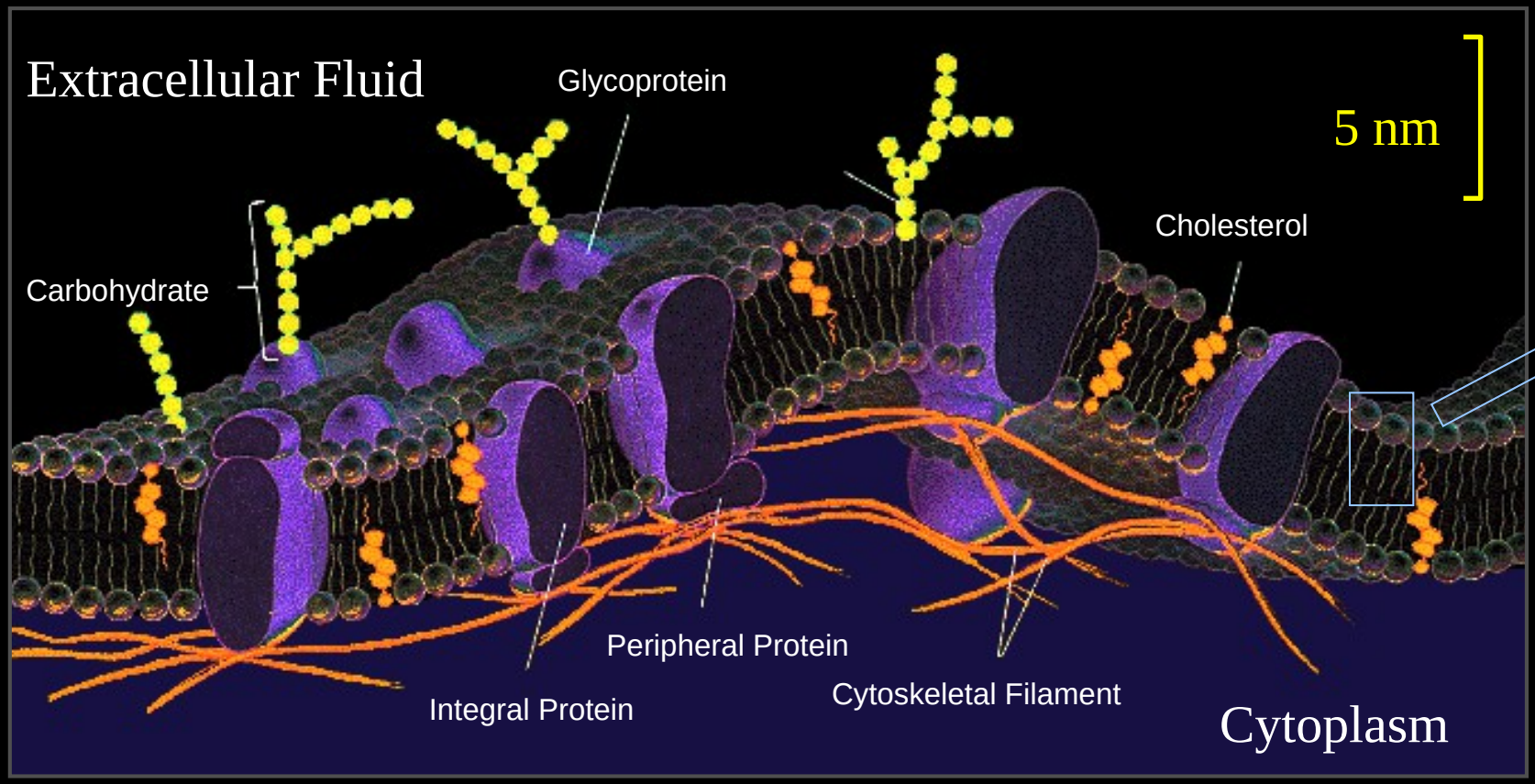
Structure of the Cell Membrane



Note: E-field is >10 MV/m!

Taken from *Human Biology* by Daniel Chiras

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The Neural Membrane

Observed Capacitance: 1 μF/cm^2

Since: $$C \approx \frac{1.1k}{4\pi d \times 10^{-12}}$$

If *k* (the dielectric constant) is about 6, then d ≈ 5 x 10^{-7}cm = 50 Å.

If P.D. ≈ 0.1 Volt, then the E field is
2 x 10^7 V/m !

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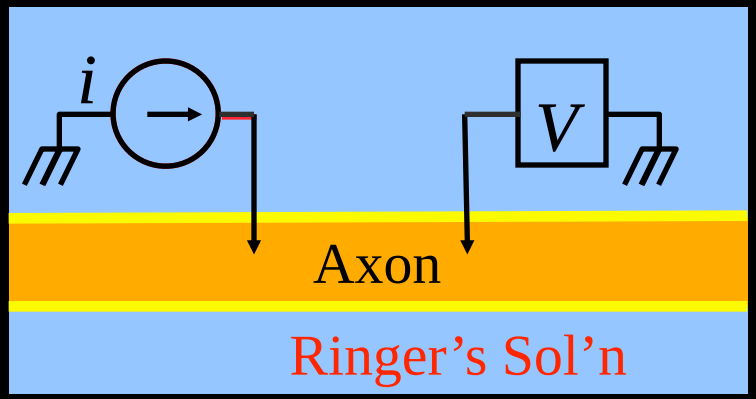
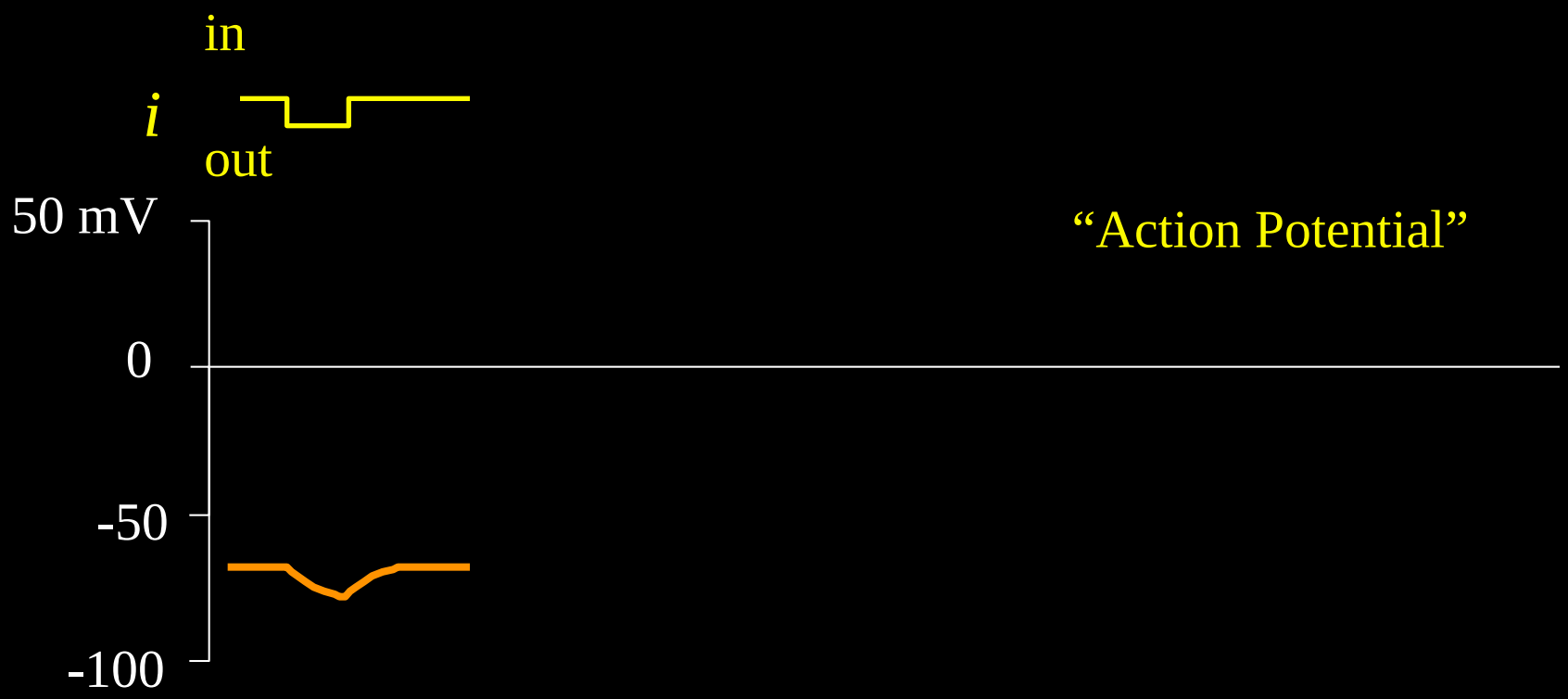
Electrical Behavior of Neurons





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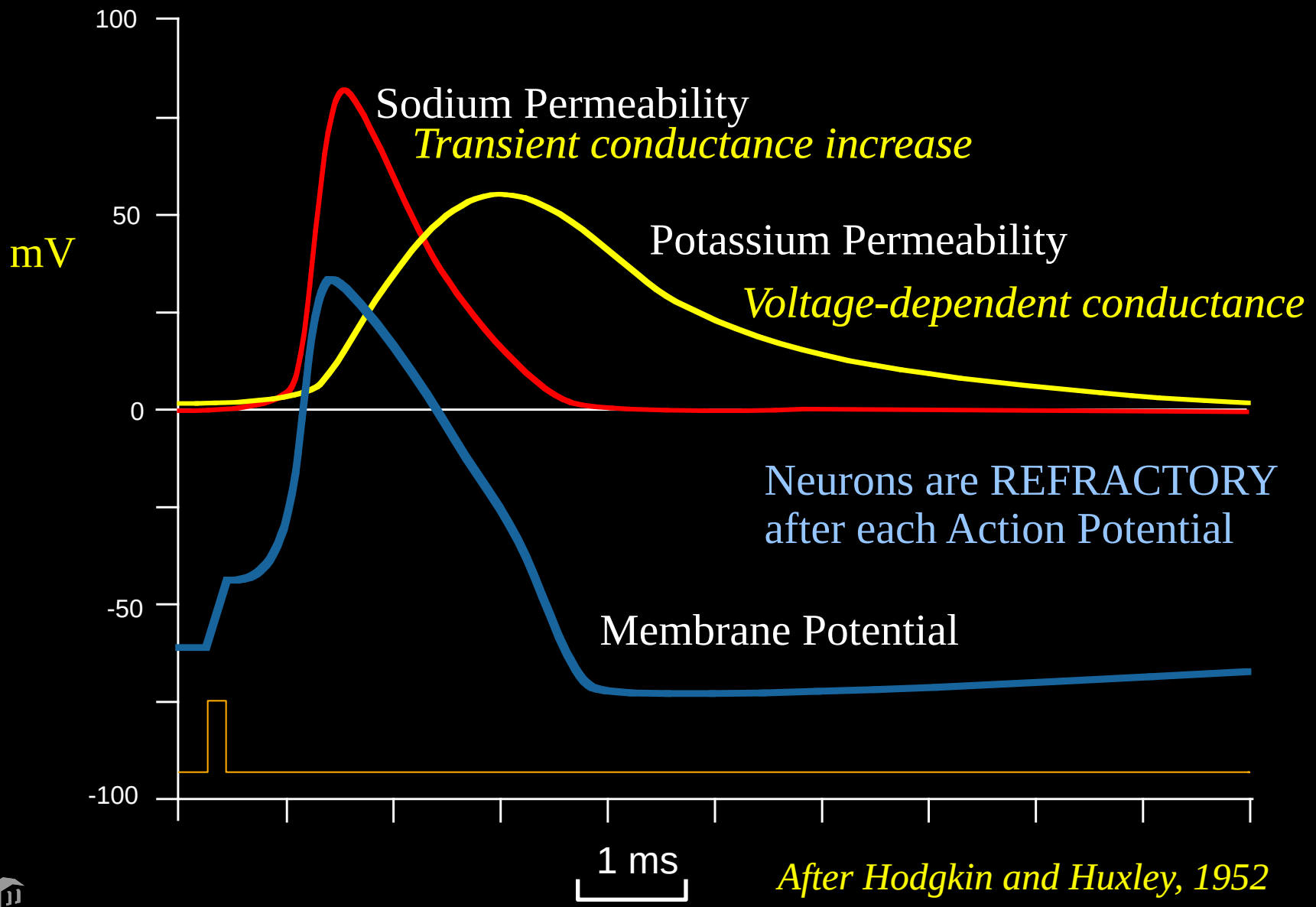
Current and Voltage



After Hodgkin and Huxley, 1952

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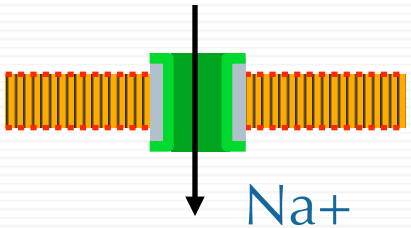
Sodium Leakage with Action Potentials

Cell Volume = 9×10^{-13} liters,
about half of which is liquid.

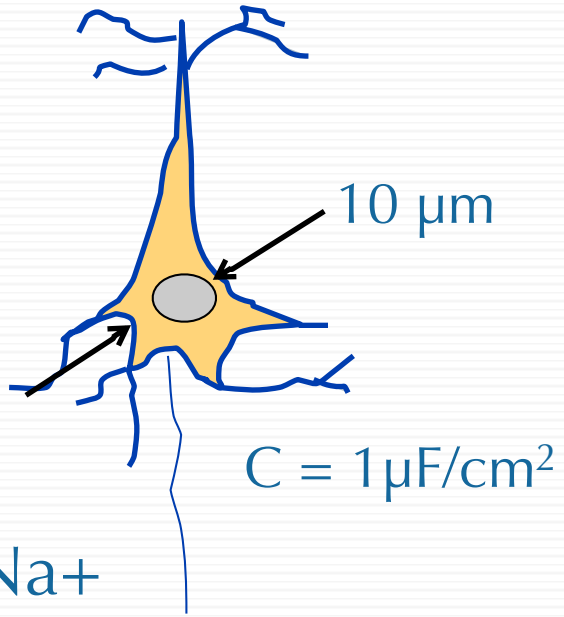
At 40 mM Sodium:
= 4.0×10^{-14} Moles Sodium/cell



With Each Action Potential:

$\Delta V = 0.13$ Volt

$Q = CV = 1.3 \times 10^{-7}$ Coulombs /cm^2
$= 1.4 \times 10^{-12}$ Moles/cm^2



Surface Area = 2.8×10^{-5} cm^2

Each AP passes 3.7×10^{-17} Moles of Na+

[Na+] is increased by 0.1% with each Action Potential!

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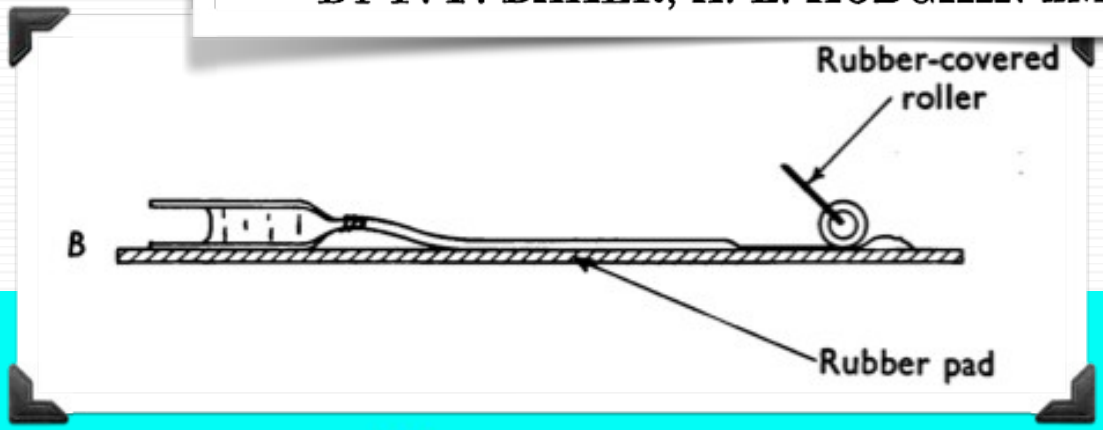
Passive Firing of Action Potentials

J. Physiol. (1962), **164**, *pp.* 330–354
With 5 plates and 12 text-figures
Printed in Great Britain

REPLACEMENT OF THE AXOPLASM OF GIANT NERVE FIBRES WITH ARTIFICIAL SOLUTIONS

By P. F. BAKER, A. L. HODGKIN and T. I. SHAW



Row	Axon	Diameter (μ)	Temperature (° C)	Condition	Internal solution	Period of stimulation (min)	Main stimulation frequency (shocks/sec)	Number of impulses
1	59	770	15	Fully inflated	K- isethionate	120	50	$3{\cdot}6 \times 10^5$
2	101	720	21	40 % inflated	K_2SO_4	80	50	$2{\cdot}3 \times 10^5$
3	114	880	18	60 % inflated	K_2SO_4	120	50	$4{\cdot}1 \times 10^5$
4	115	810	18	Intact	Axoplasm	107	50	$3{\cdot}9 \times 10^5$
5	118	750	19·5	Intact	Axoplasm	186	125	$1{\cdot}1 \times 10^6$

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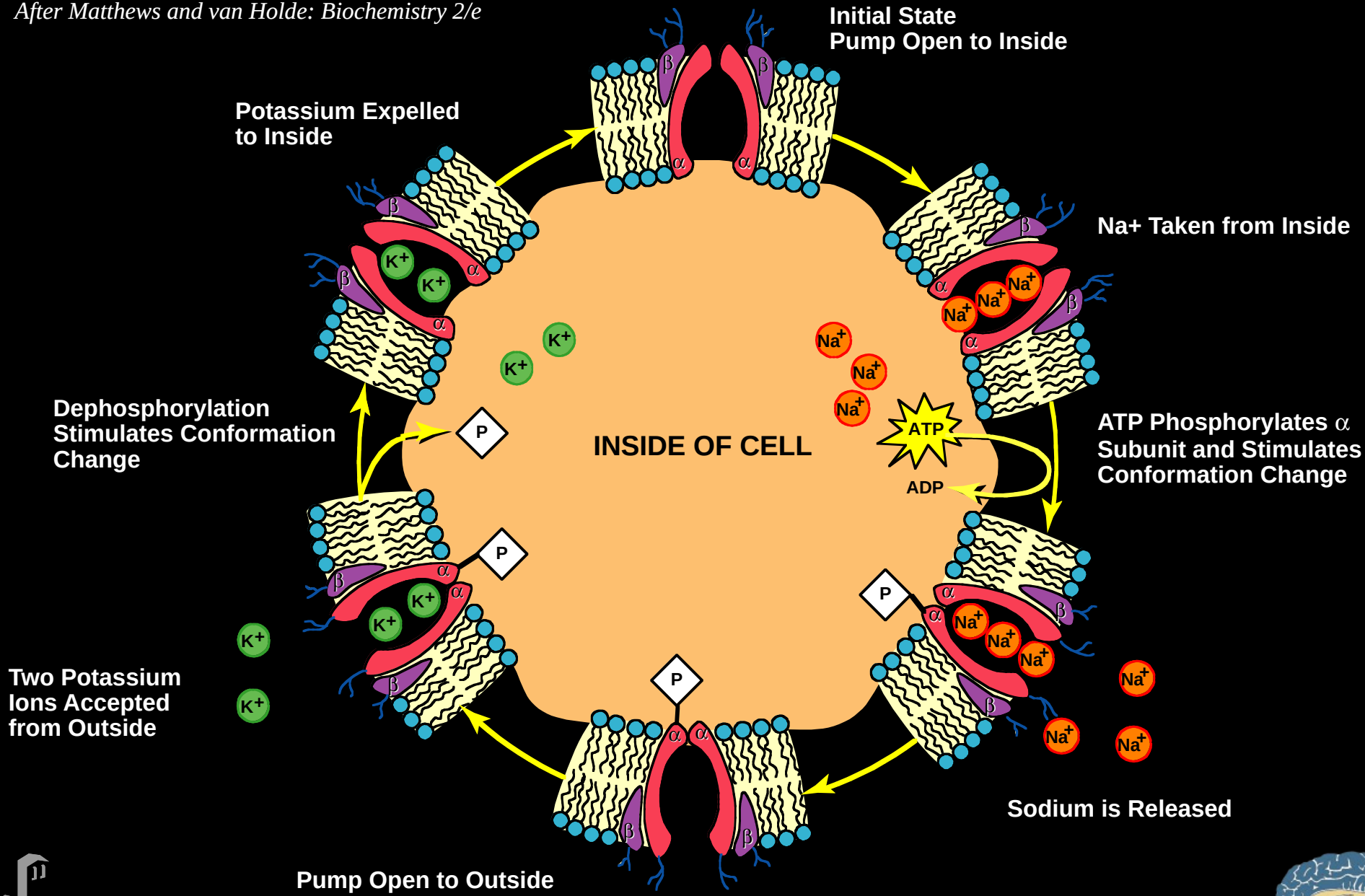
Sodium Potassium Pump

