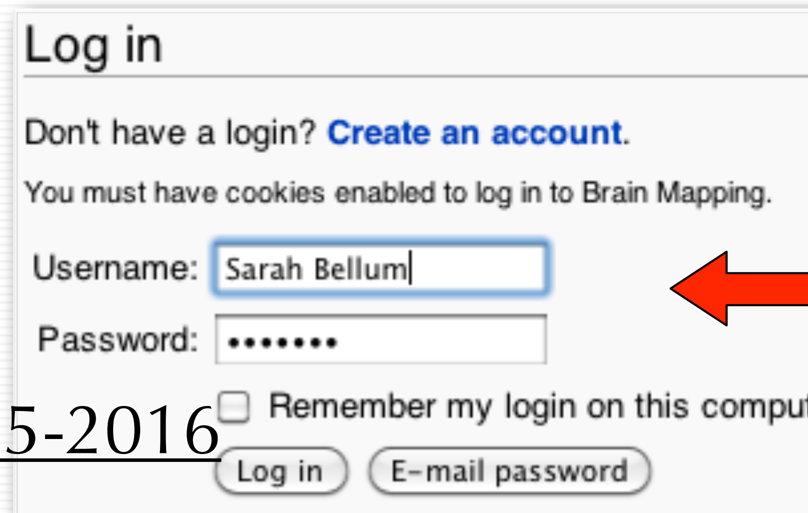
Organizational

- **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

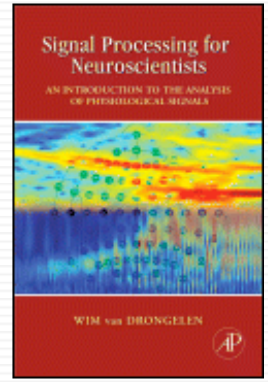


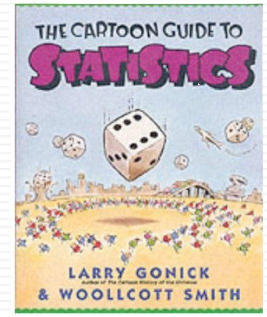
Organizational

- 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)

Requirements

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





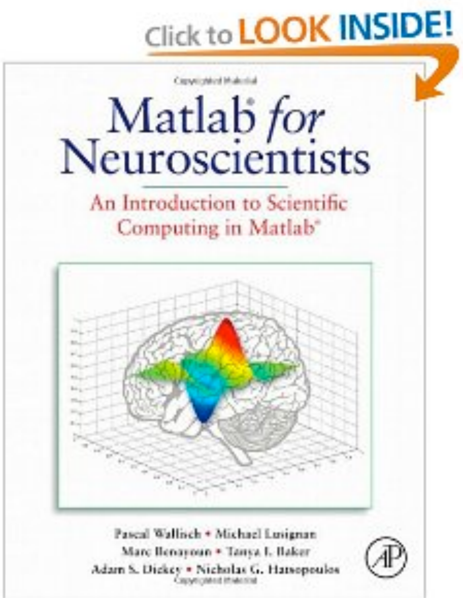
- MATLAB
- Signal Processing for Neuroscientists
- Cartoon Guide to Statistics (optional)
- Class List

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)

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)

List Price: ~~$79.95~~

Price: $59.74 Prime

You Save: $20.21 (25%)

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Concepts (M284A)

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

Grading

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

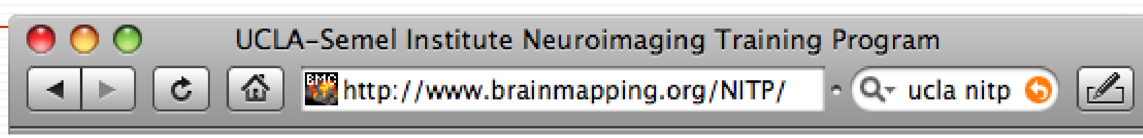
- M284 is a required course for some students continuation in several Ph.D. programs, grading will be rigorous.

UCLA

NeuroImaging Training Program

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



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

Neuronal Anatomy and Electrical Activity

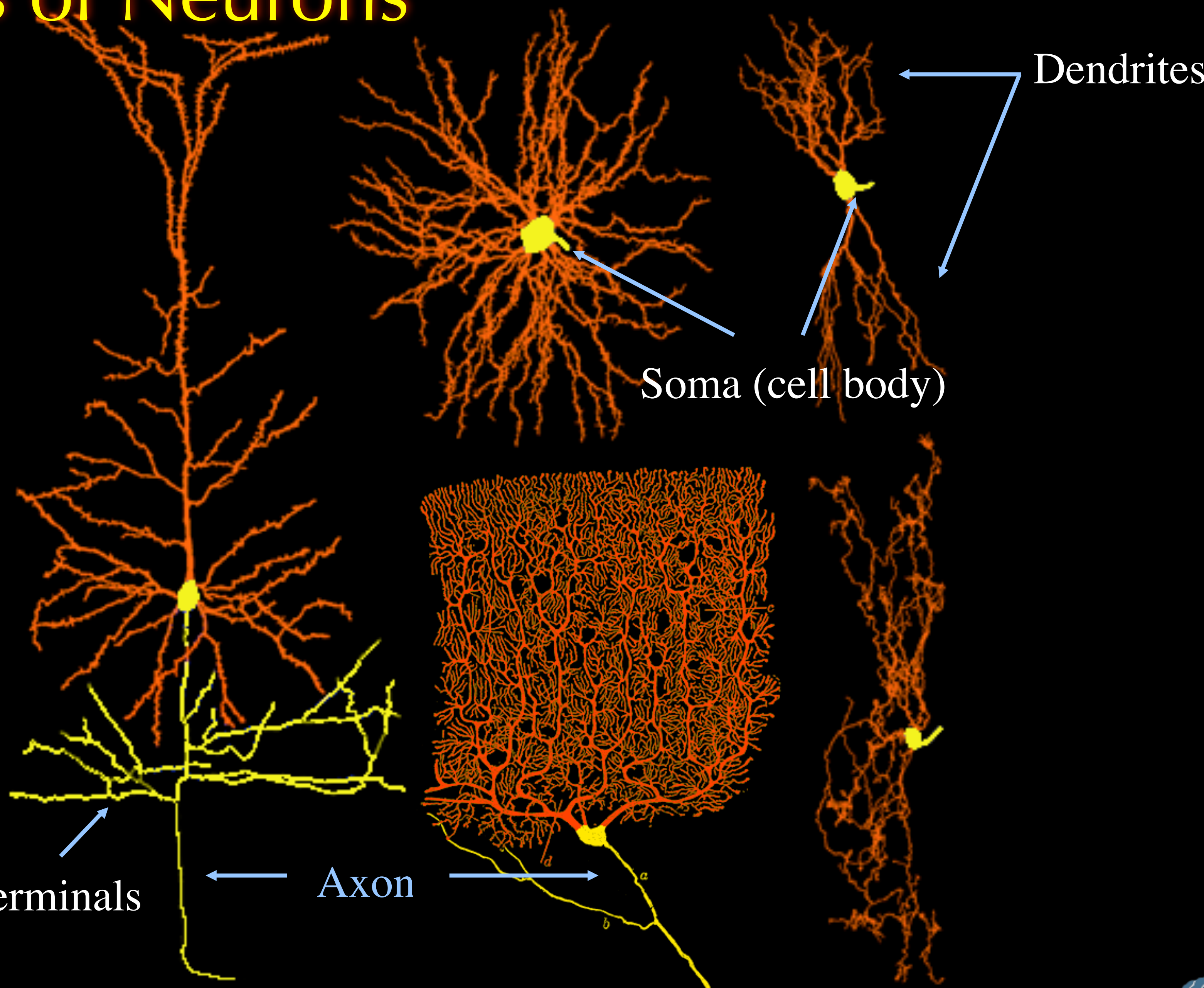
Mark S. Cohen
UCLA Psychiatry, Neurology, Radiology, Psychology, Biomedical Engineering, Biomedical Physics