After Matthews and van Holde: Biochemistry 2/e



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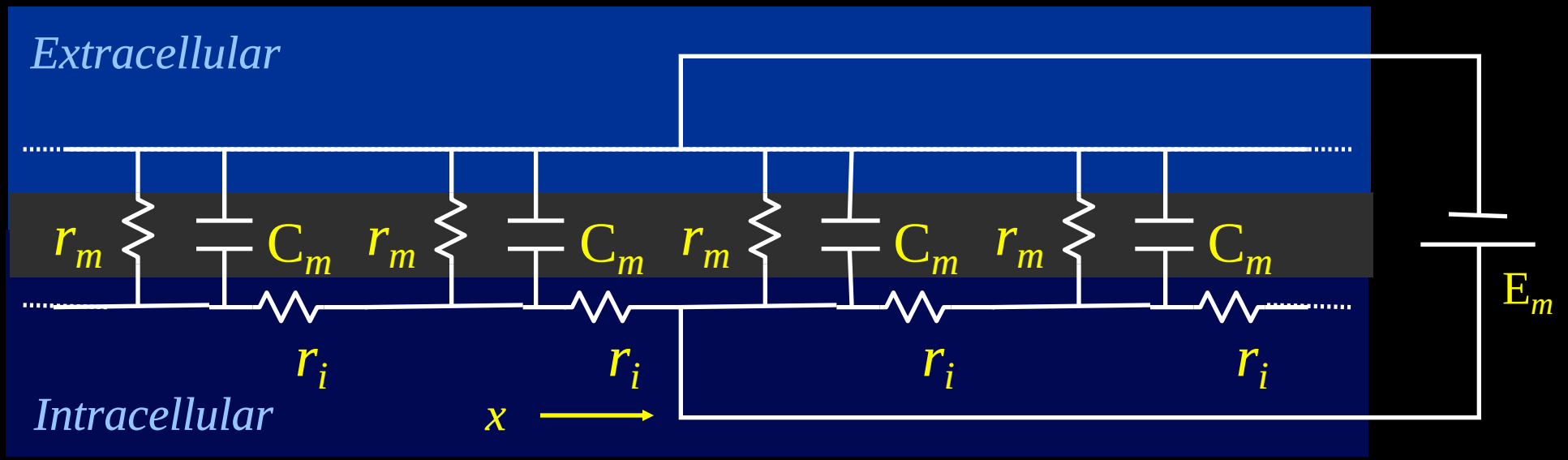
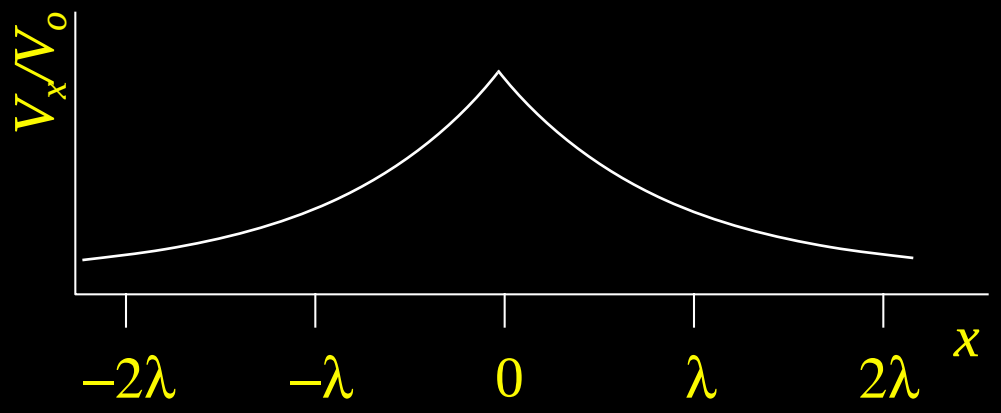
Cable Properties





$$\frac{V_x}{V_0} = e^{-x/\lambda}$$

$$\lambda = \sqrt{r_m / r_i}$$

For vertebrate neurons:
μm < λ < mm

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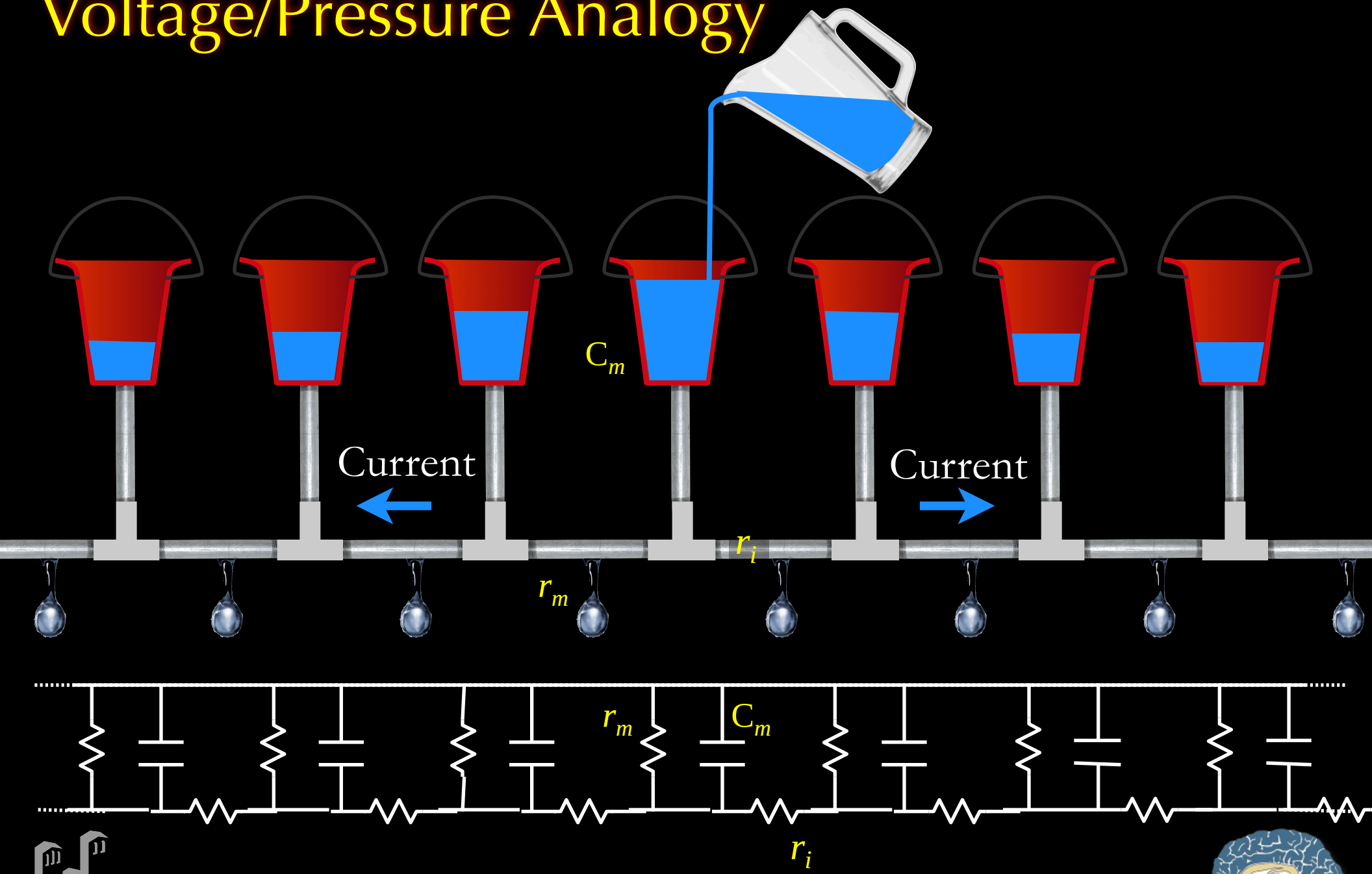
Voltage/Pressure Analogy



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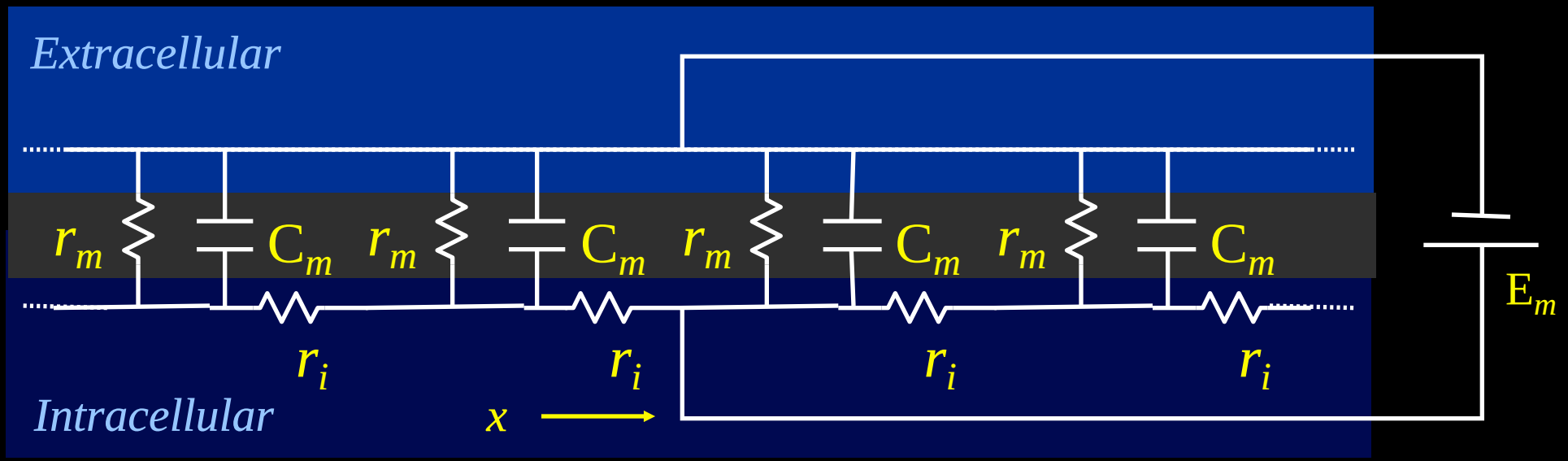
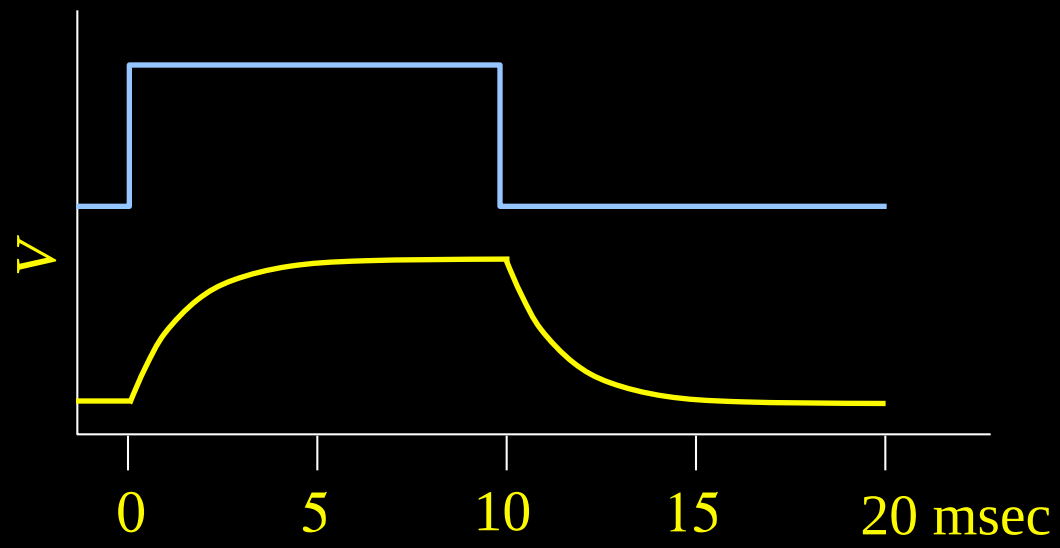
Cable Properties





For vertebrate neurons:
$0.5 \text{ msec} < \tau < 5 \text{ msec}$

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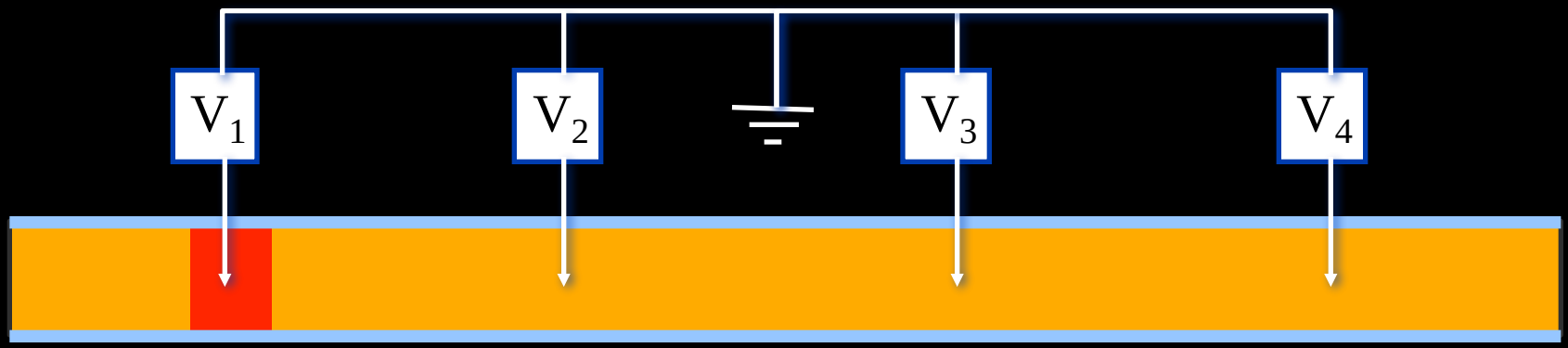
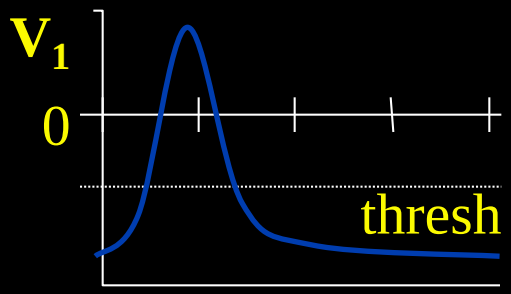
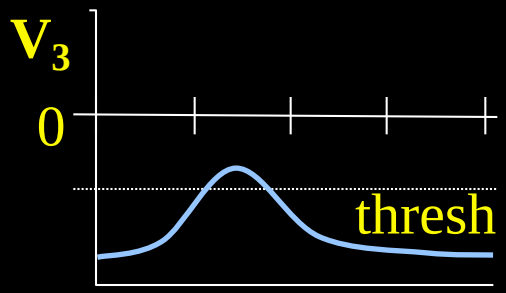
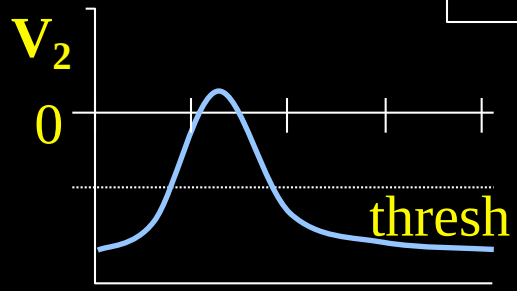
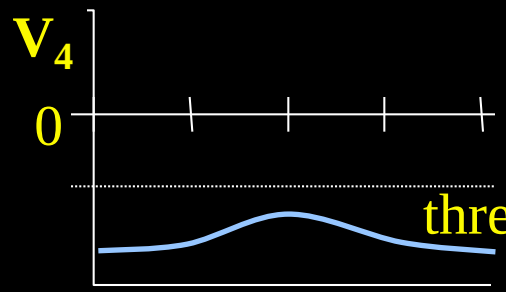
Propagation of the Action Potential











Resulting Velocity ~1-3m/sec

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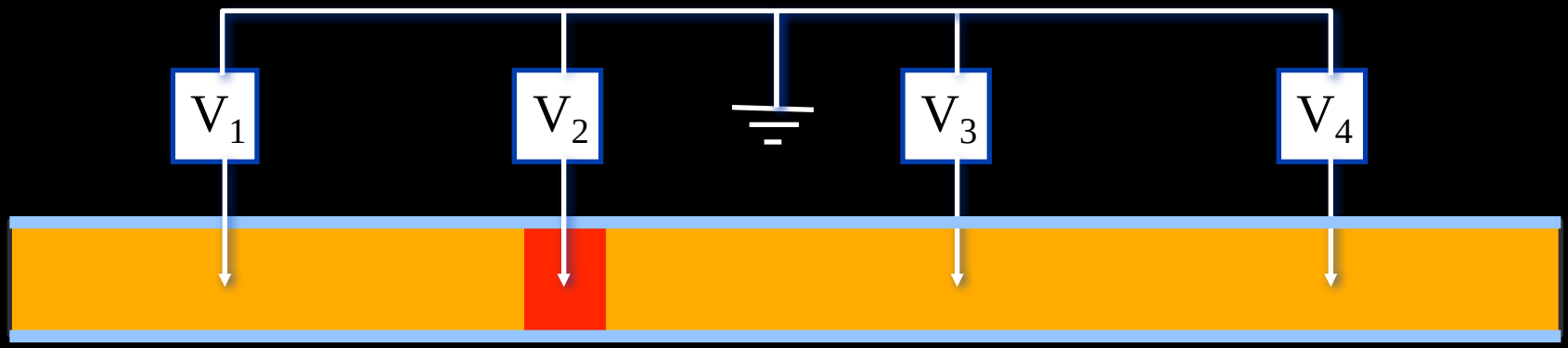
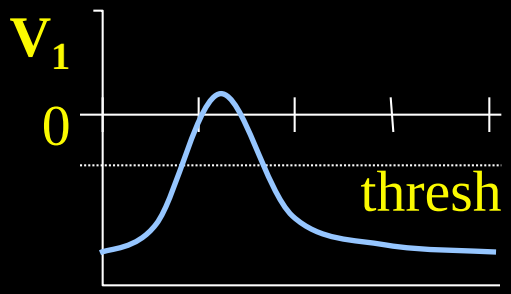
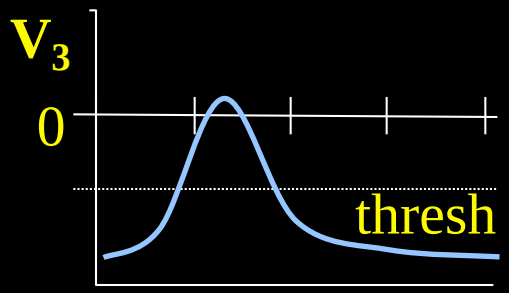
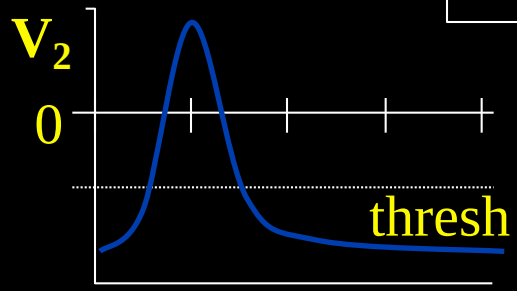
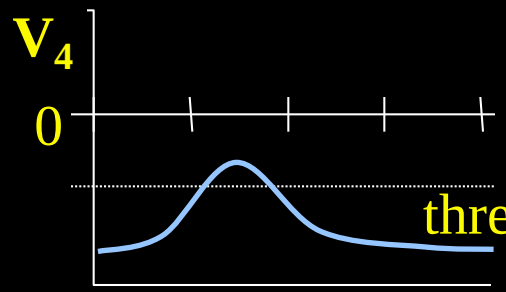
Propagation of the Action Potential











Resulting Velocity ~1-3m/sec

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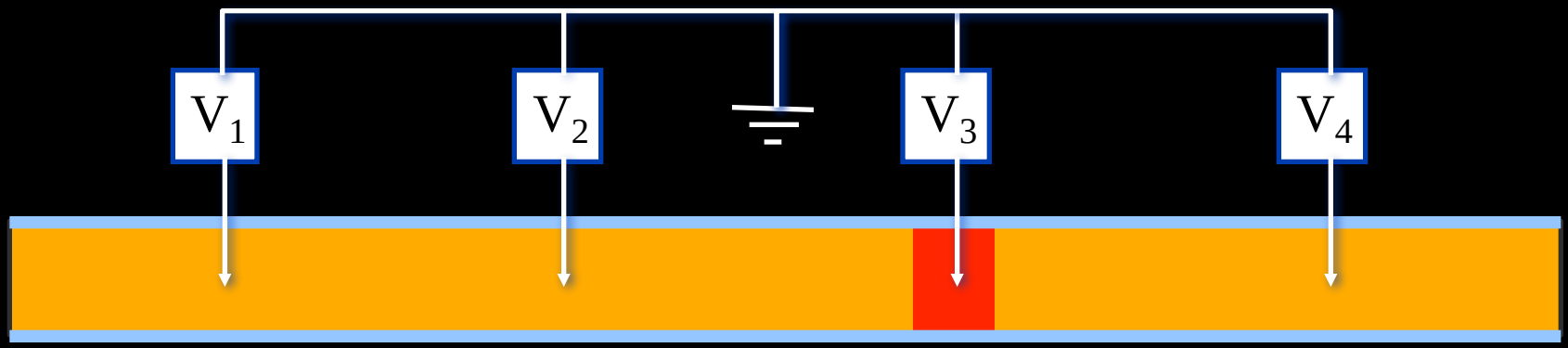
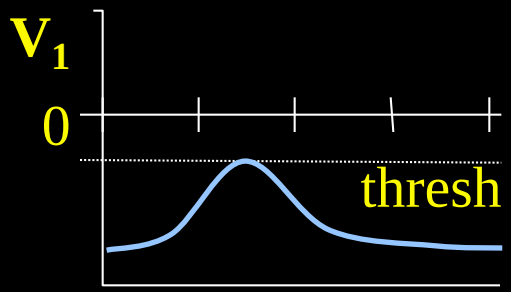
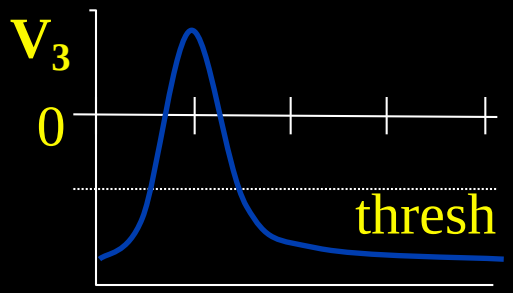
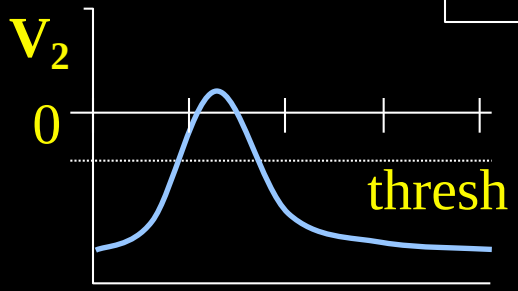
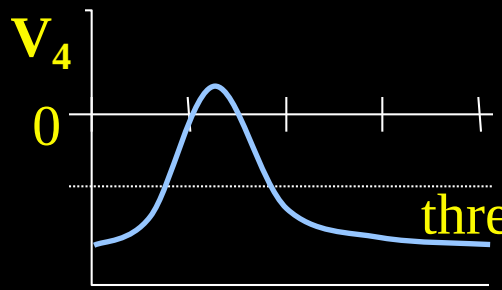
Propagation of the Action Potential











Resulting Velocity ~1-3m/sec

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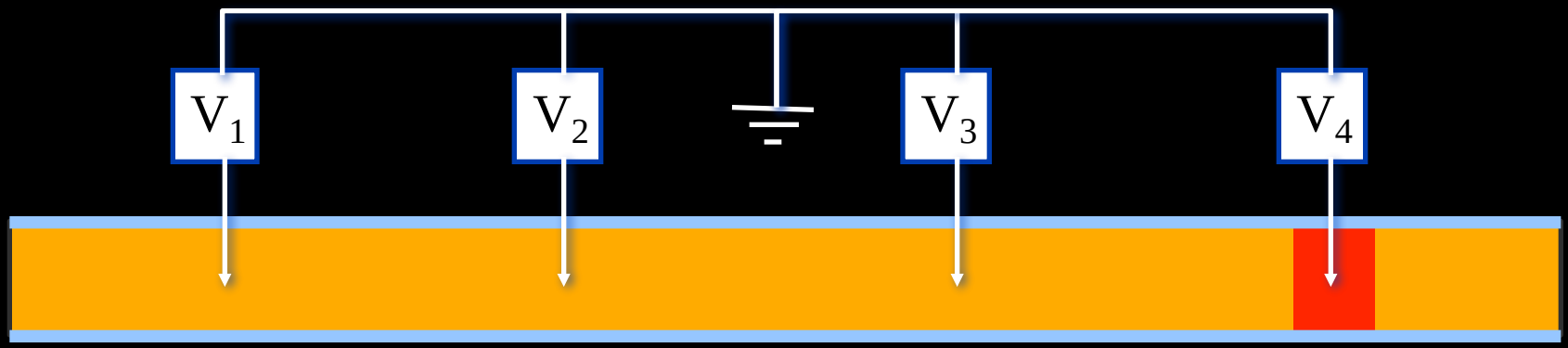
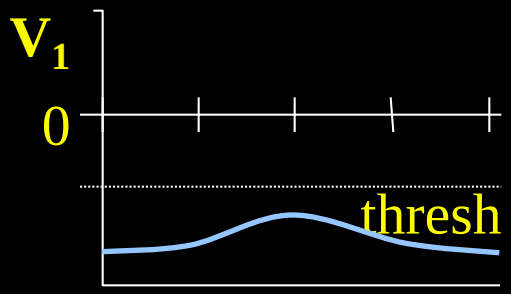
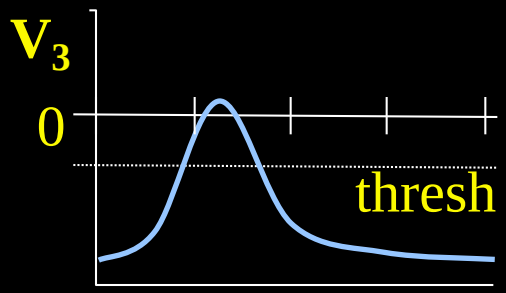
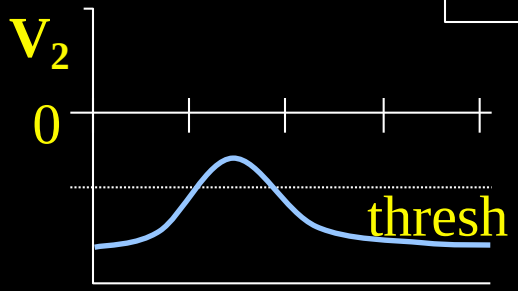
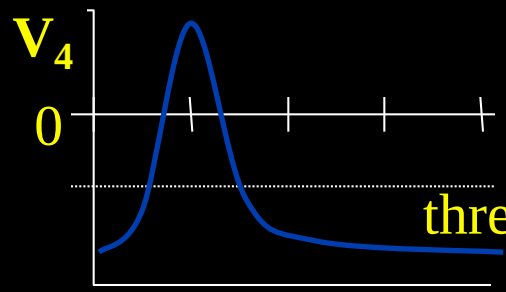
Propagation of the Action Potential











Resulting Velocity ~1-3m/sec

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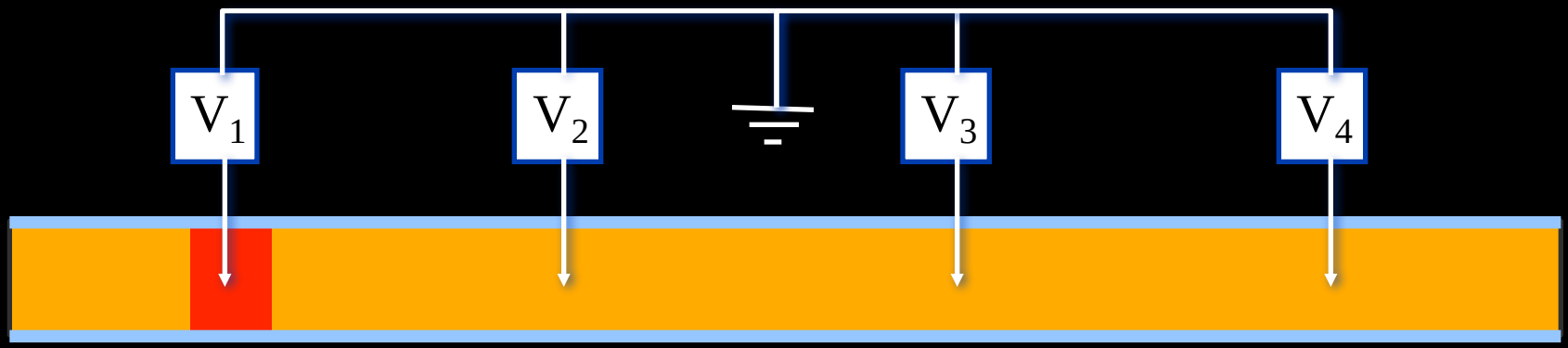
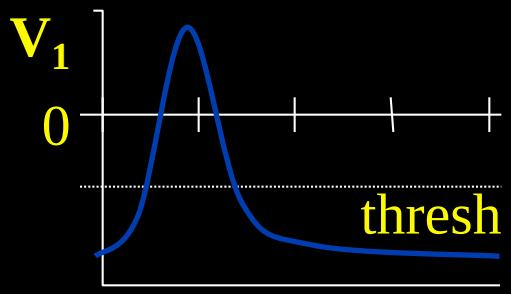
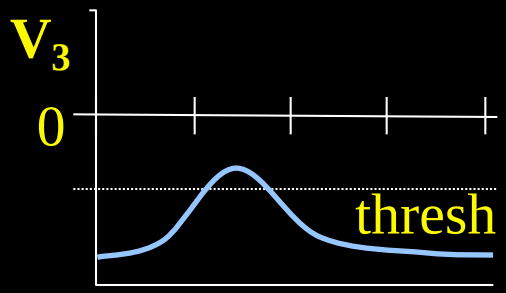
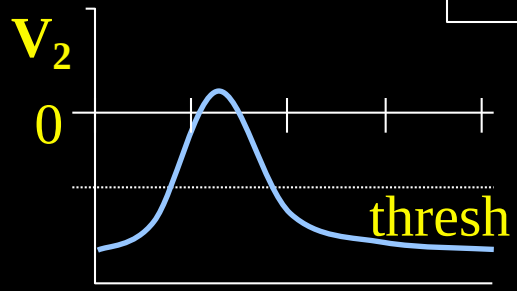
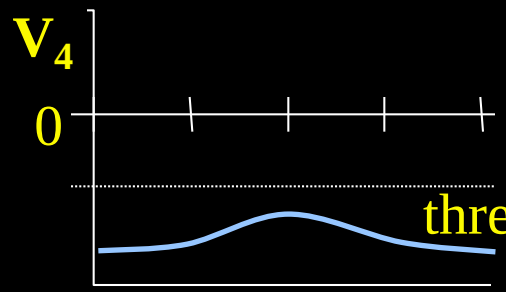
Propagation of the Action Potential











Resulting Velocity ~1-3m/sec

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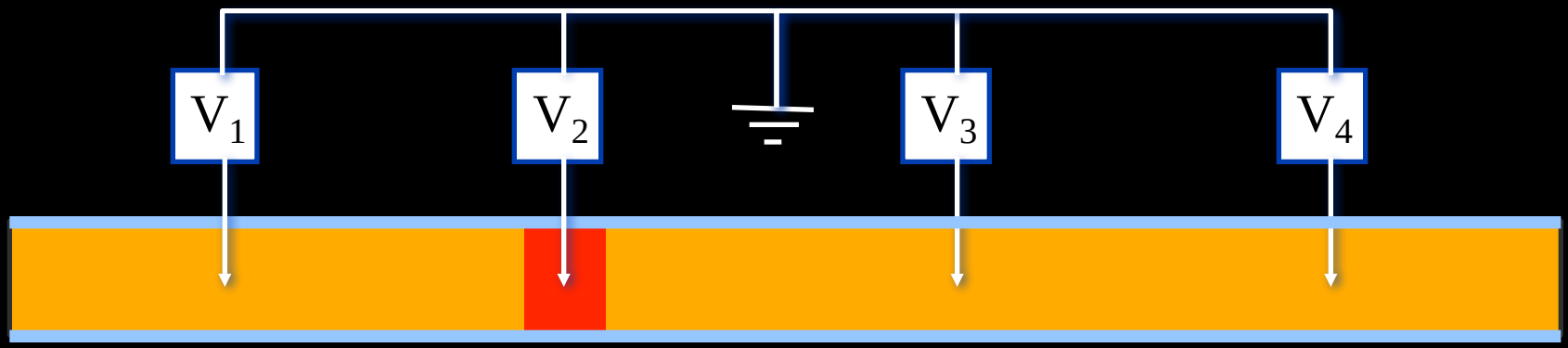
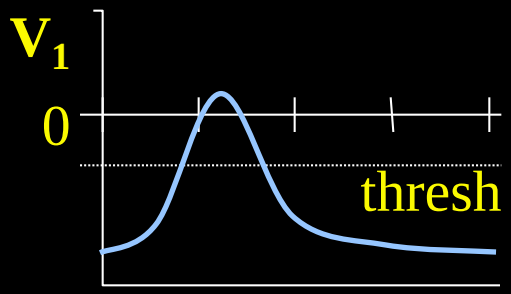
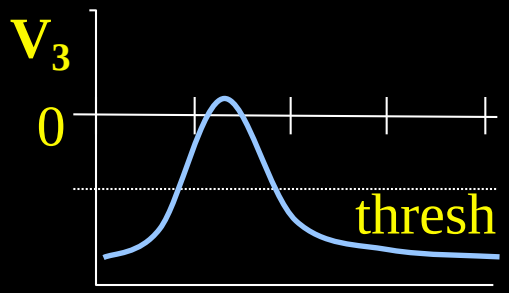
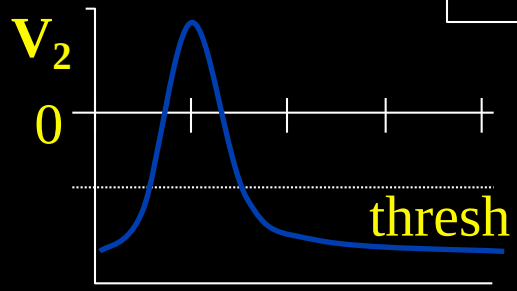
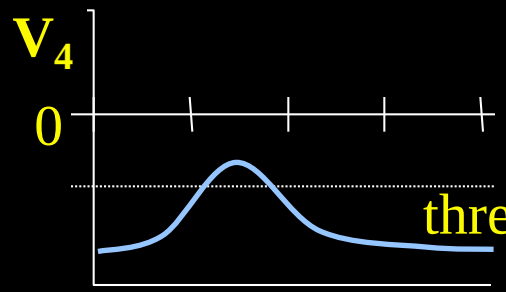
Propagation of the Action Potential











Resulting Velocity ~1-3m/sec

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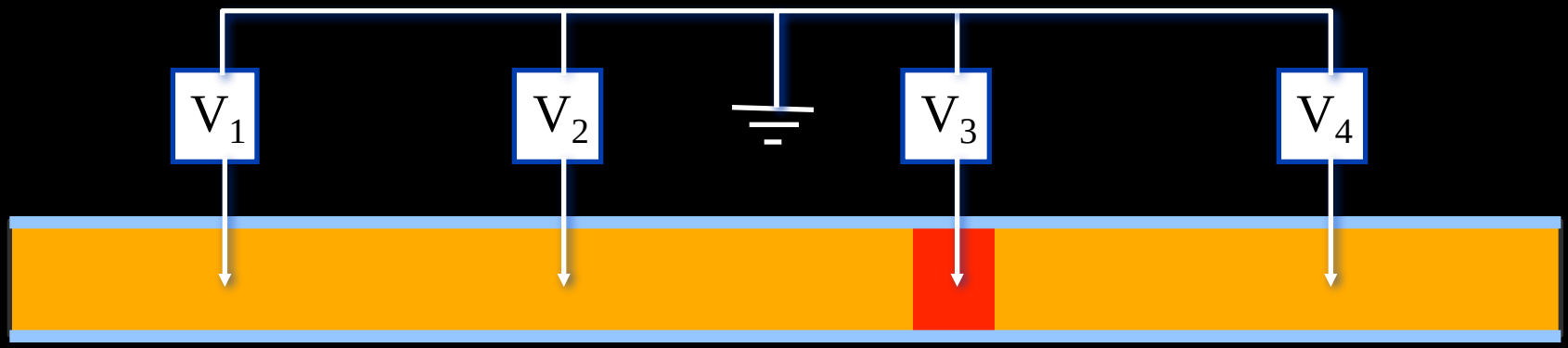
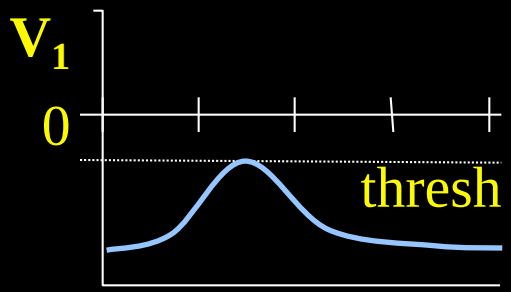
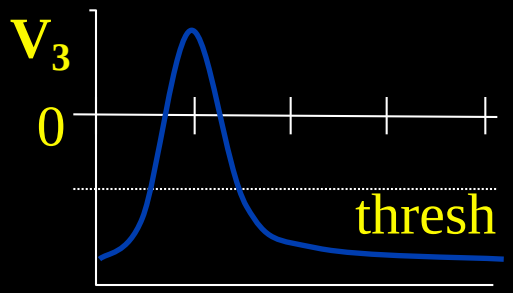
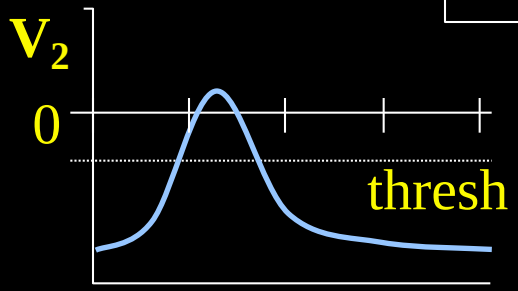
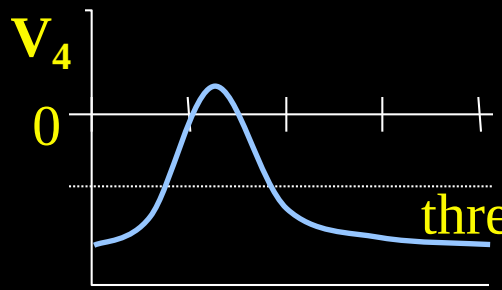
Propagation of the Action Potential