Suite 17-369 NPI

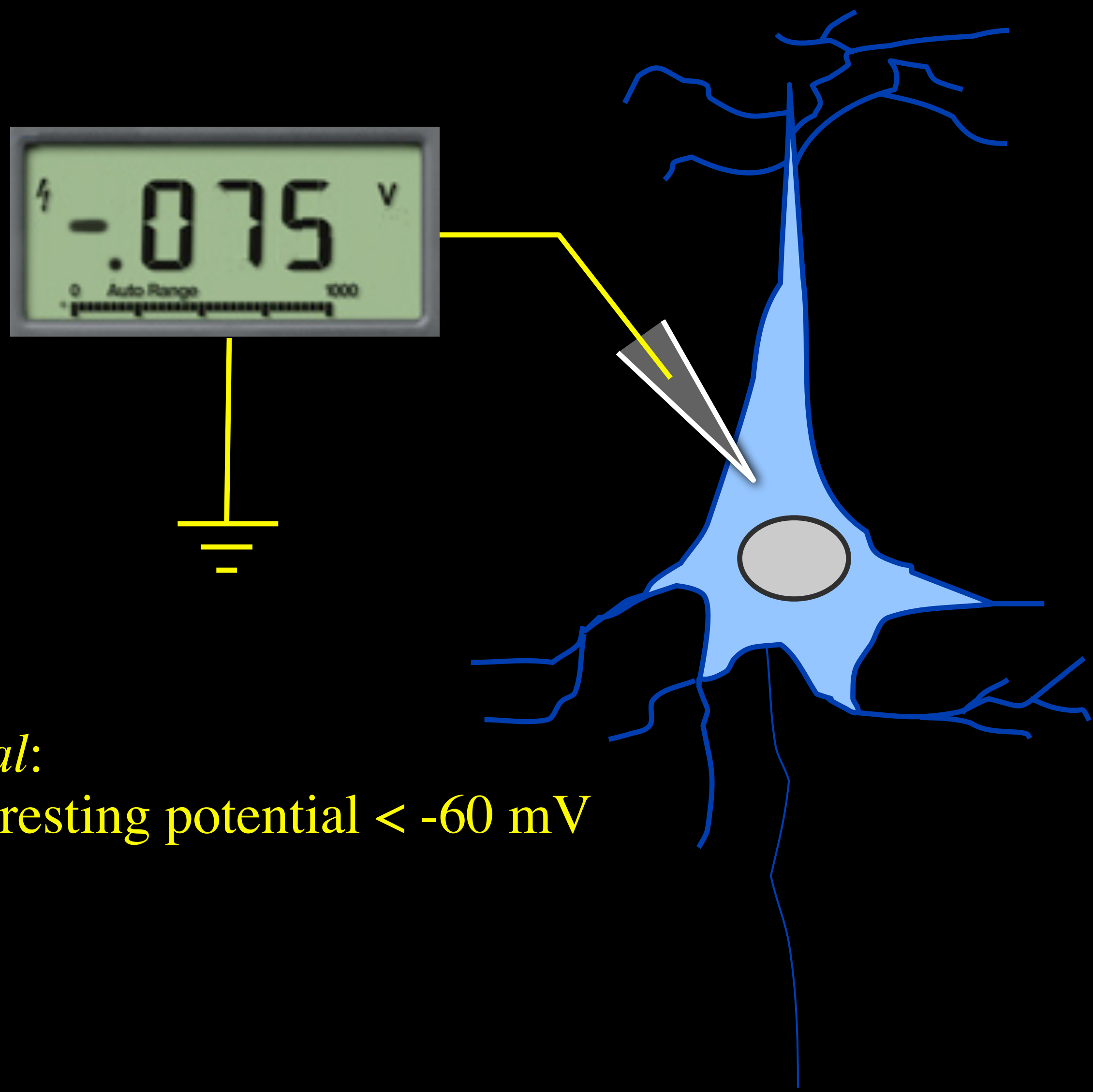
Topics

- 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

Types of Neurons

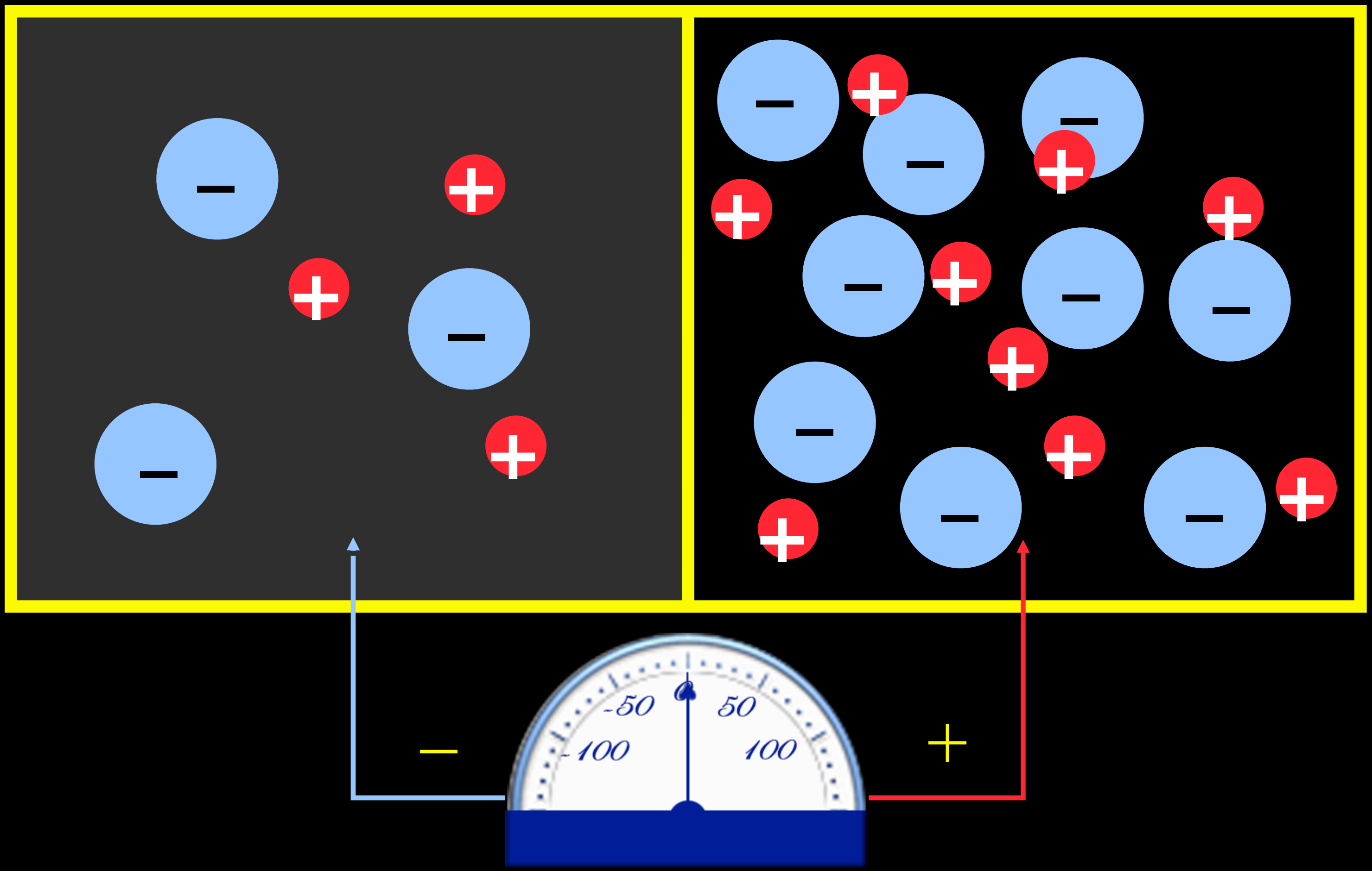


Resting Potential

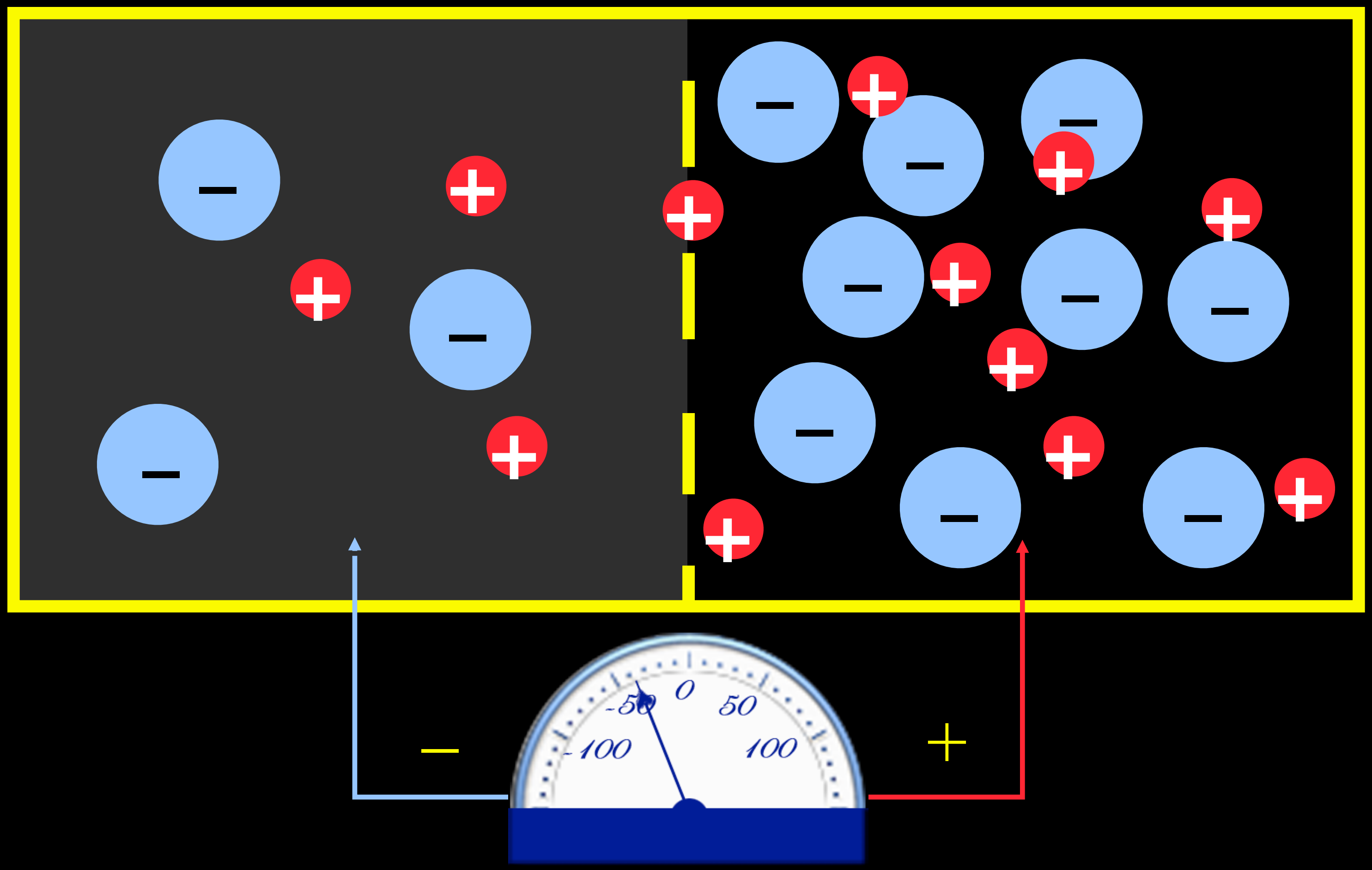


Typical:
-90 < resting potential < -60 mV