Resulting Velocity ~1-3m/sec

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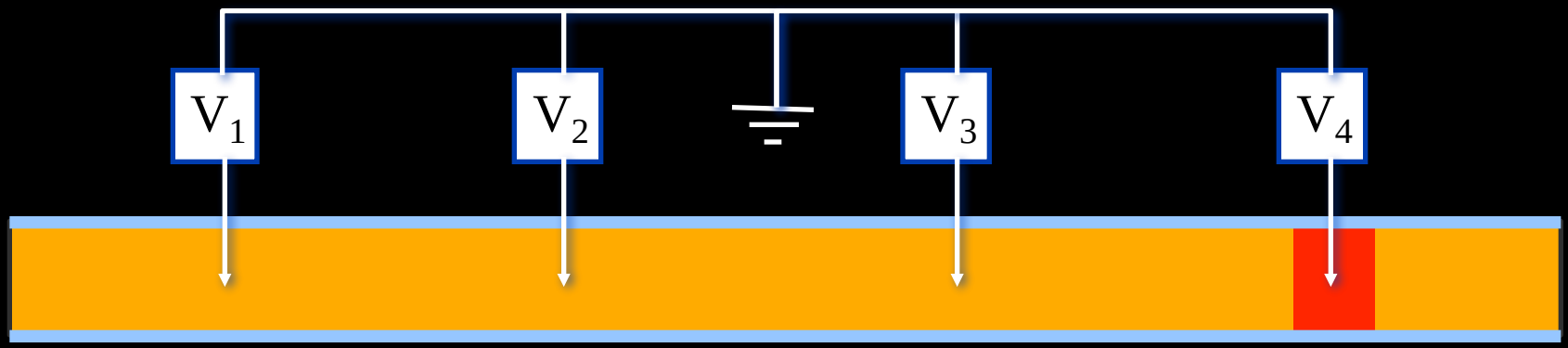
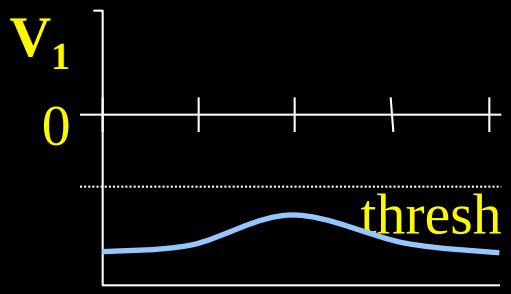
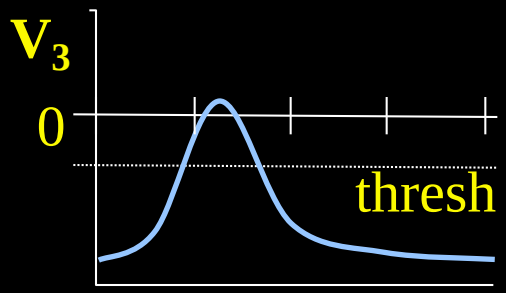
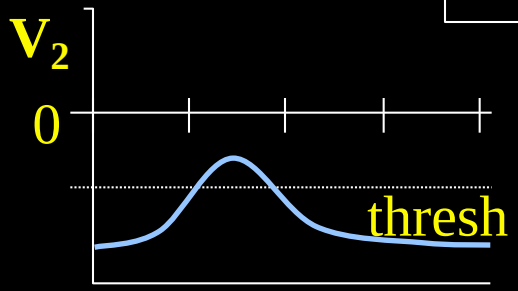
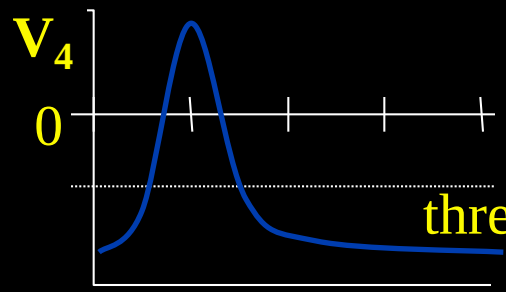
Propagation of the Action Potential











Resulting Velocity ~1-3m/sec

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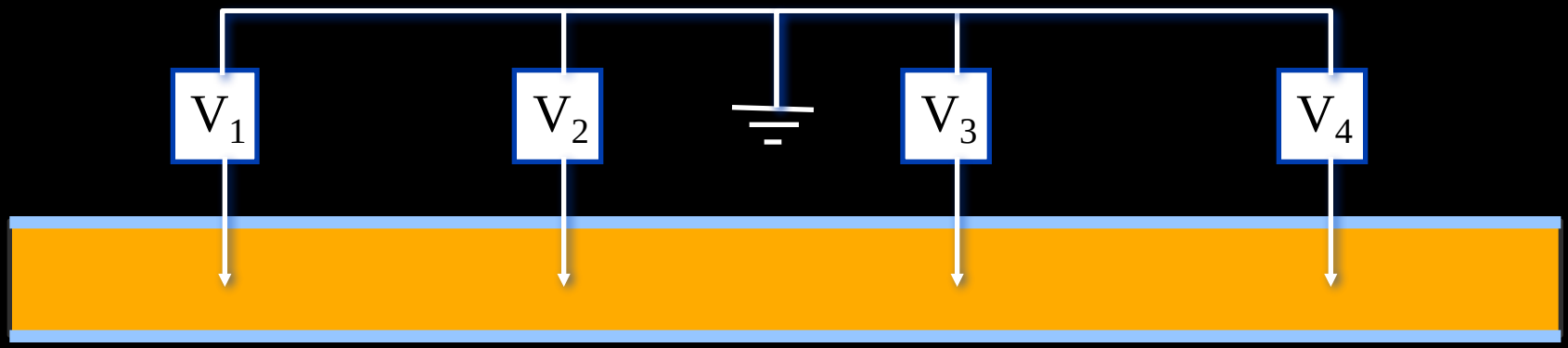
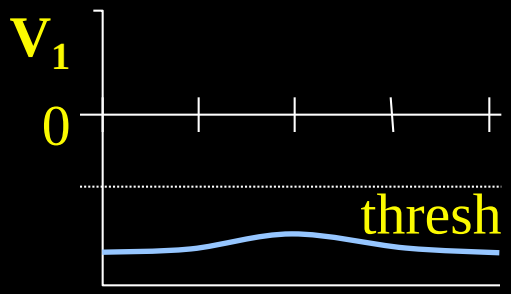
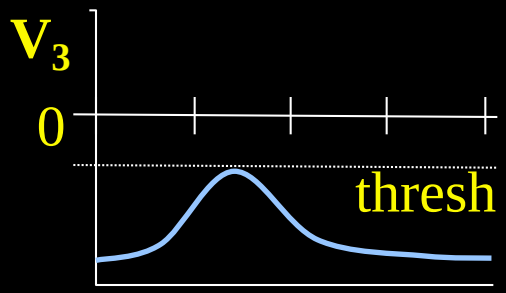
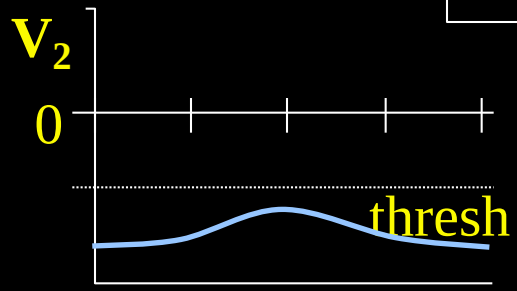
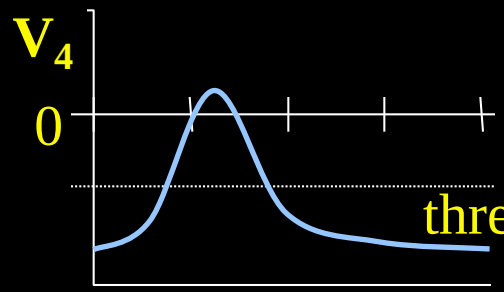
Propagation of the Action Potential











Resulting Velocity ~1-3m/sec

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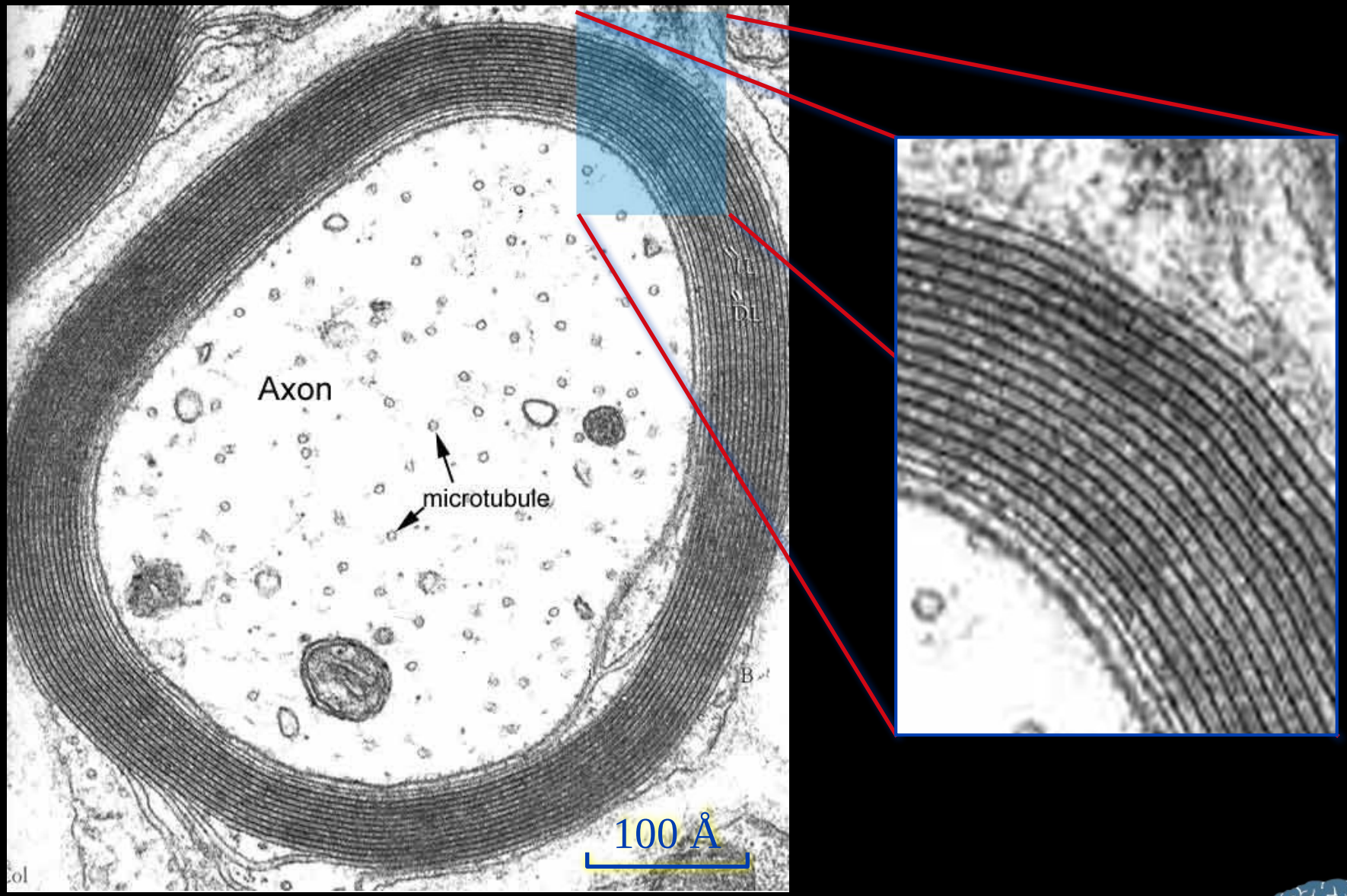
Myelin Sheath



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Nodes of Ranvier

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Saltatory Conduction

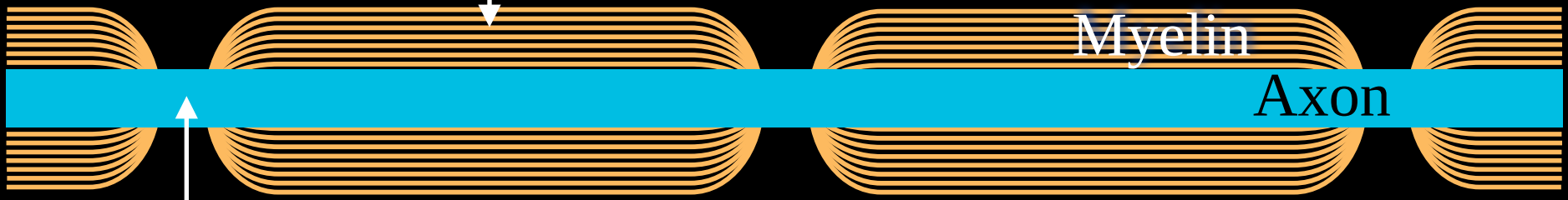
Internode:

High Membrane Resistance

Long Spatial Constant

Short Time Constant

Efficient Electrotonic Conduction



Node:

Low Membrane Resistance

High Membrane Current Flow

Fires Action Potential

Action Potential Regeneration

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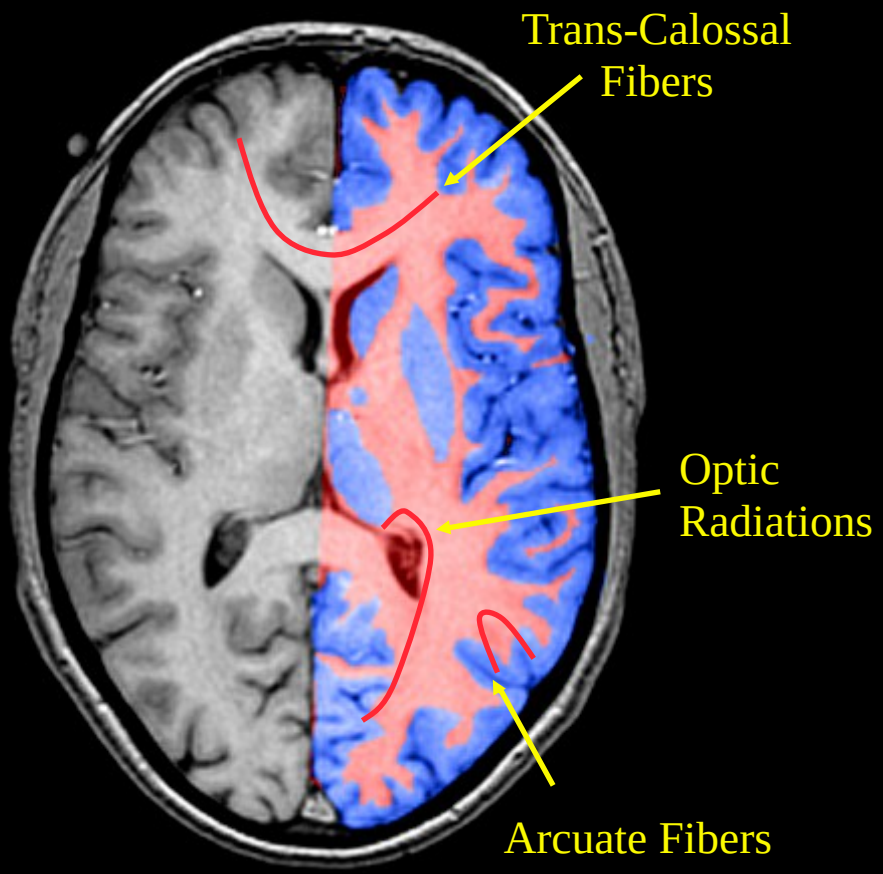
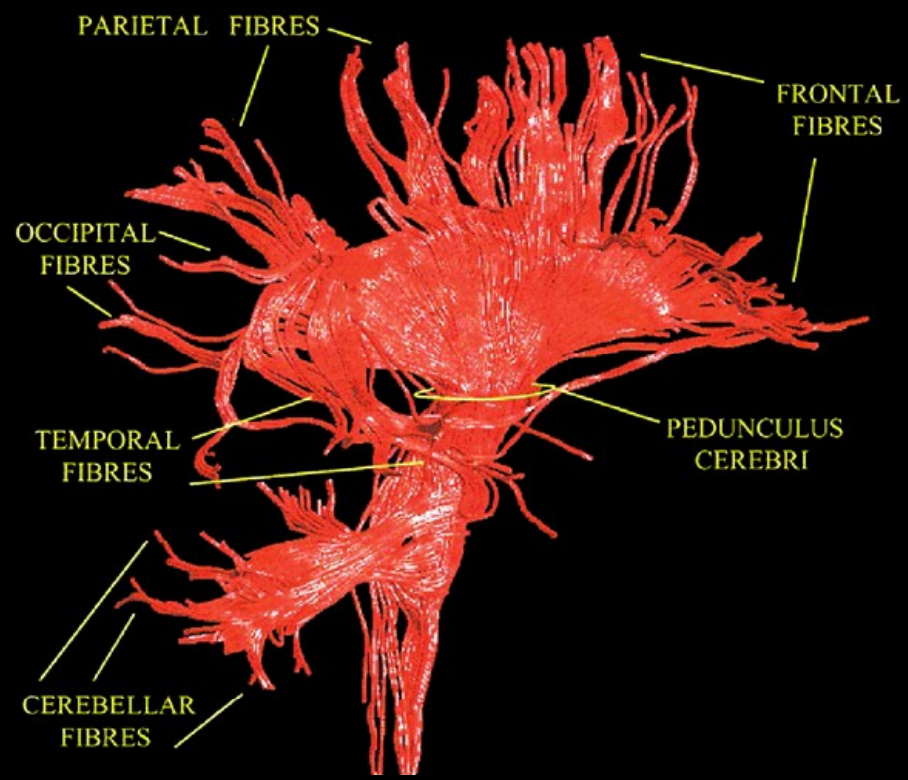
White and Gray Matter





After: Catani, et al., NeuroImage 17:77, 2002

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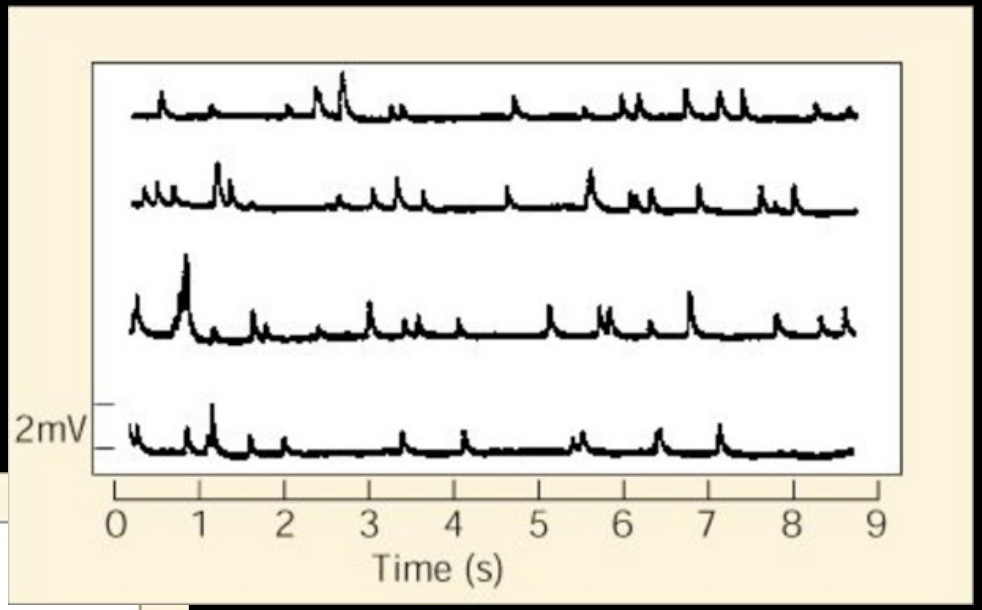
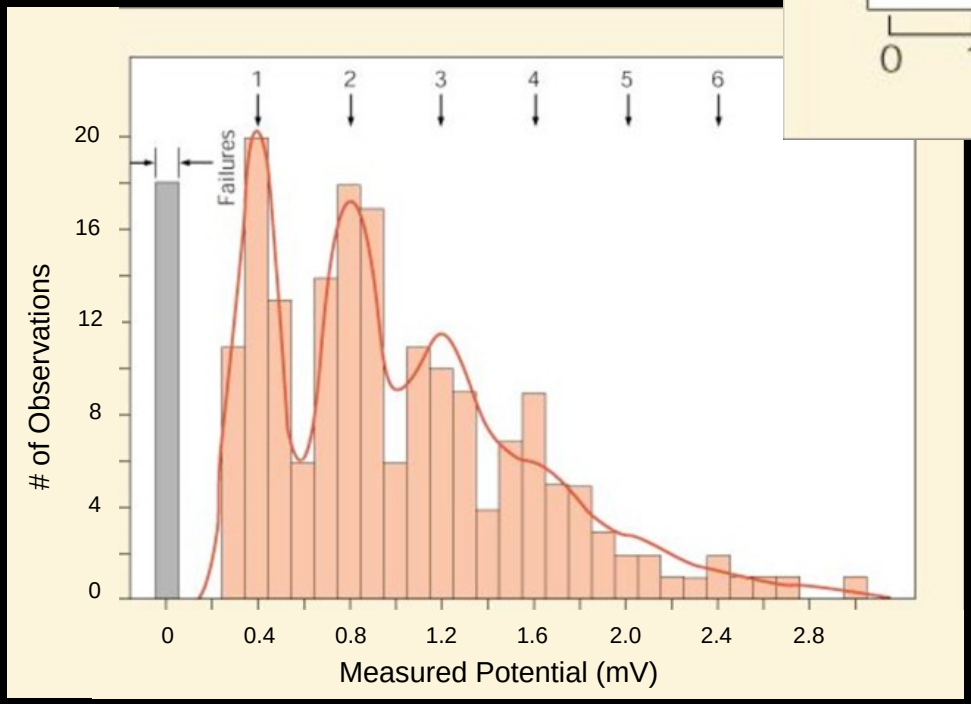
EPSP's: *E*xcitatory *P*ost-*S*ynaptic *Potentials*

Muscle end plate potentials
Recorded in low Ca^{2+} / high Mg^{2+}
Boyd & Martin, 1956





Amplitudes are *quantized* and display a Poisson distribution

$$f(k;\lambda) = \frac{\lambda^k e^{-\lambda}}{k!}$$

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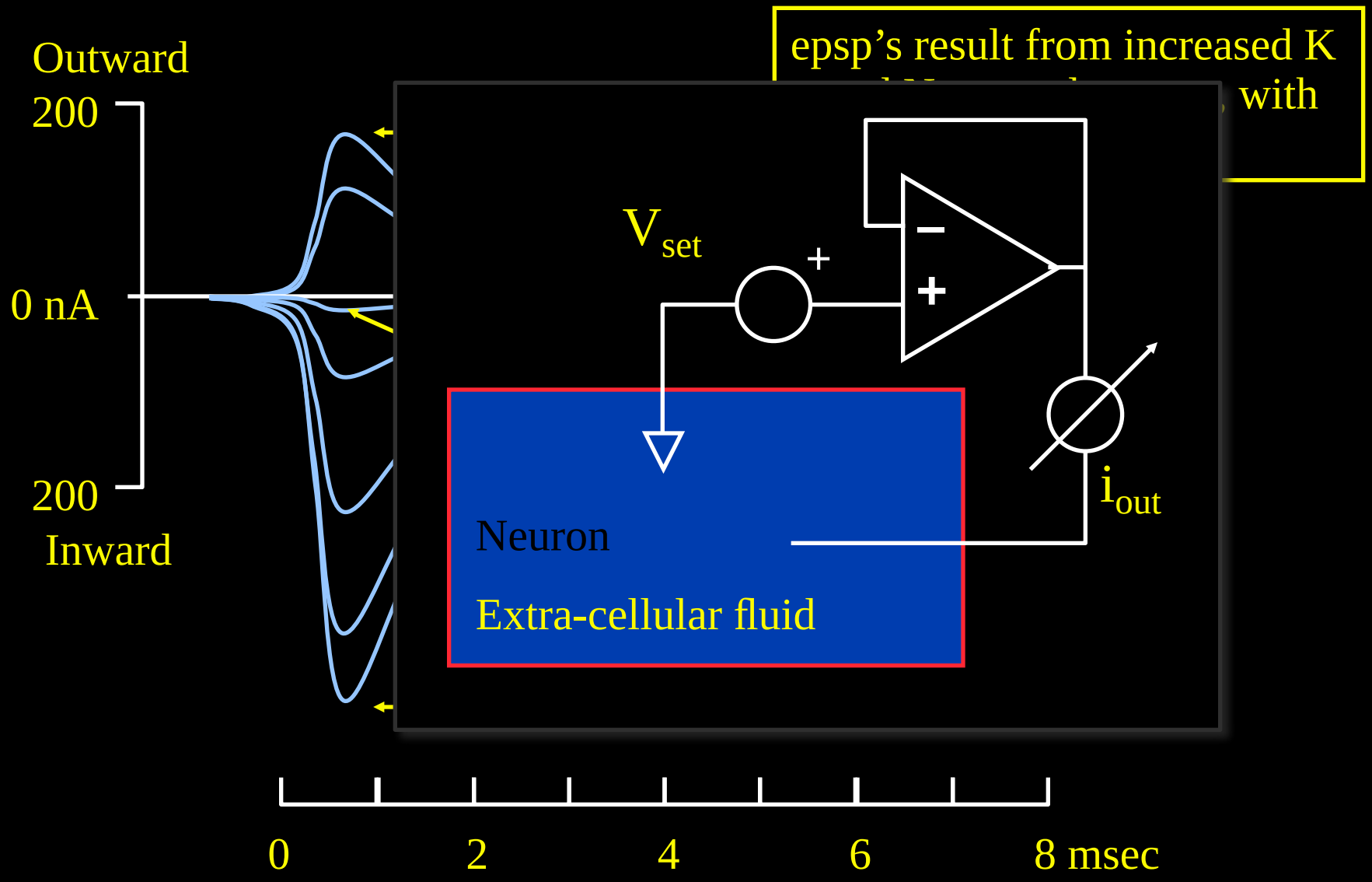
Reversal Potential



After Magleby and Stevens, 1972

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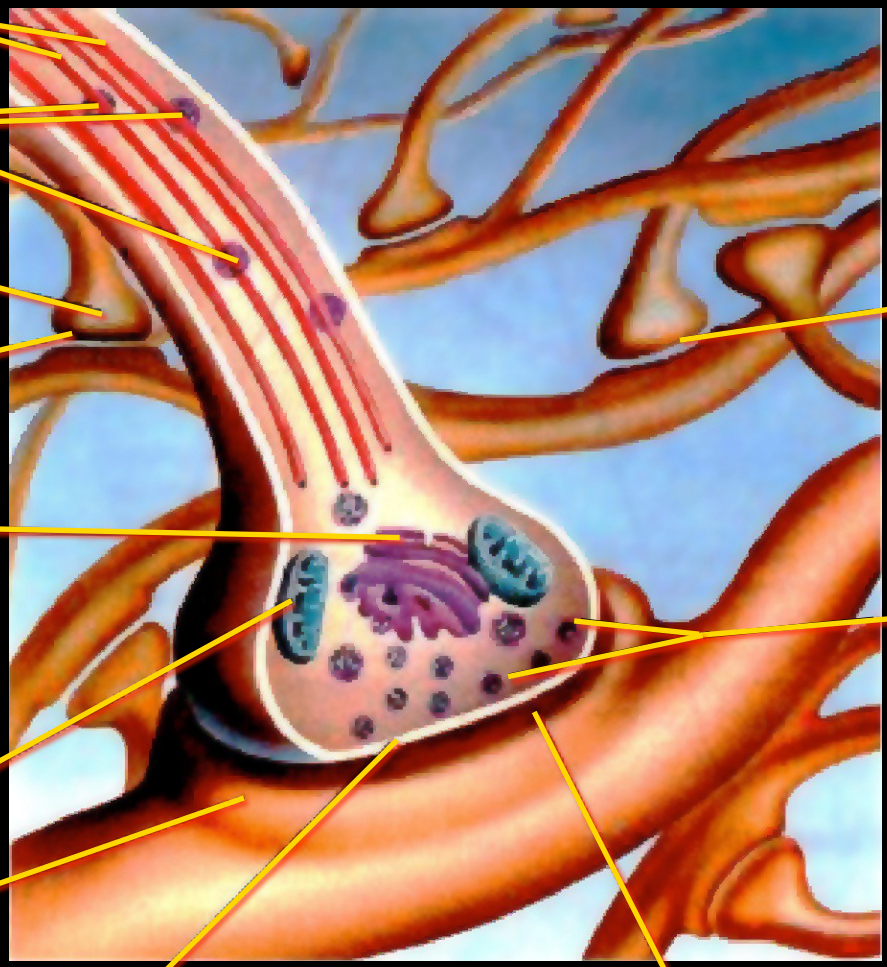
Neural Synapse



From: http://www.driesen.com/synapse.htm

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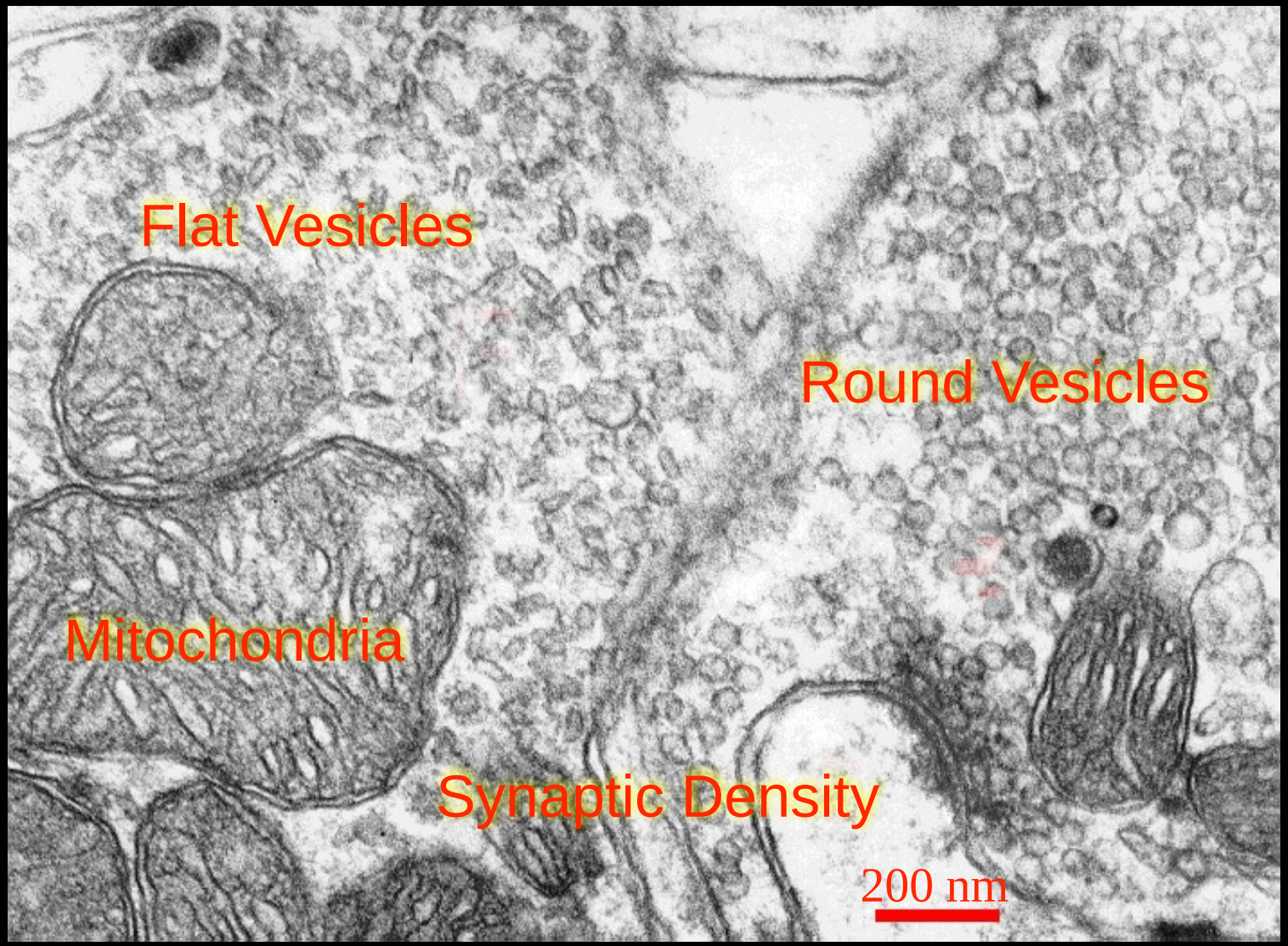
Synapses by EM



Atlas of Ultrastructural Neurocytology
http://synapses.mcg.edu/atlas/1_6_1.stm

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Synaptic Mechanism (movie)

Delay from Presynaptic Action Potential to Post-synaptic Voltage Change is ≈ 0.5 msec

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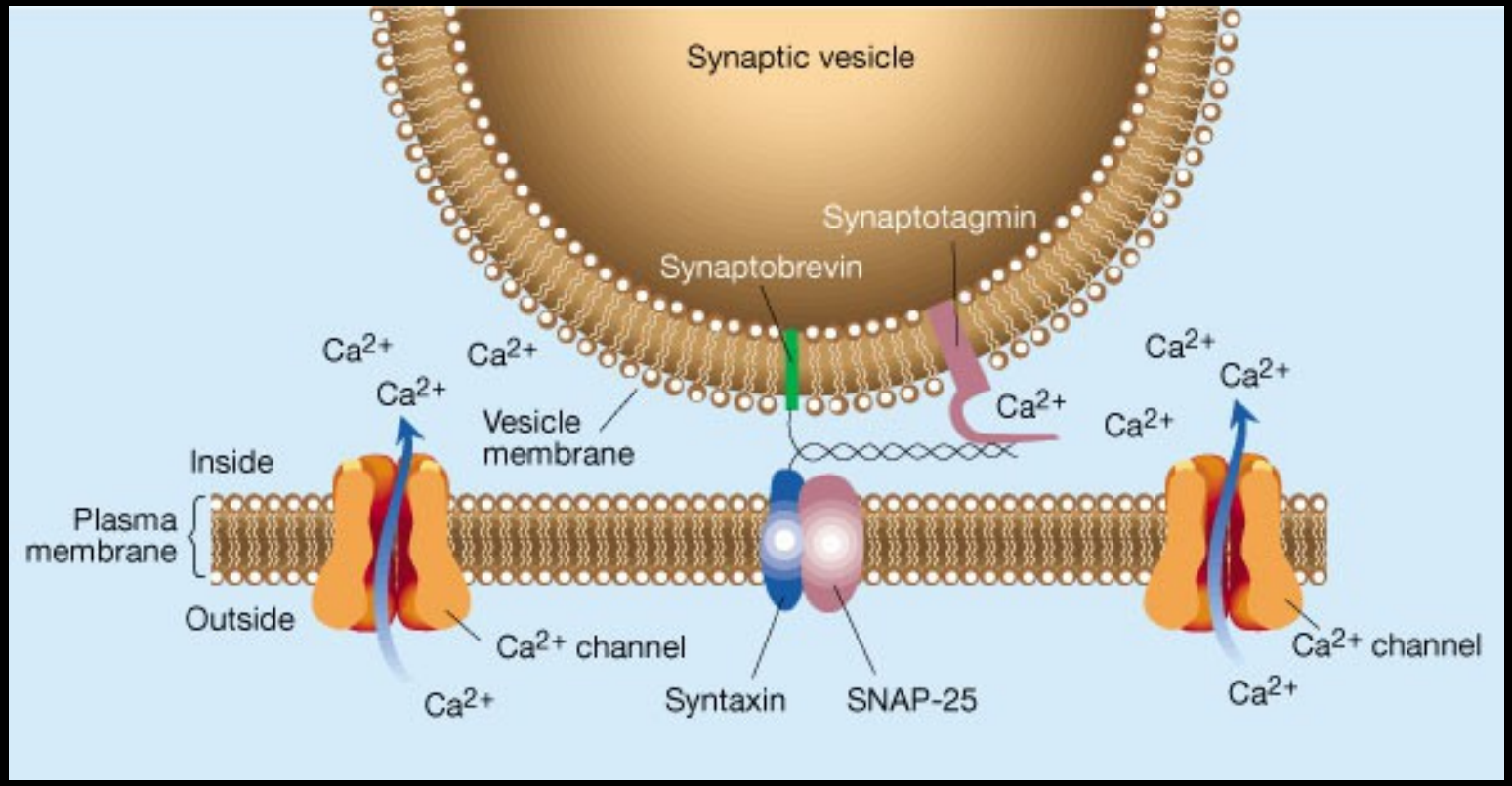
Synaptic Vesicles



Exocytosis of Transmitter requires Ca^{2+}

From: Matthews, G. *Neurobiology: Molecules, Cells and Systems* 2nd edn

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Neurotransmitters

Small Molecules:

- Acetylcholine
- Serotonin
- Histamine
- Epinephrine
- Norepinephrine
- Dopamine
- Adenosine
- ATP
- Nitric Oxide

Amino Acids

- Aspartate
- Gamma-aminobutyric Acid
- Glutamate
- Glycine

Peptides

- Angiotensin II
- Bradykinin
- Beta-endorphin
- Bombesin
- Calcitonin
- Cholecystokinin
- Enkephalin
- Dynorphin
- Insulin
- Galanin
- Gastrin
- Glucagon
- GRH
- GHRH
- Motilin
- Neurotensin
- Neuropeptide Y
- Substance P
- Secretin
- Somatostatin
- Vasopressin
- Oxytocin
- Prolactin
- Thyrotropin
- THRH
- Luteinizing Hormone
- Vasoactive Intestinal Peptide
- *…and many others*