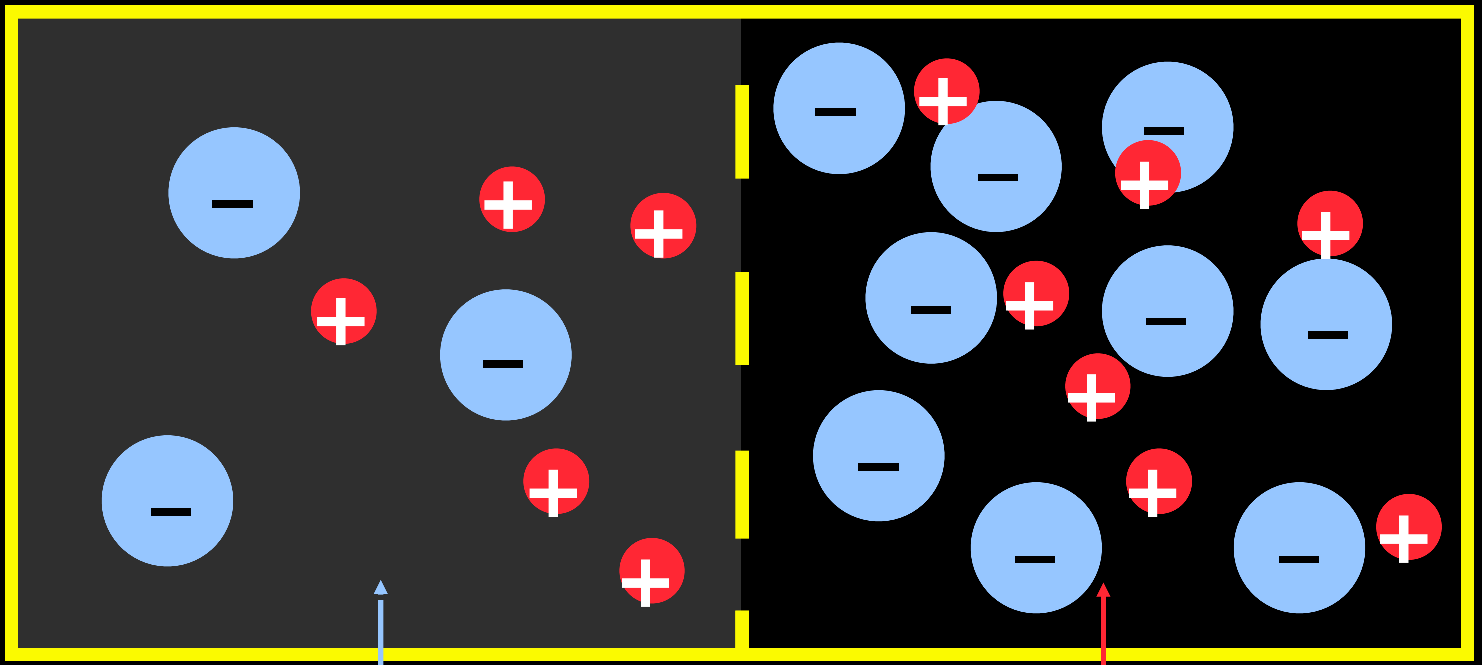
Development of the Membrane Potential



Development of the Membrane Potential



Development of the Membrane Potential

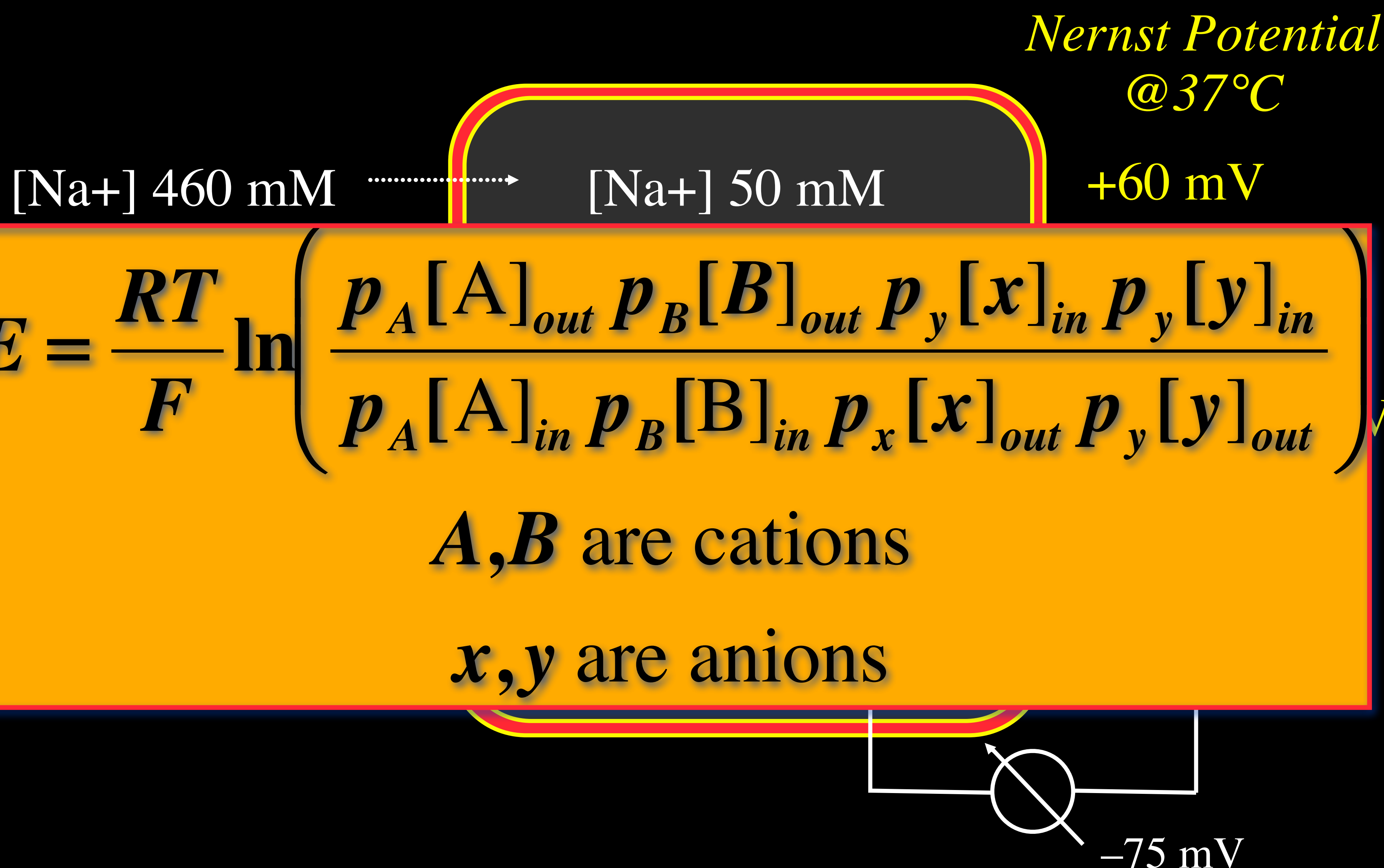


$$E = \frac{RT}{F} \ln \frac{[C_{inside}]}{[C_{outside}]}$$

Nernst Potential:

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

Observed Ion Concentrations

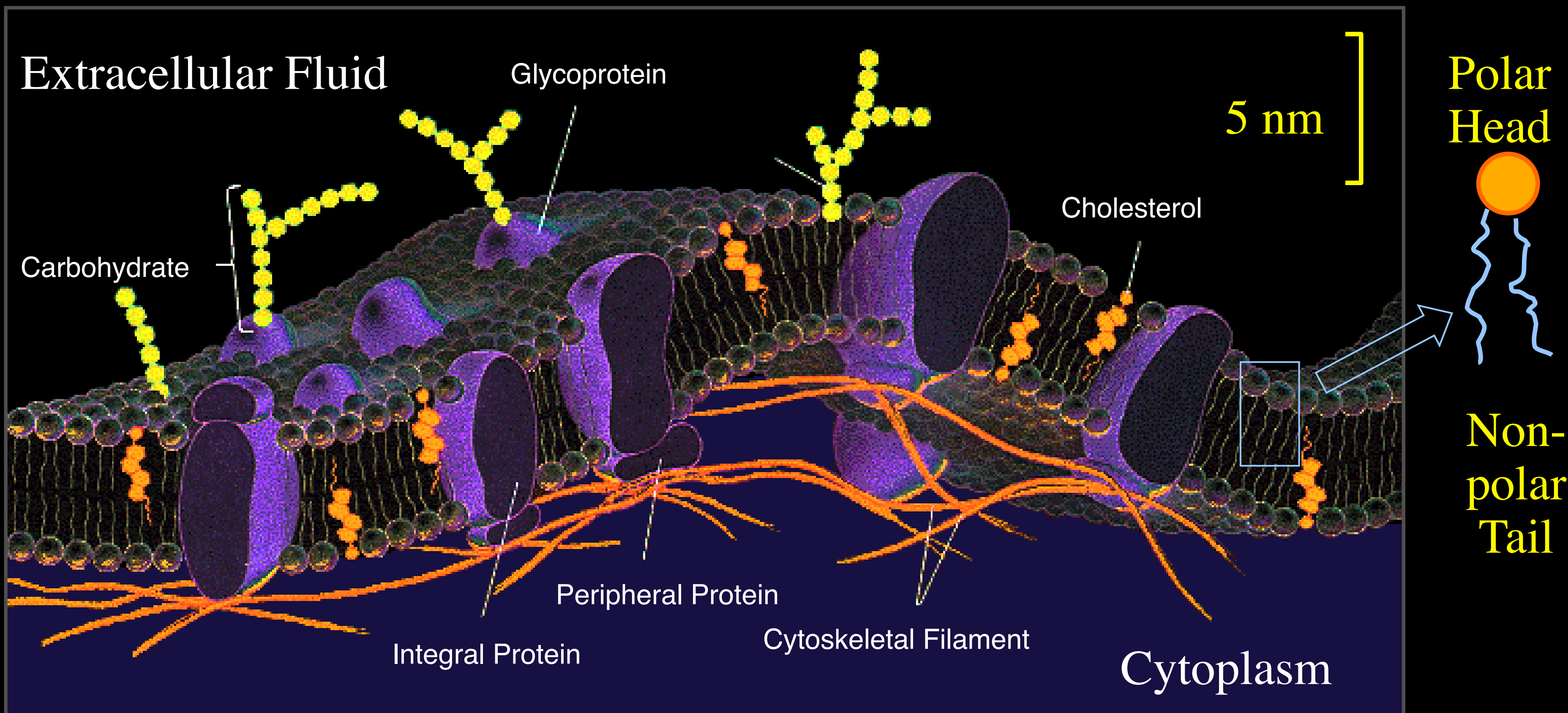


$$E = \frac{RT}{F}\ln\left(\frac{p_A[\mathrm{A}]_{out}\, p_B[B]_{out}\, p_y[x]_{in}\, p_y[y]_{in}}{p_A[\mathrm{A}]_{in}\, p_B[\mathrm{B}]_{in}\, p_x[x]_{out}\, p_y[y]_{out}}\right)$$

A,B are cations

x,y are anions

Structure of the Cell Membrane



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

Taken from *Human Biology* by Daniel Chiras

The Neural Membrane

Observed Capacitance: 1 μF/cm^2

Since:

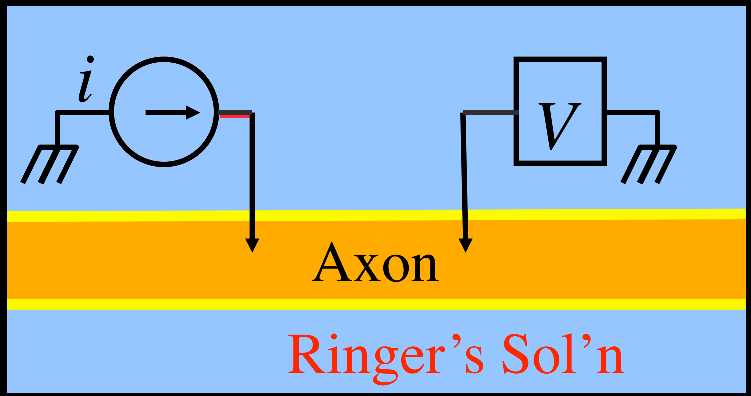
$$C \approx \frac{1.1k}{4\pi d \times 10^{-12}}$$

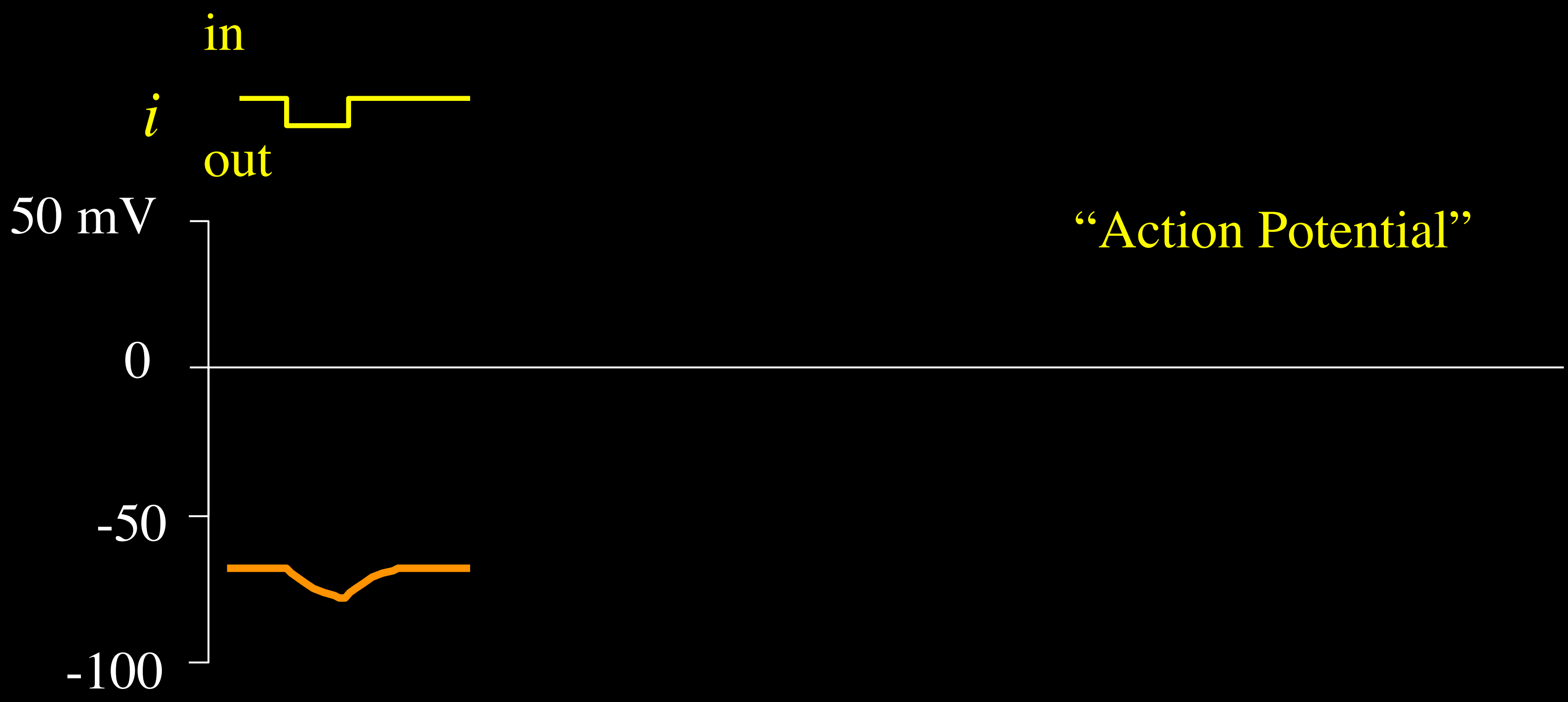
If k (the dielectric constant) is about 6, then d ≈ 5 x 10^{-7}cm = 50 Å.

If P.D. ≈ 0.1 Volt, then the E field is

2 x 10^{7} V/m !