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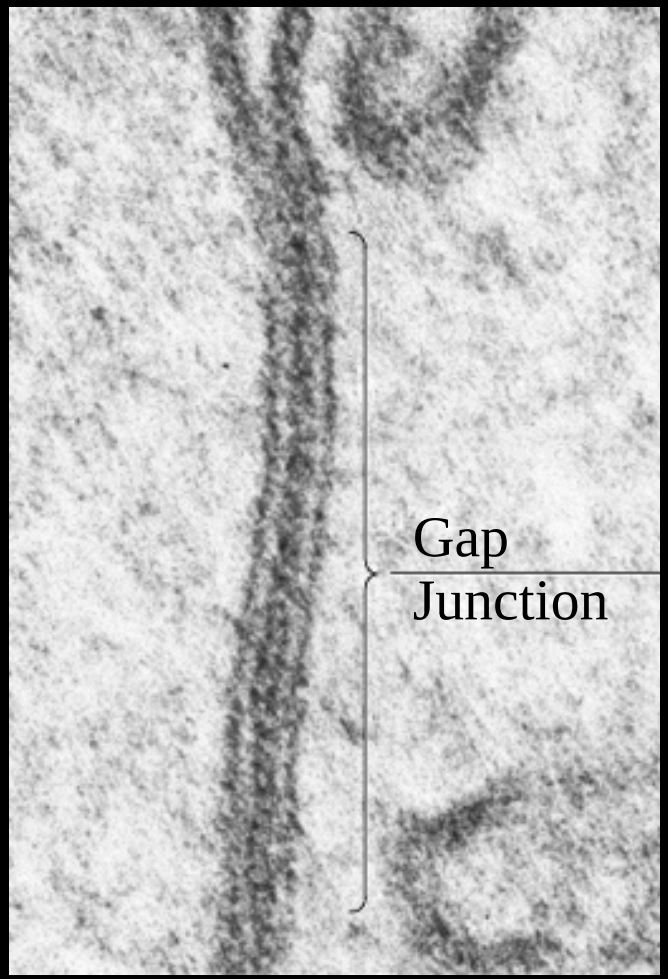
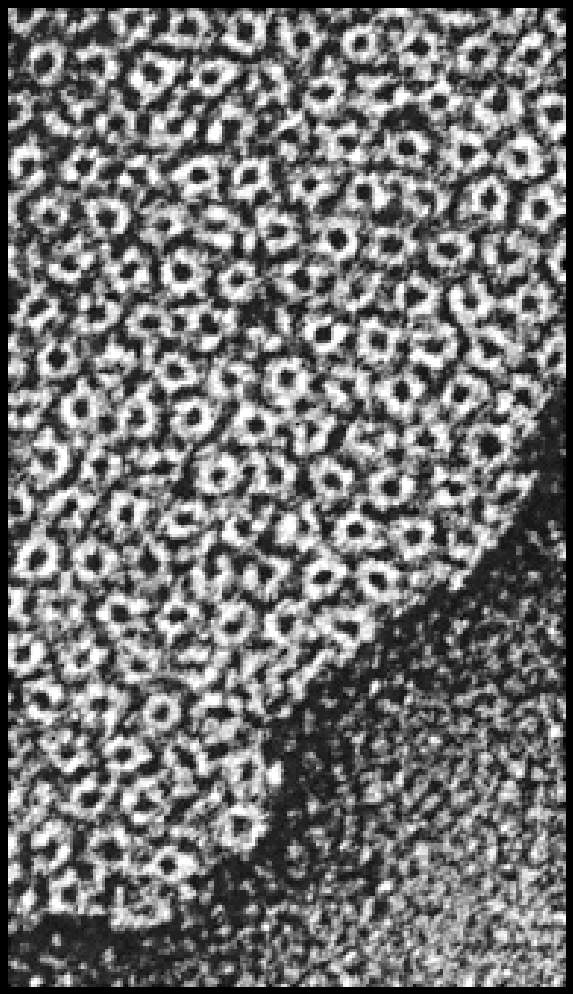
Electrical Synapses



50 nm



50 nm

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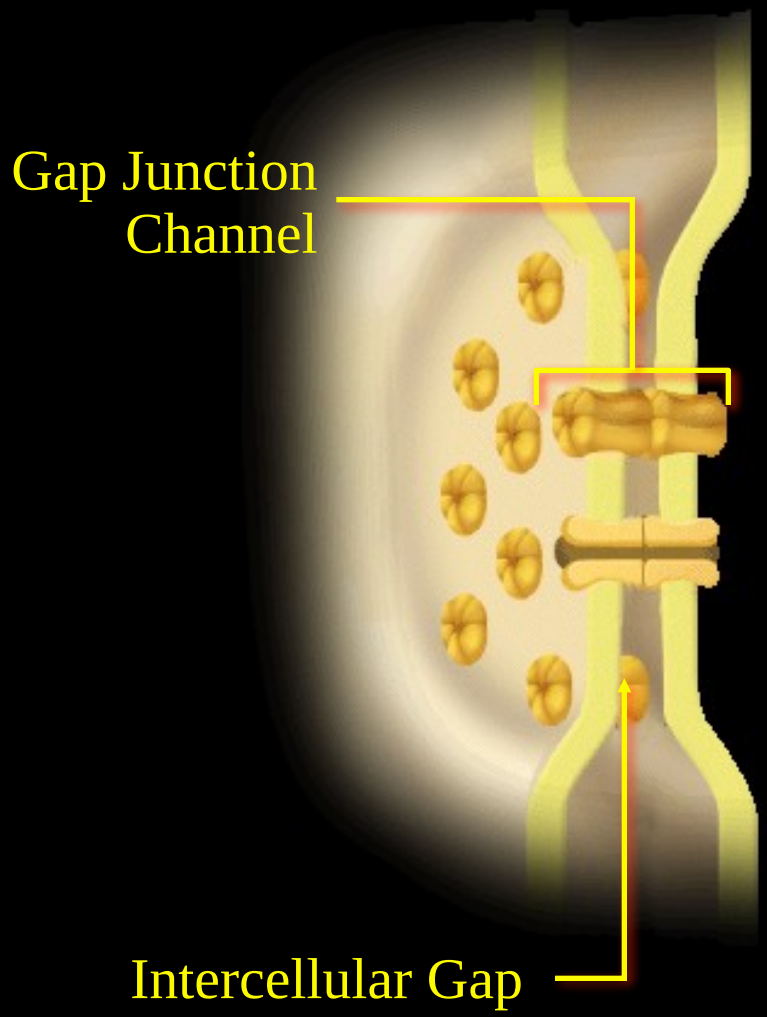
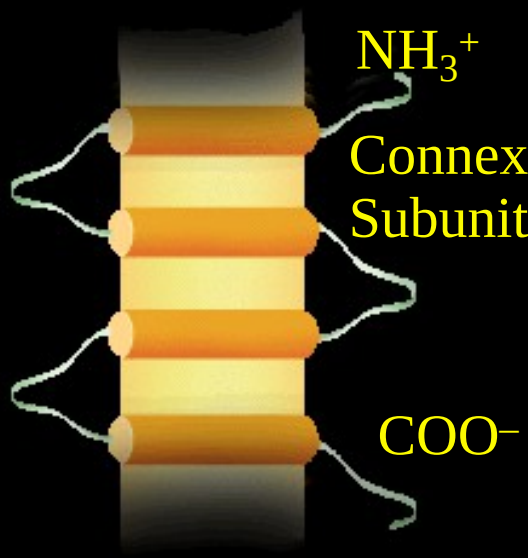
Gap Junction Microstructure





Gap Junctions have no synaptic delay, and may act as simple resistance or as electrical *rectifiers*

Modified from: *http://aids.hallym.ac.kr*

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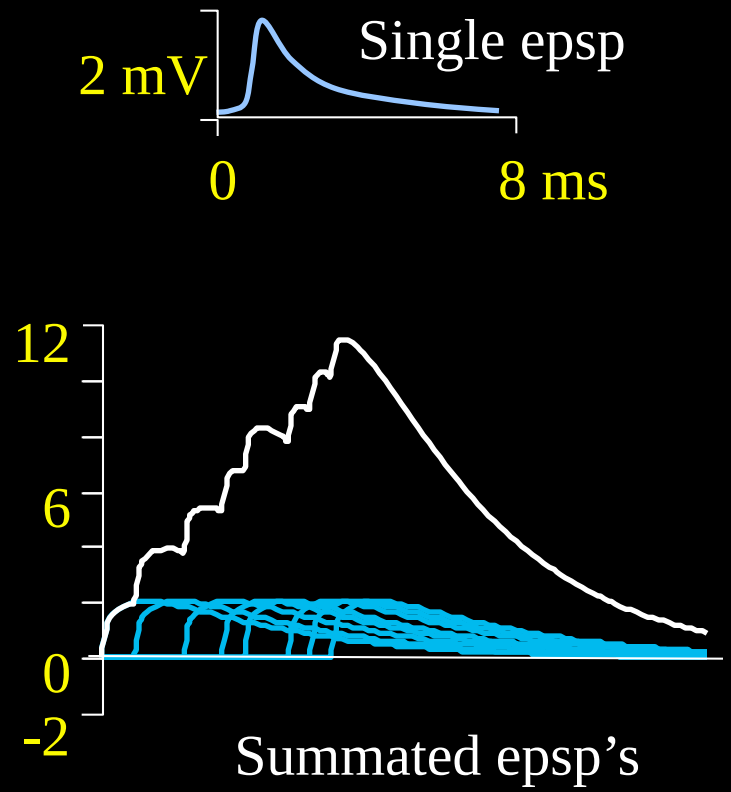
SpatioTemporal Summation of psp's



http://www.oseplus.de/Images/jpg/Synapse1.jpg

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Integration of Inputs

Electrotonic properties of cells can result in spatial information zones within cells

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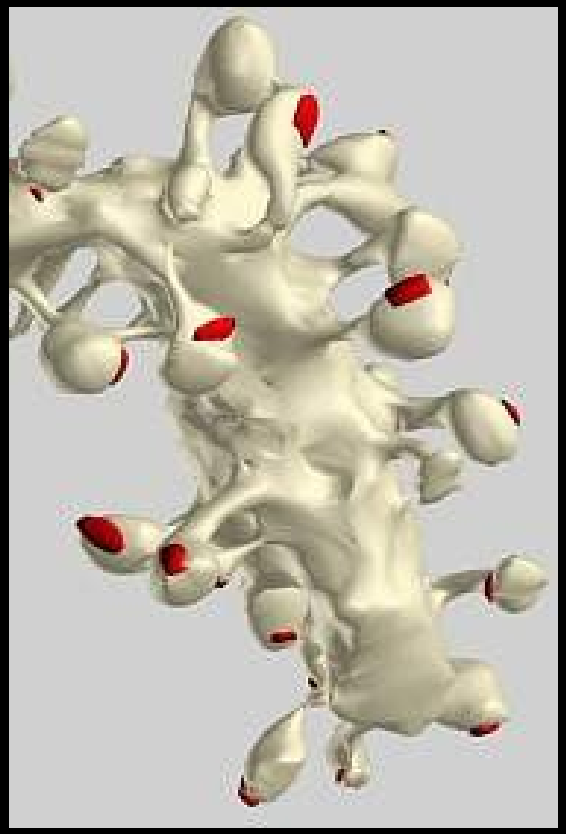
Dendritic Spines



1 µm

Atlas of Ultrastructural Neurocytology

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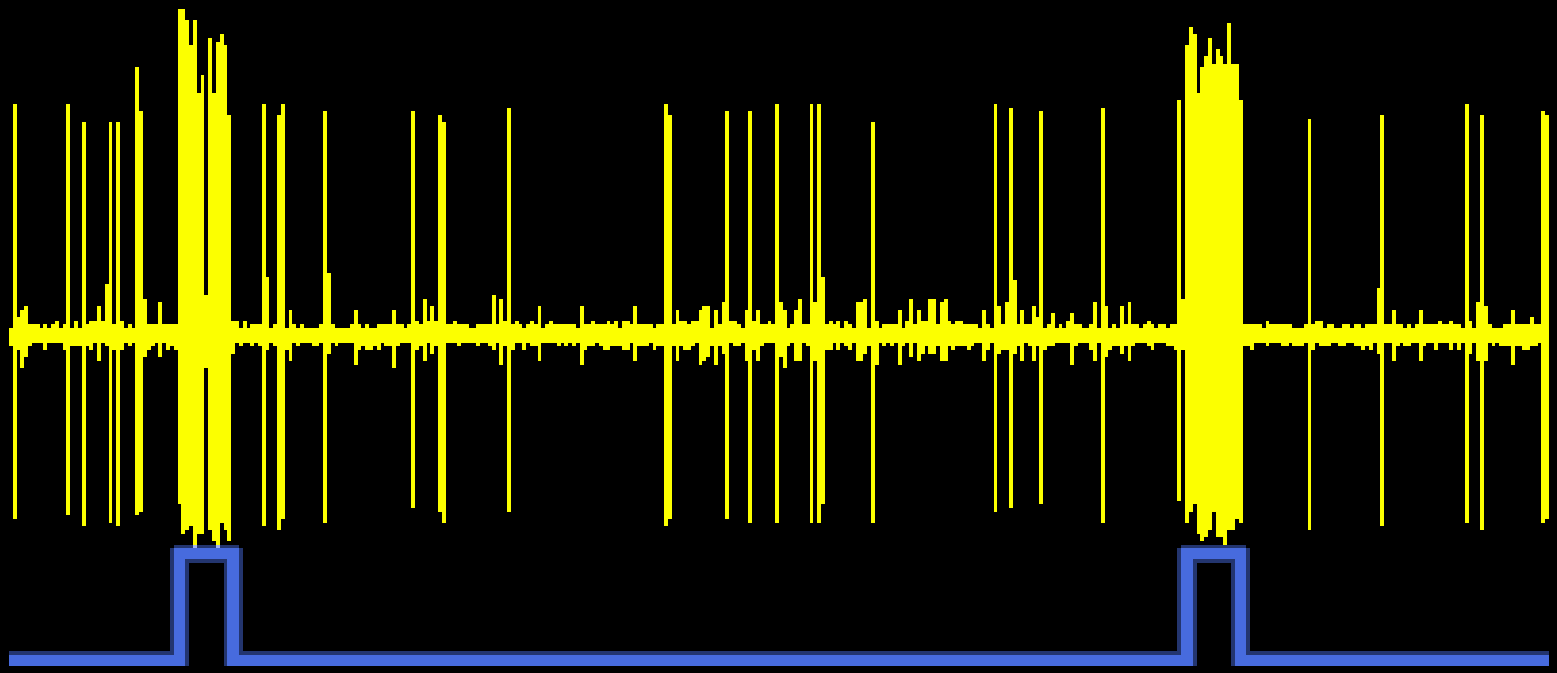
How Do Neurons Encode Information?

Action Potentials are Identical!



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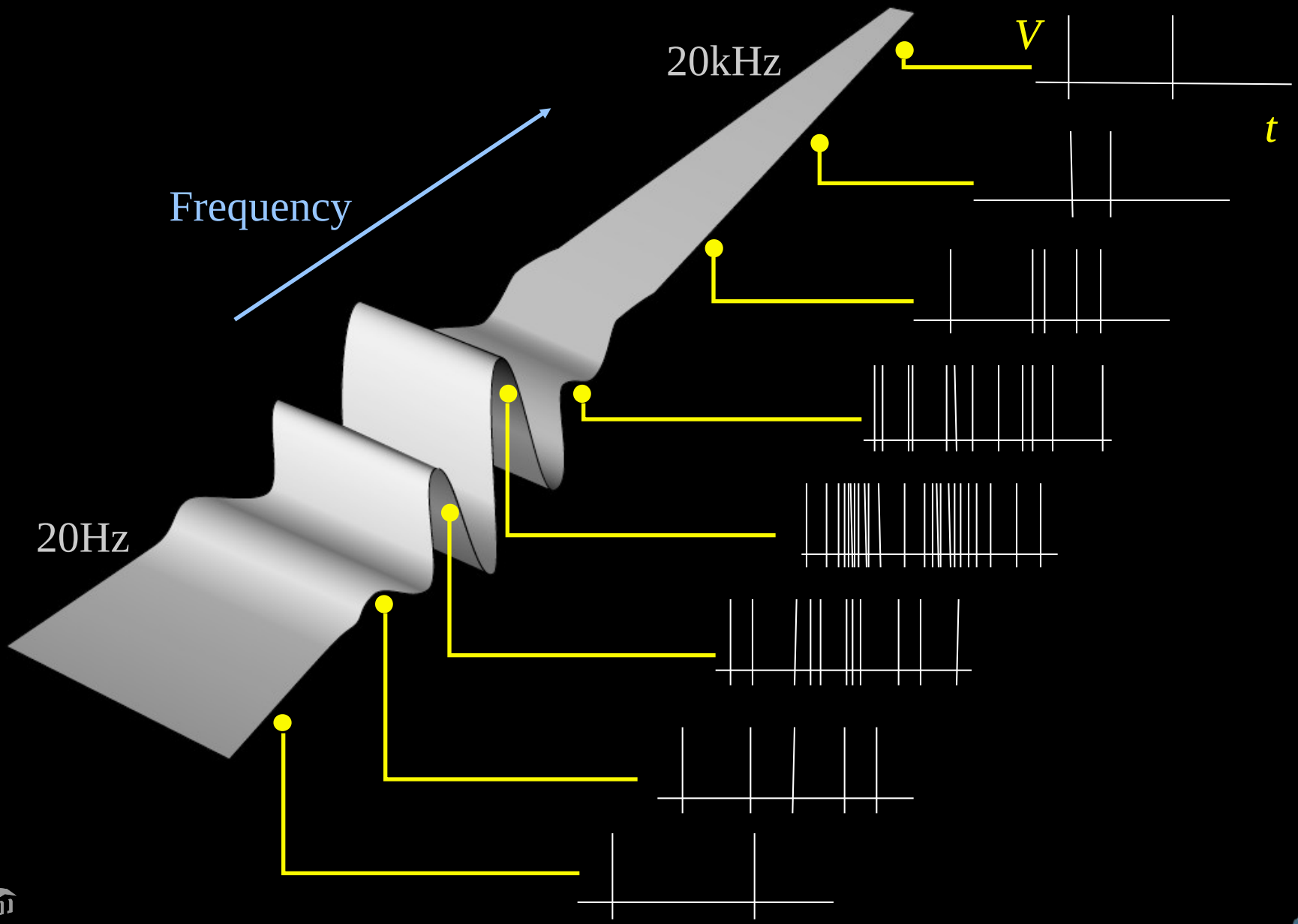
Place Encoding - Basilar Membrane



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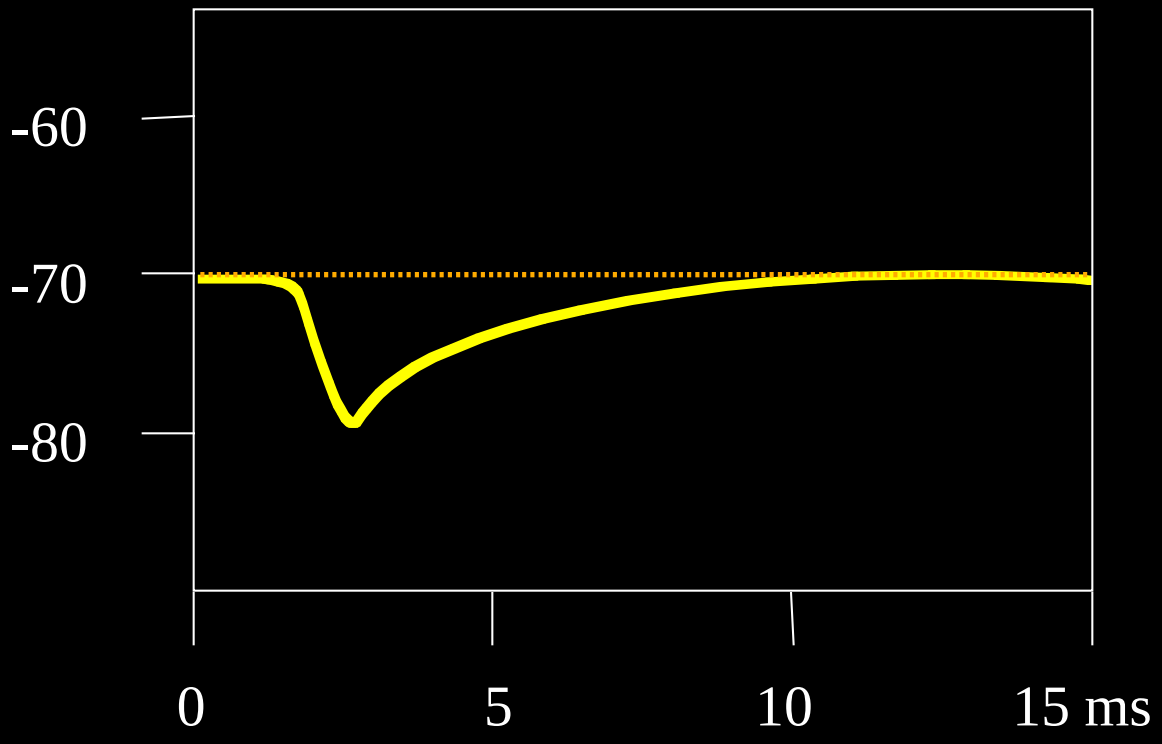
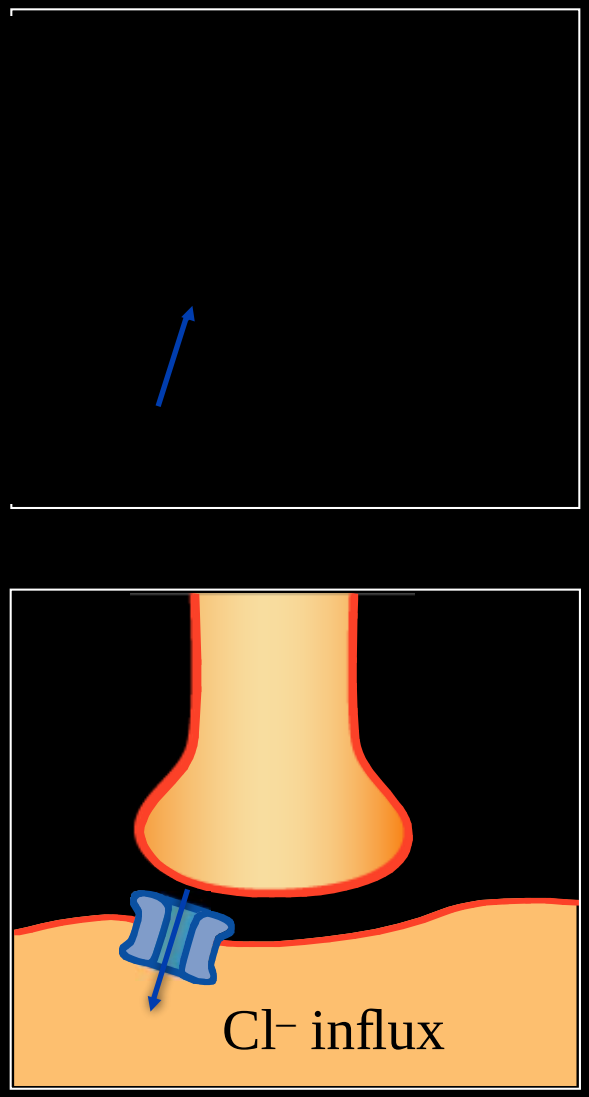
Inhibition





Reversal potential of Cl^- is near the resting potential. Therefore, its inhibition may be silent.

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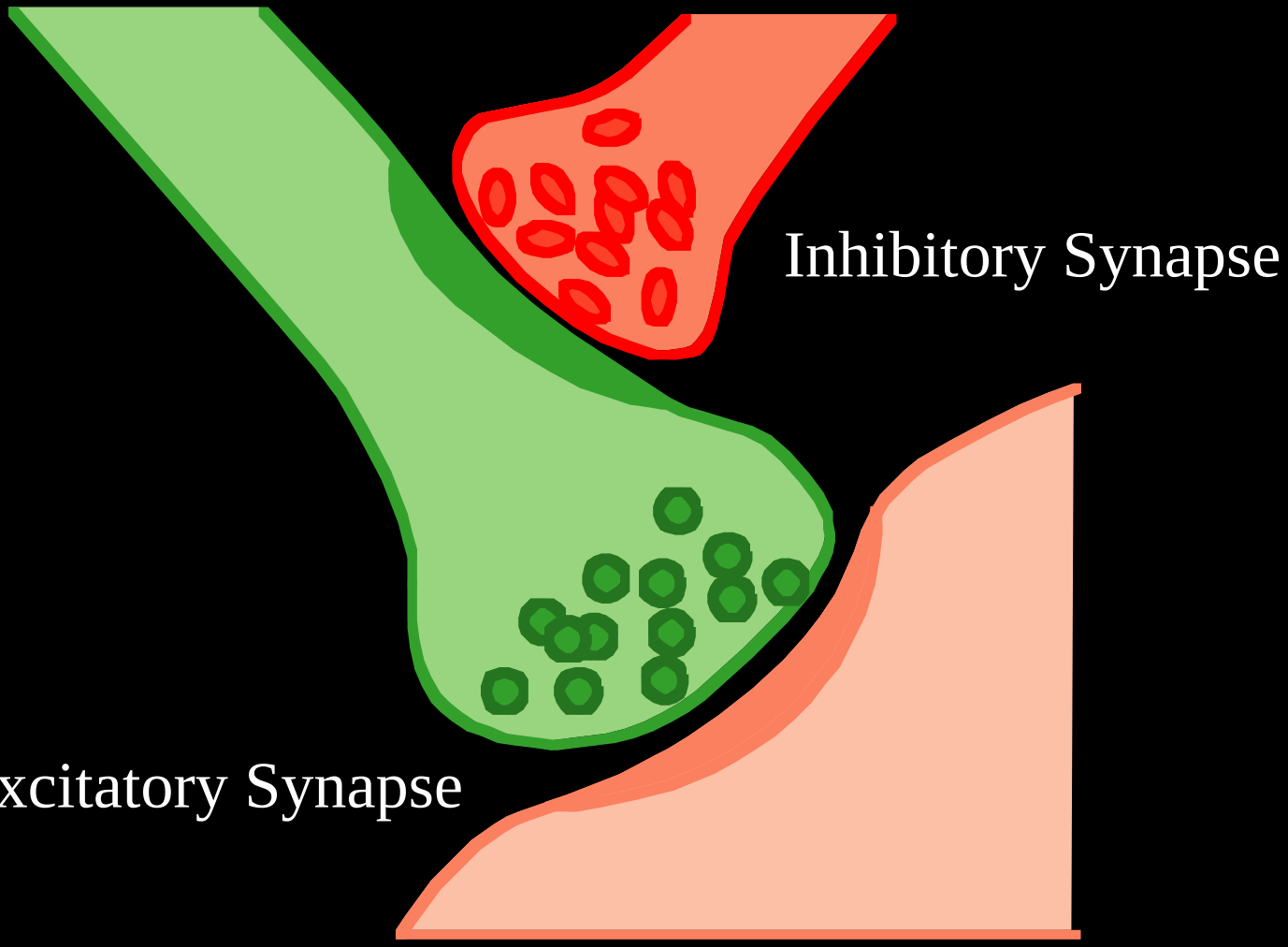
Pre-Synaptic Inhibition



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What Might We Detect?

- Energy Demand
- Direct Electrical Signaling
- Morphological Differences
- Chemical Concentrations
- Tissue Density
- Fat/Water
- etc...

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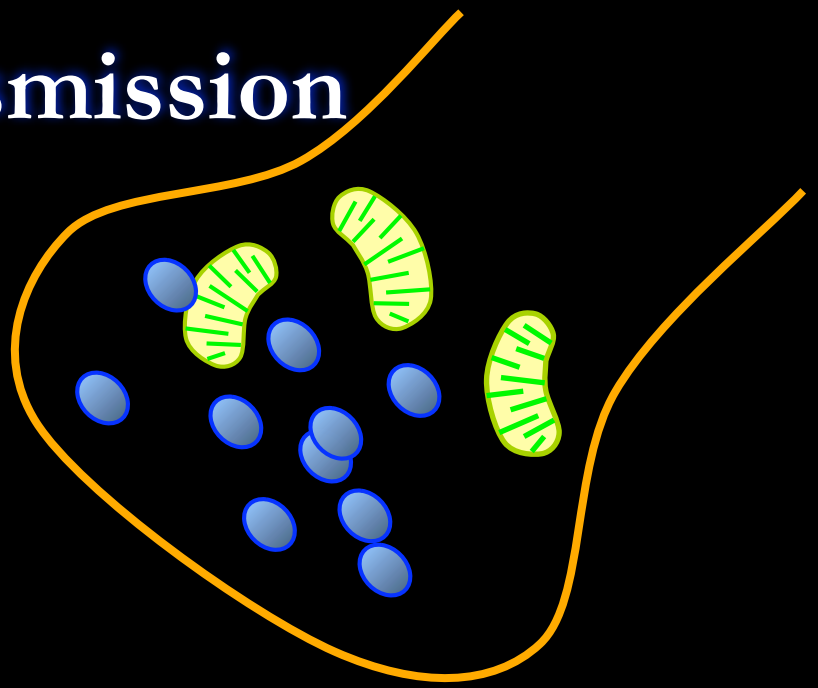
How does BOLD relate to neural firing?

Energy Demands in Transmission



Pre-synaptic:

Transmitter Synthesis

Exocytosis

Transmitter re-uptake

Post-Synaptic

Maintenance of membrane potential after ion leakage

Excitatory: *Removal of Sodium (Na/K pump)*

Inhibitory: *???*

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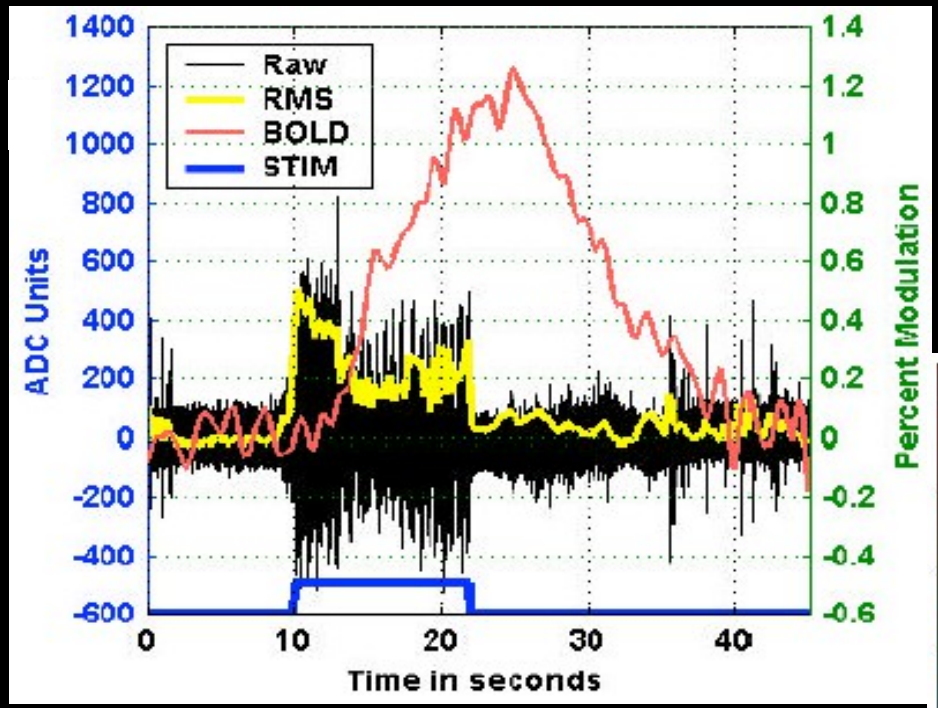
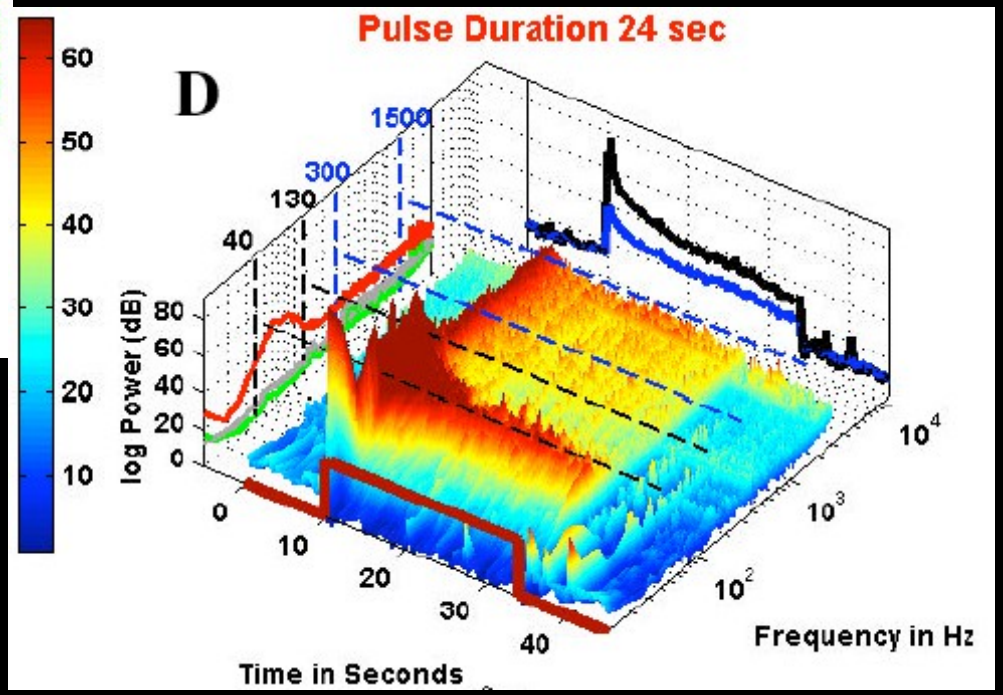
Logothetis Results



LFP = 40-130 Hz

MUA = 300-1500 Hz



Pre On Post Stim

Logothetis, et al., Nature 412:152, 2001

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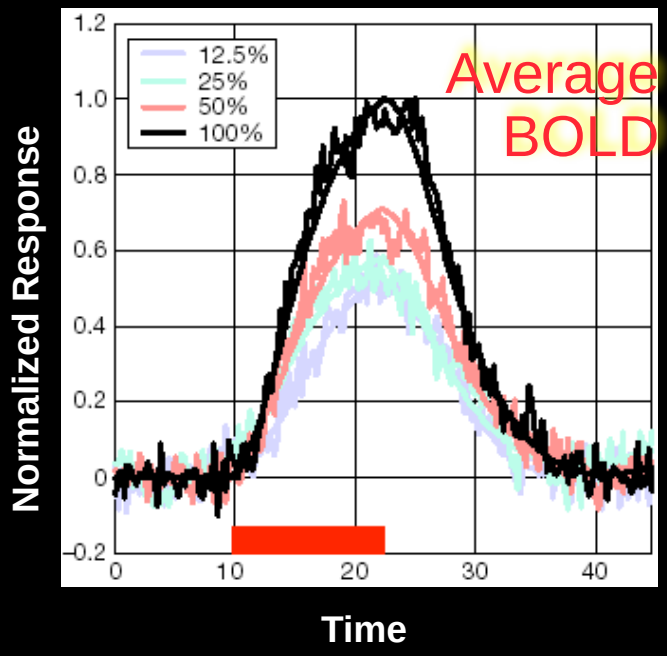
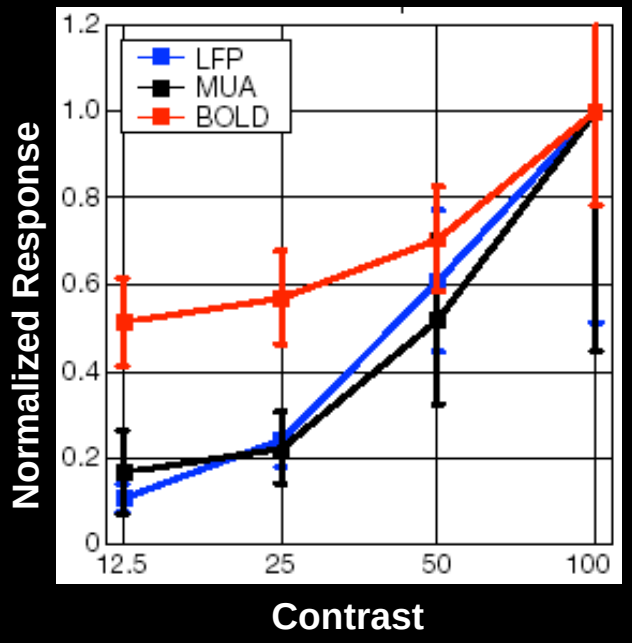
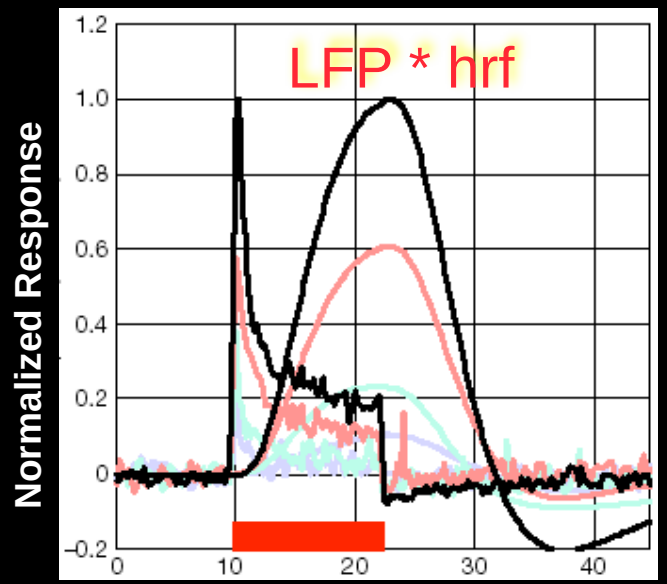
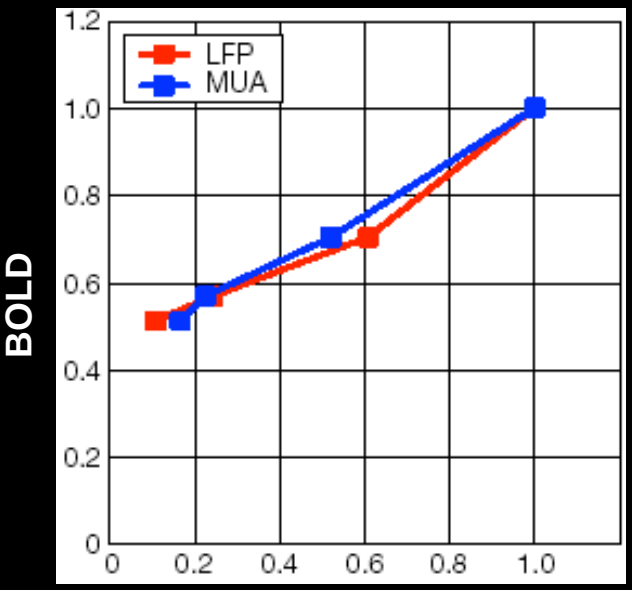
Logothetis results