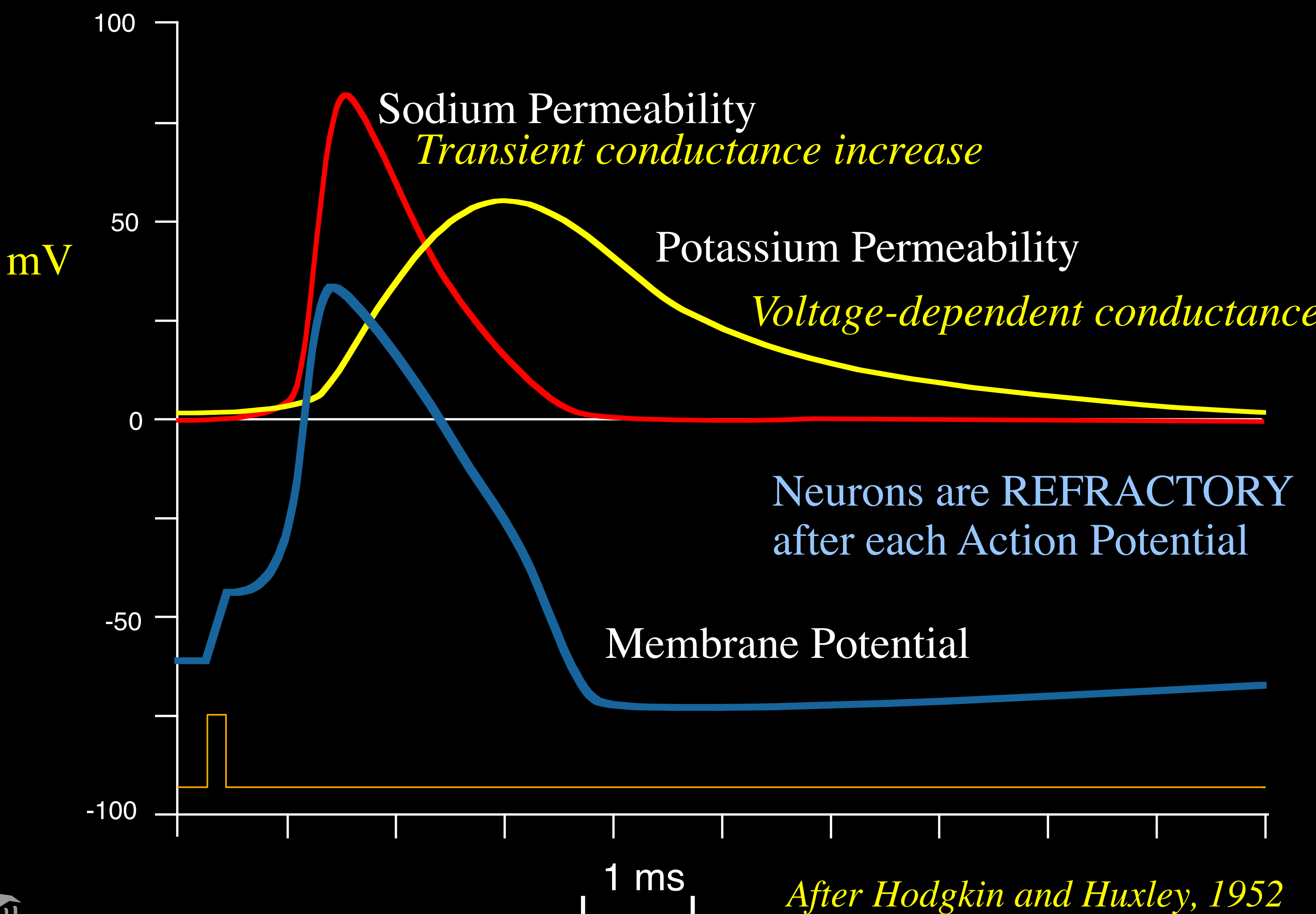
Electrical Behavior of Neurons





"Action Potential"

Current and Voltage



After Hodgkin and Huxley, 1952

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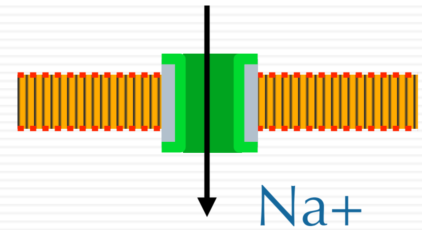
Sodium Leakage with Action Potentials

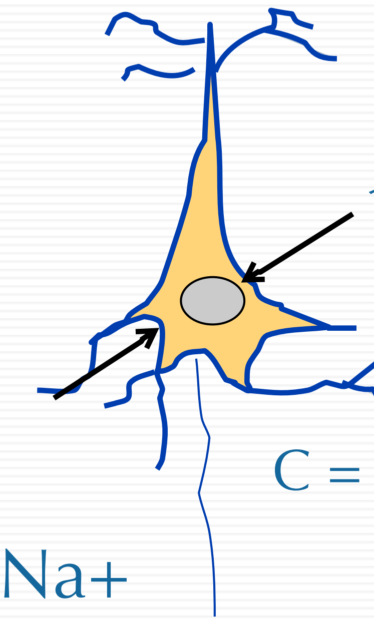
Cell Volume = 9×10^{-13} liters,
about half of which is liquid.

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+

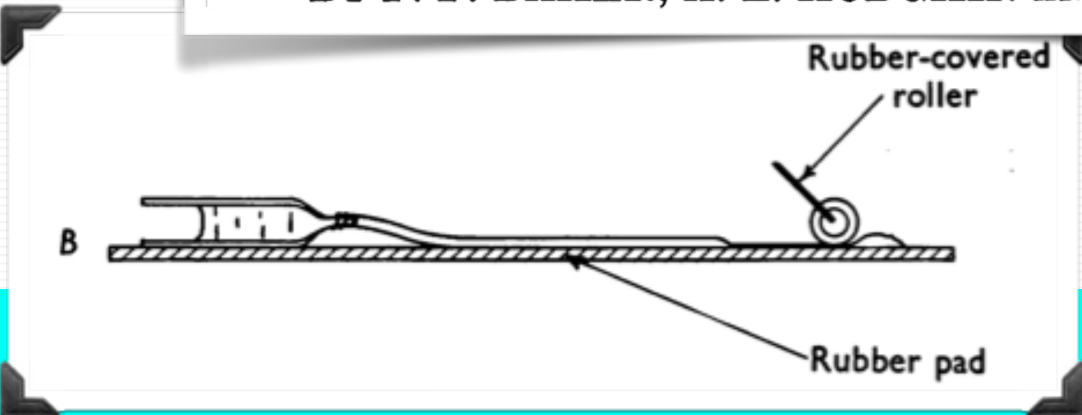
[Na+] is increased by 0.1% with each Action Potential!

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	$1{\cdot}1 \times 10^6$

NeuroImaging Training Program

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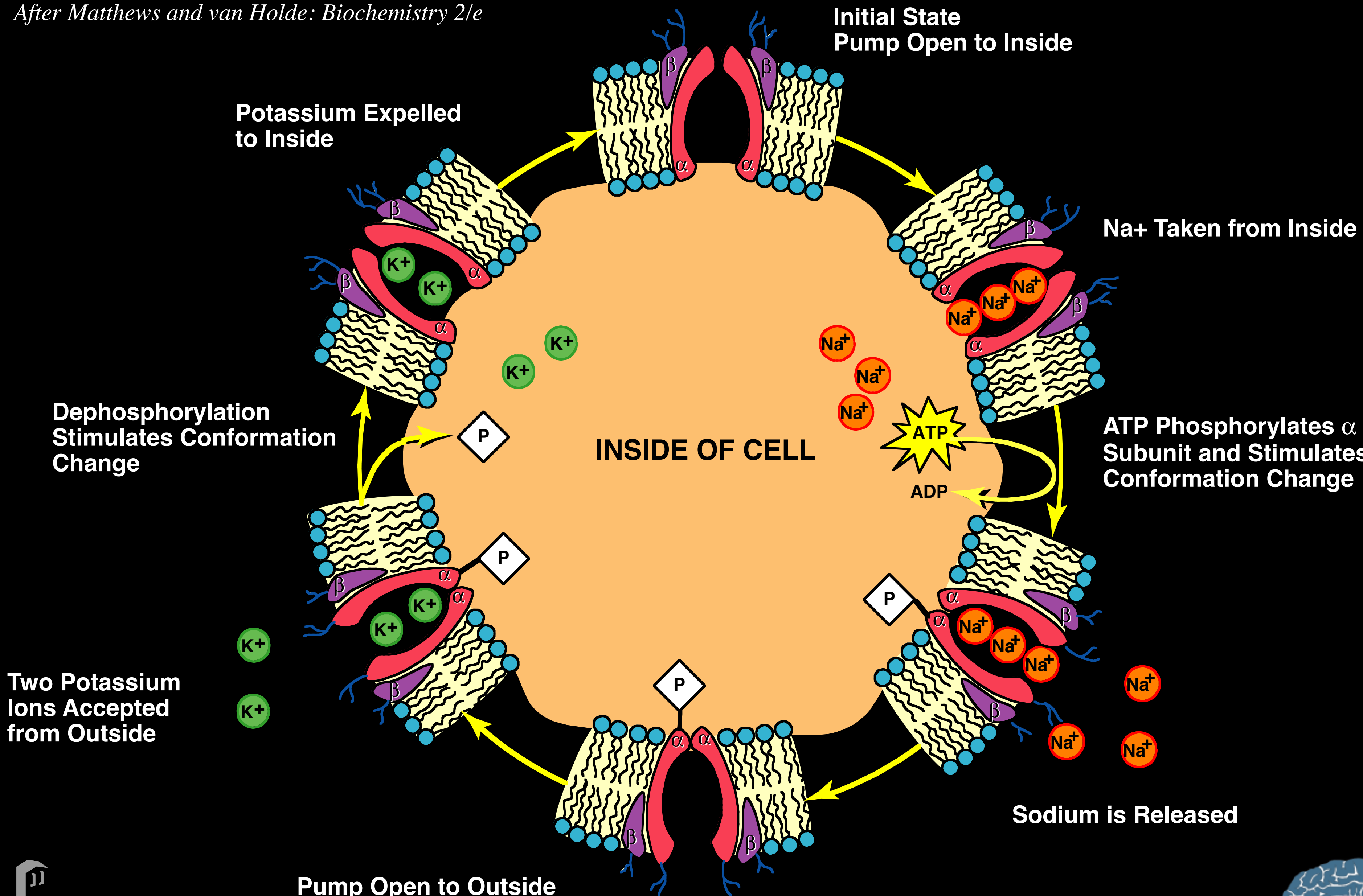
Sodium Potassium Pump

After Matthews and van Holde: Biochemistry 2/e



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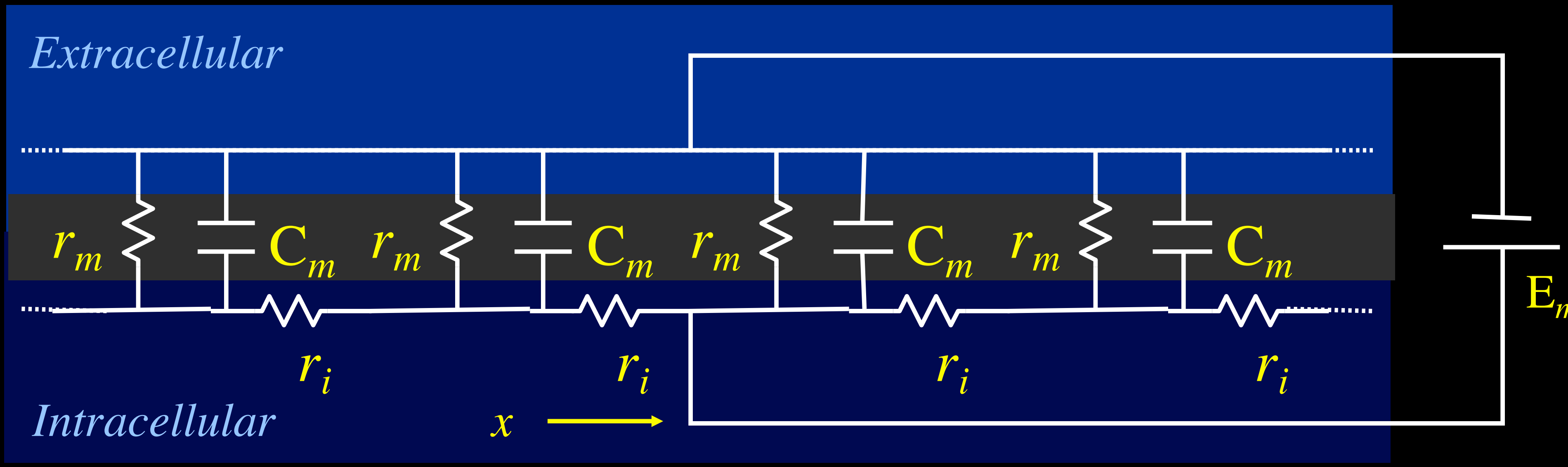
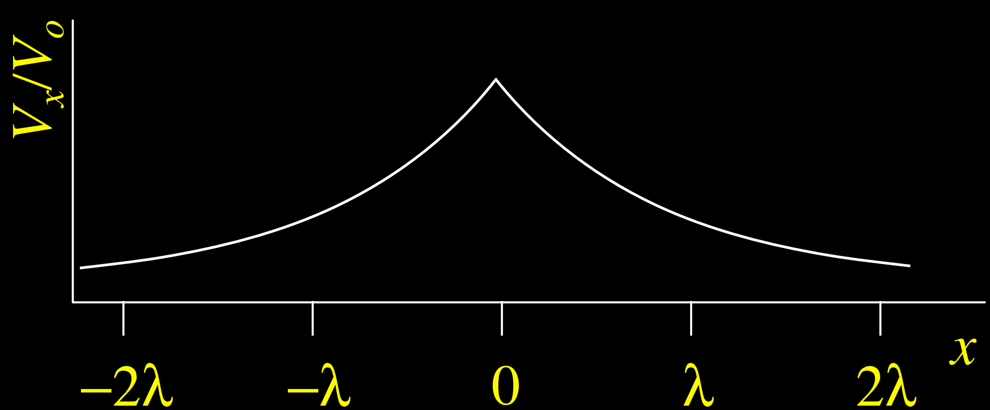
Cable Properties





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

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

For vertebrate neurons:

$\mu m < \lambda < mm$

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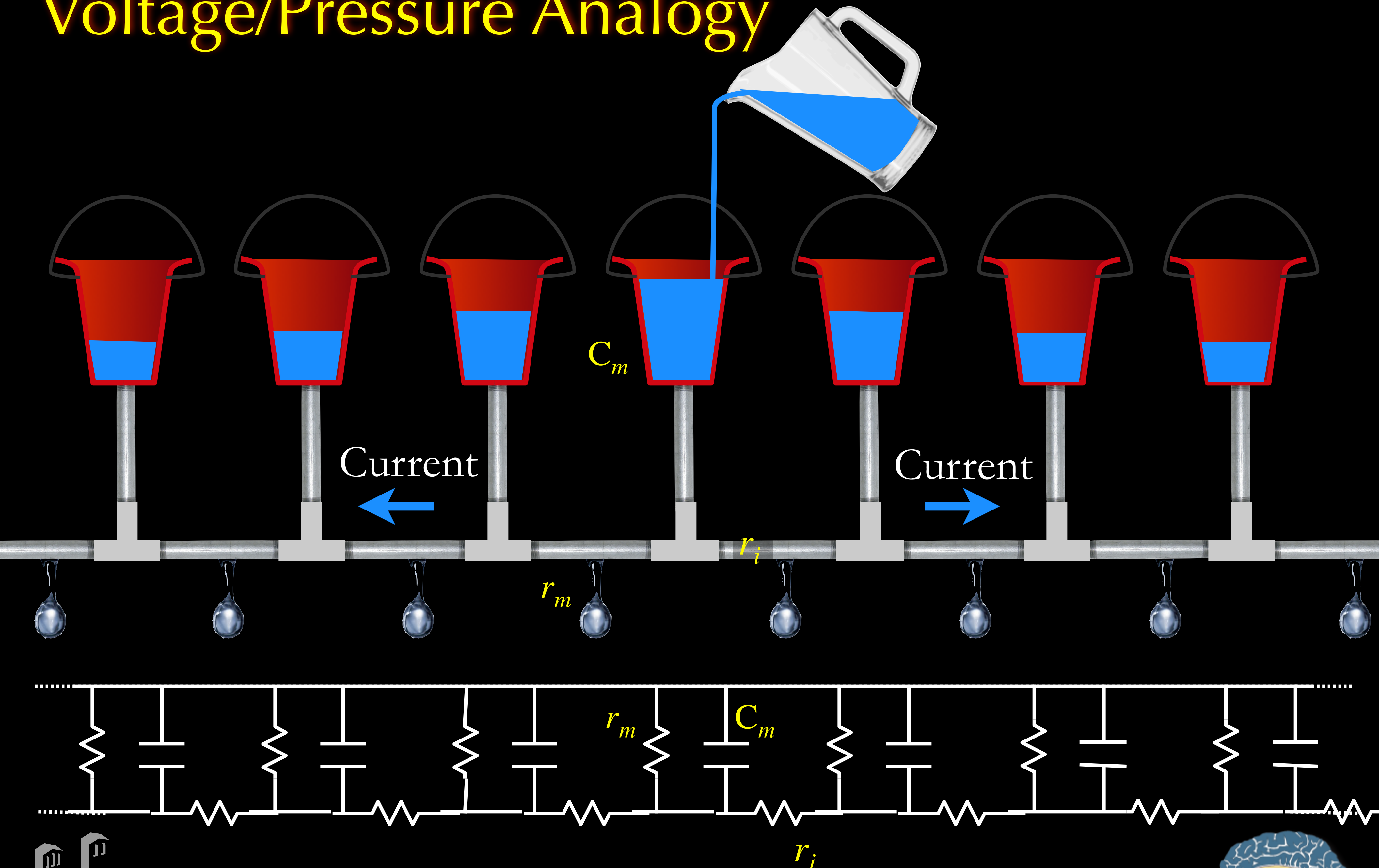
Voltage/Pressure Analogy