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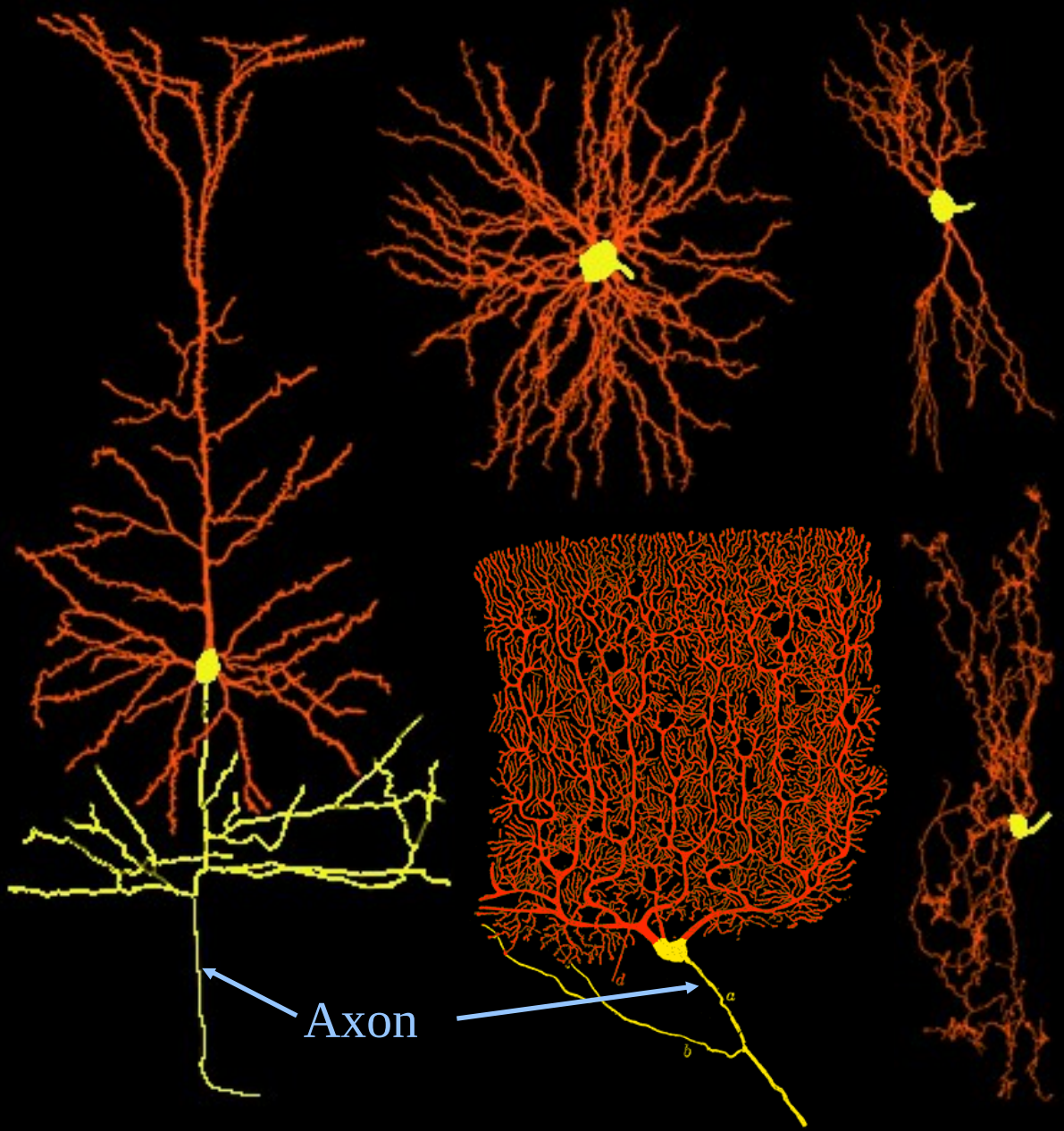
Types of Neurons



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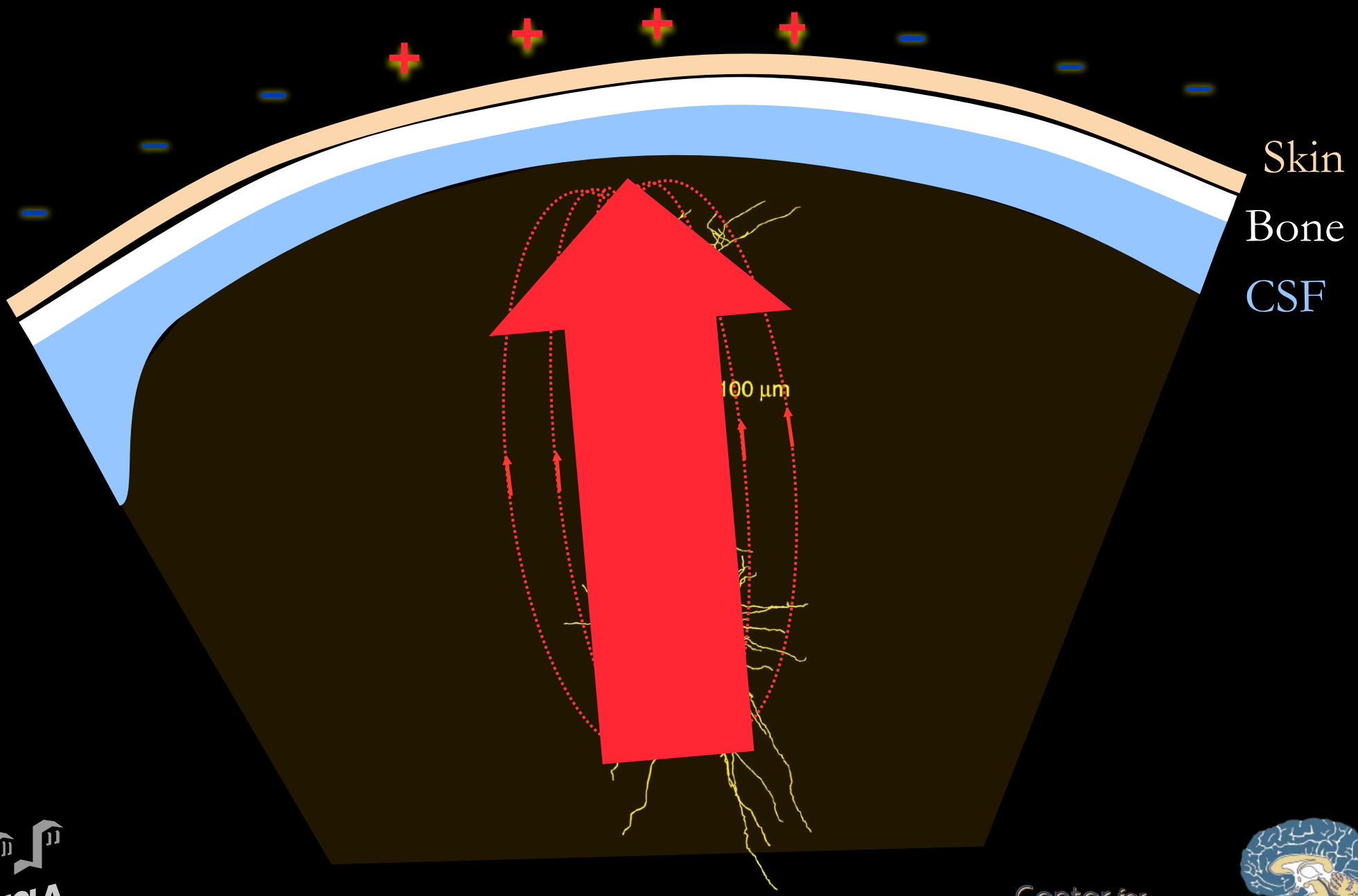
Presumed Origin of the EEG



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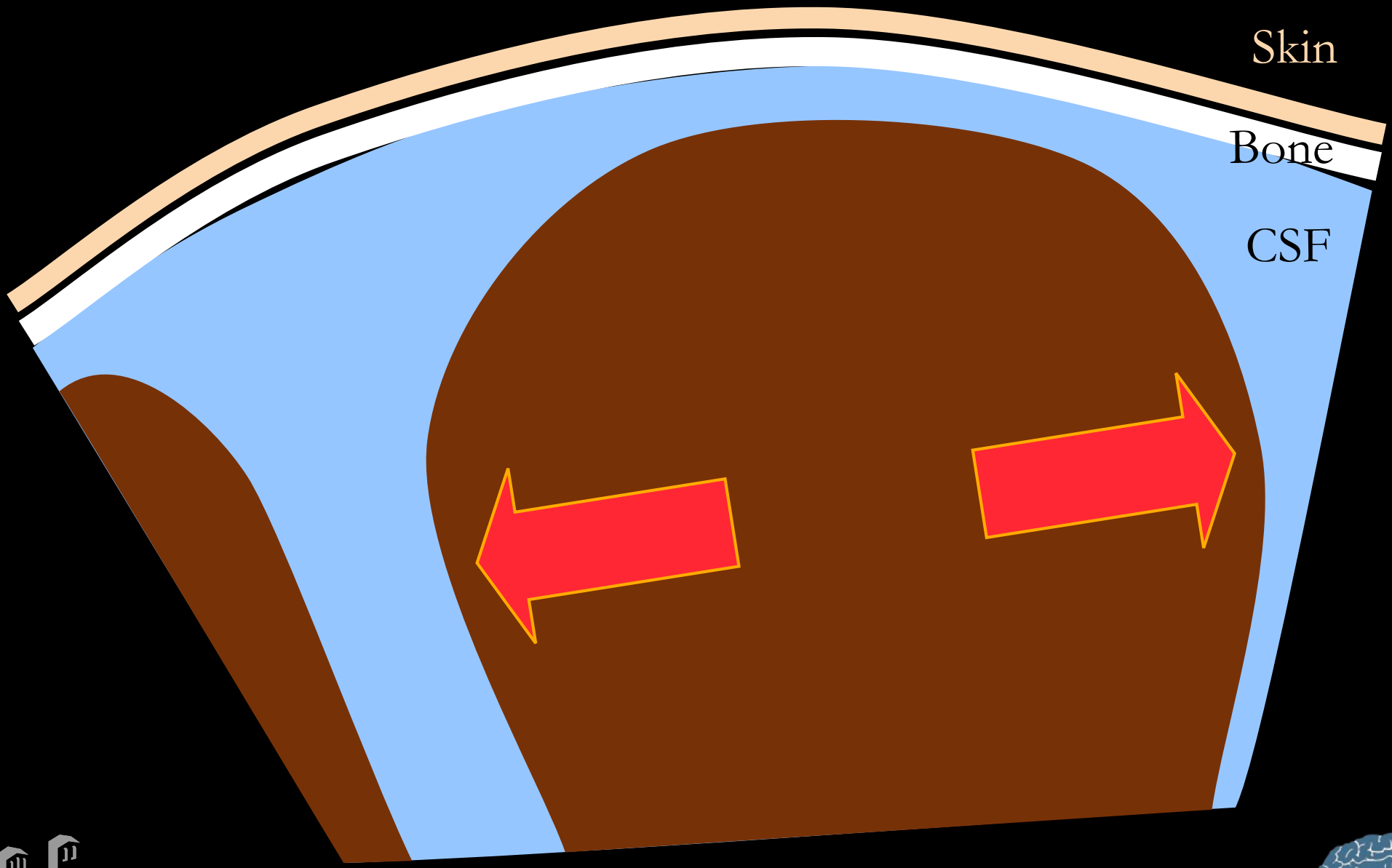
Many Neurons are Not "Seen" by EEG



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General Limitations in EEG Localization

- Deeper Sources Show Weaker Signals
- Magnitude Depends on Dipole Orientation
- Magnitude Depends on Temporal Synchrony
- Magnitude Depends on Spatial Coherence
- Conductivity of Body Tissues (CSF, scalp) Blur the Scalp Potentials

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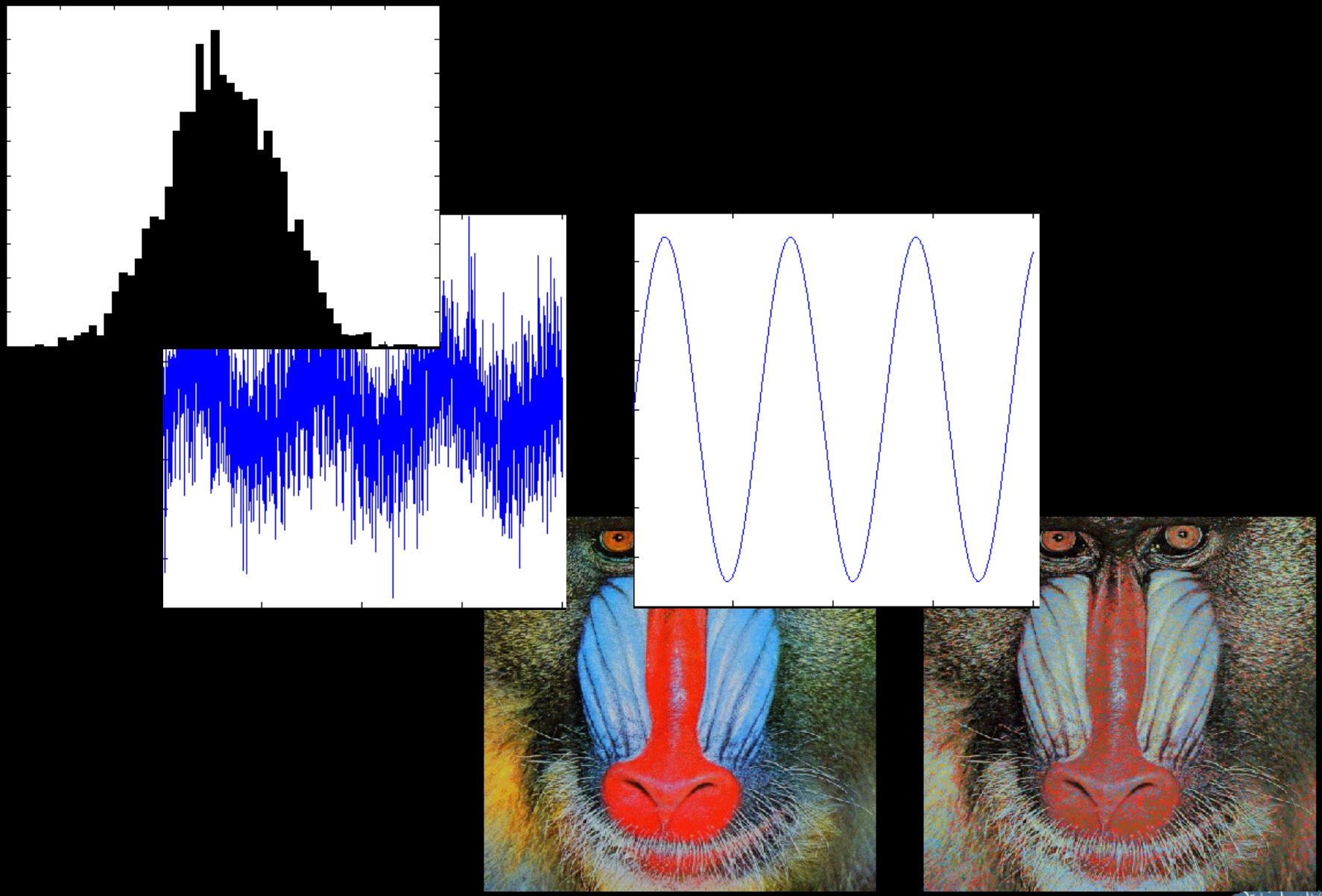
The problem of Noise



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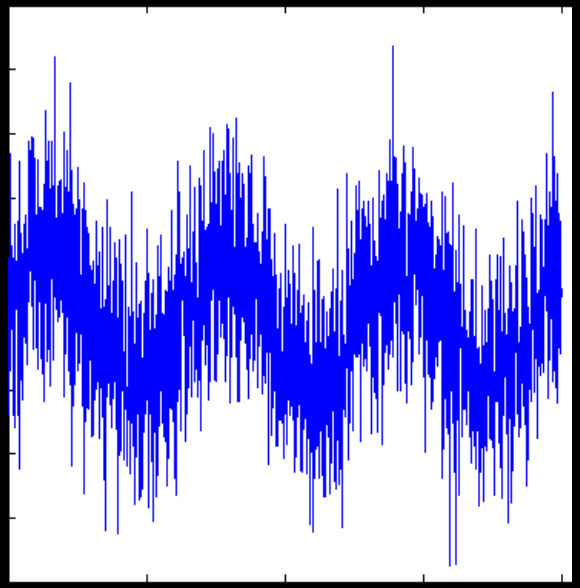
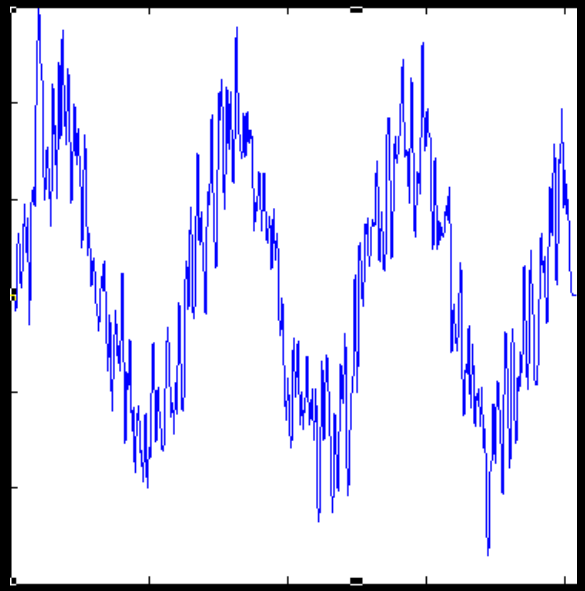
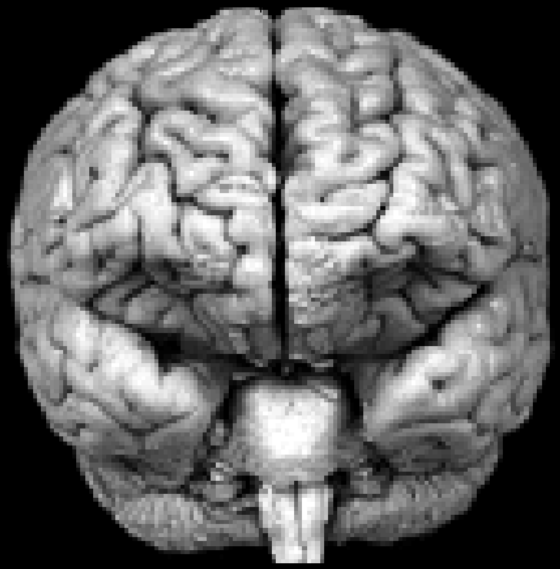
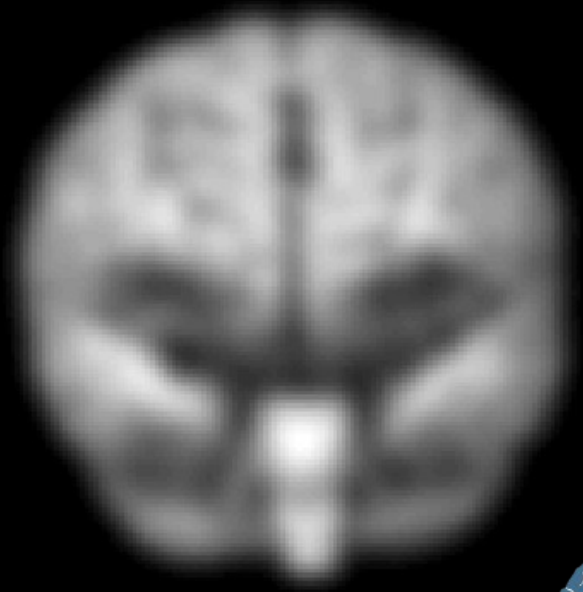
Blurring and Filtering









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