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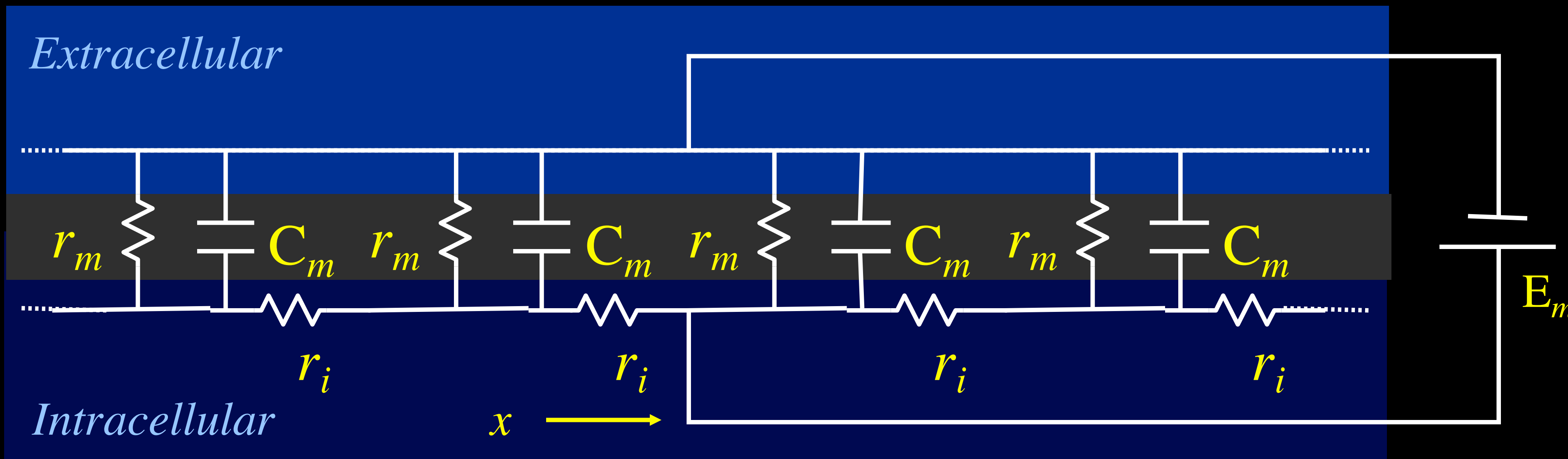
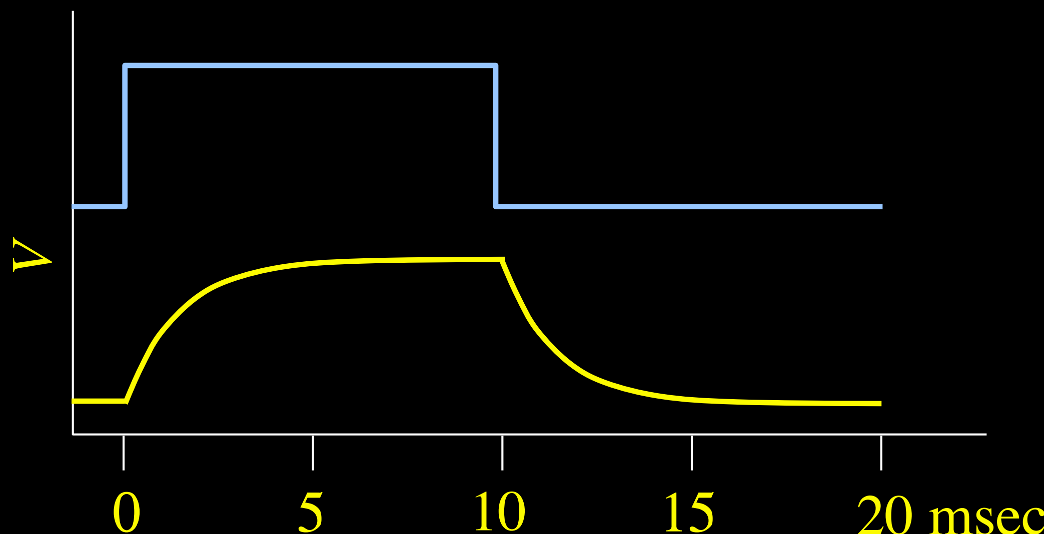
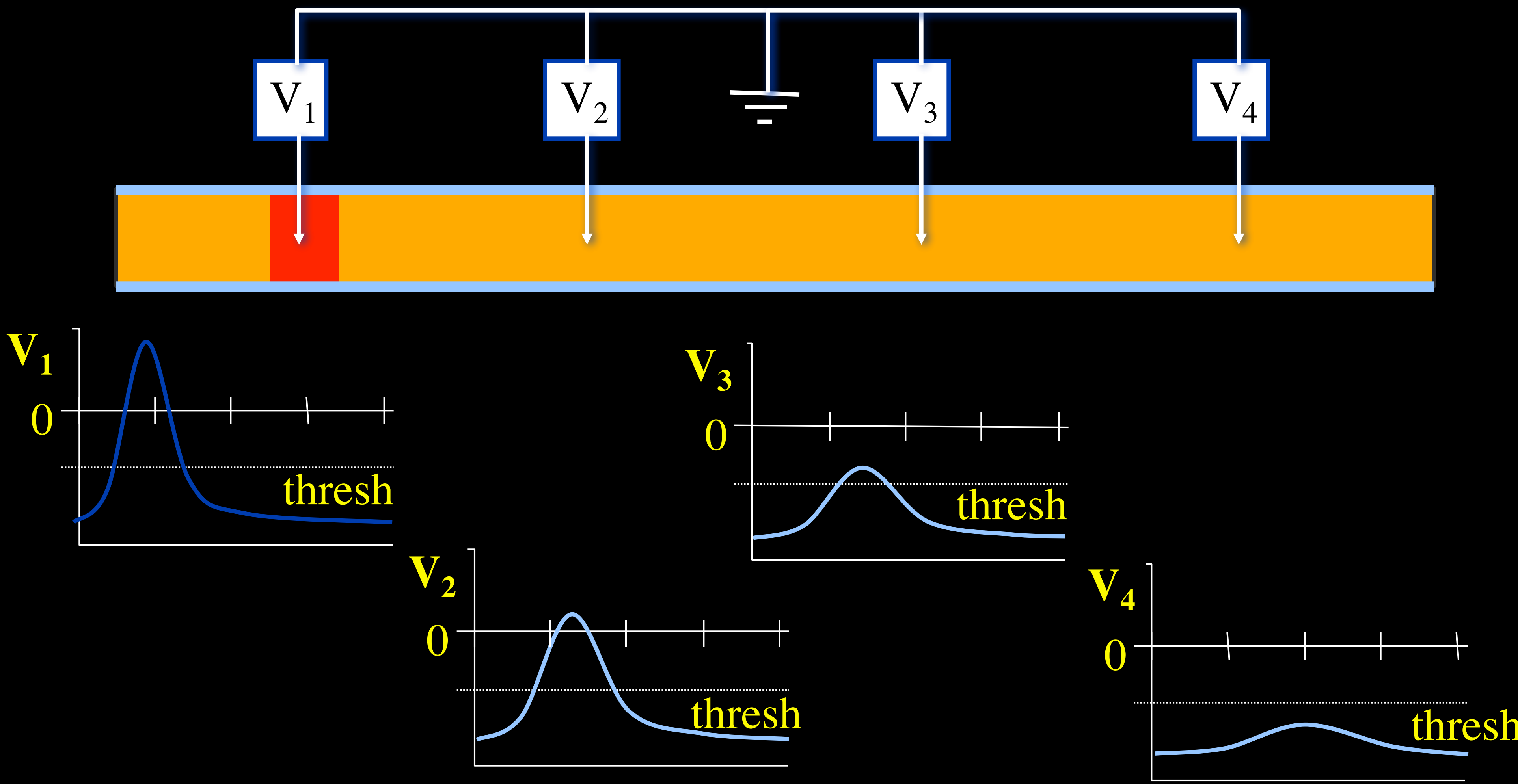
Cable Properties





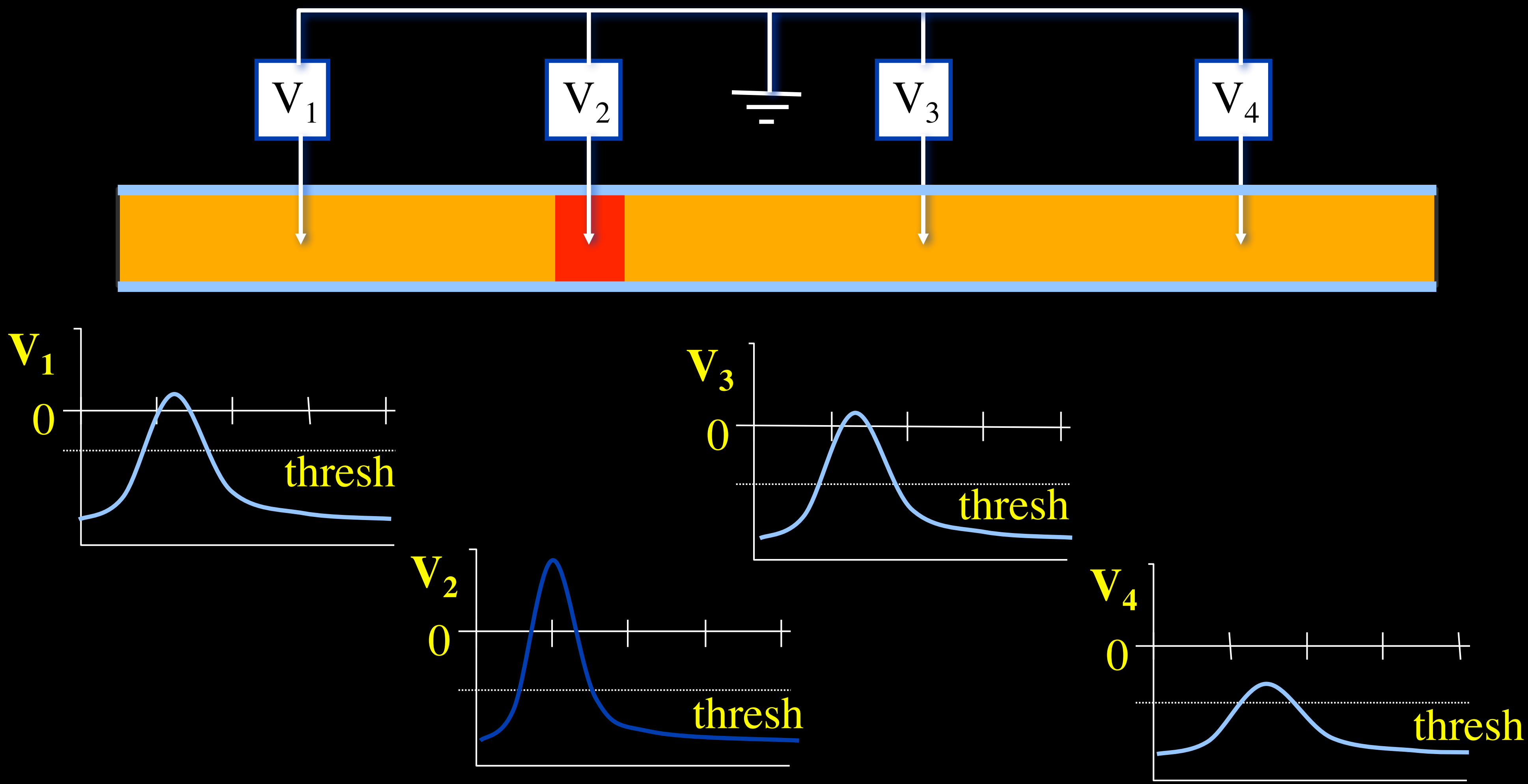
For vertebrate neurons:
0.5 msec < τ < 5 msec

Propagation of the Action Potential



Resulting Velocity ~1-3m/sec

Propagation of the Action Potential



Resulting Velocity ~1-3m/sec

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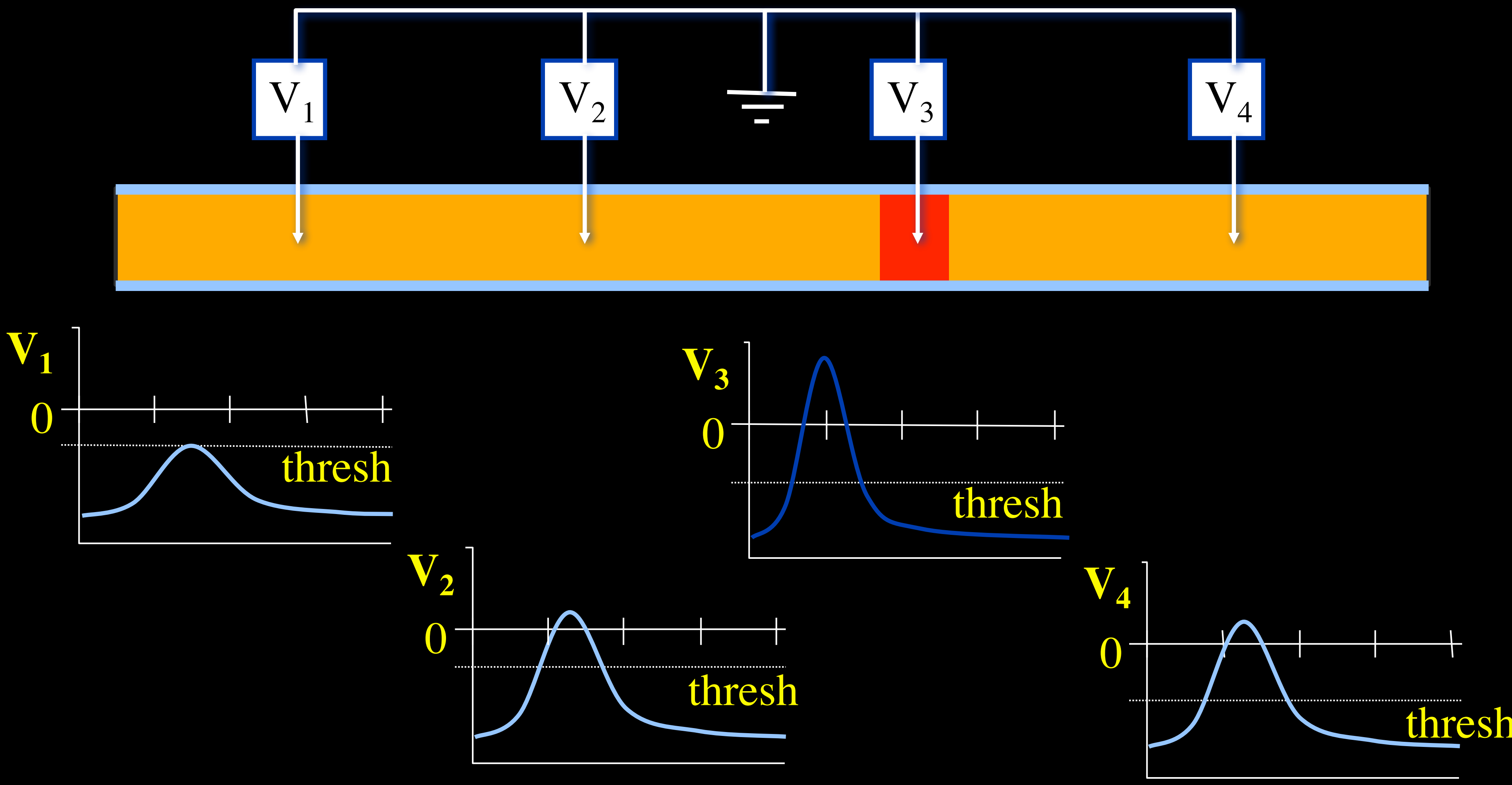
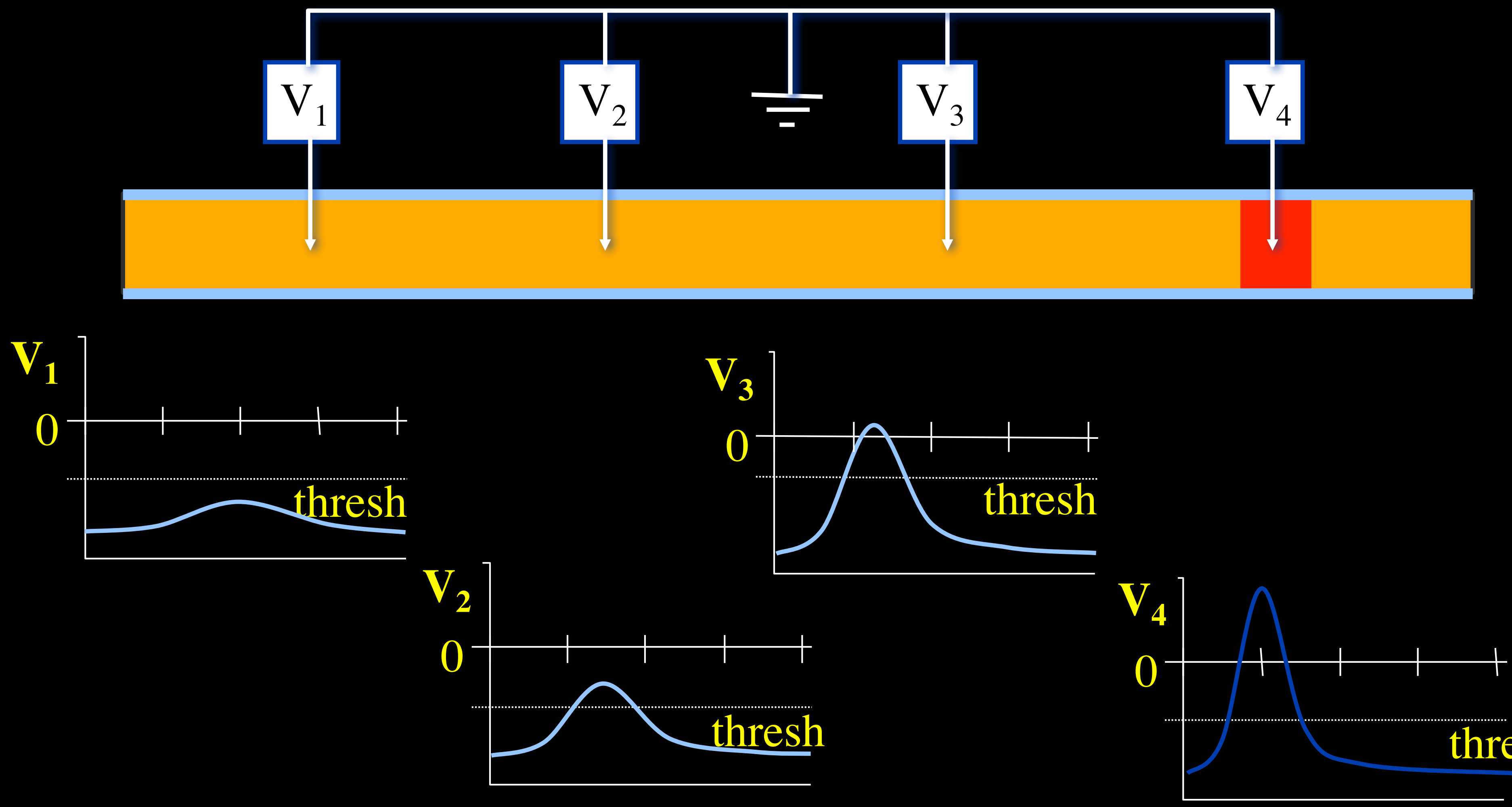
Propagation of the Action Potential



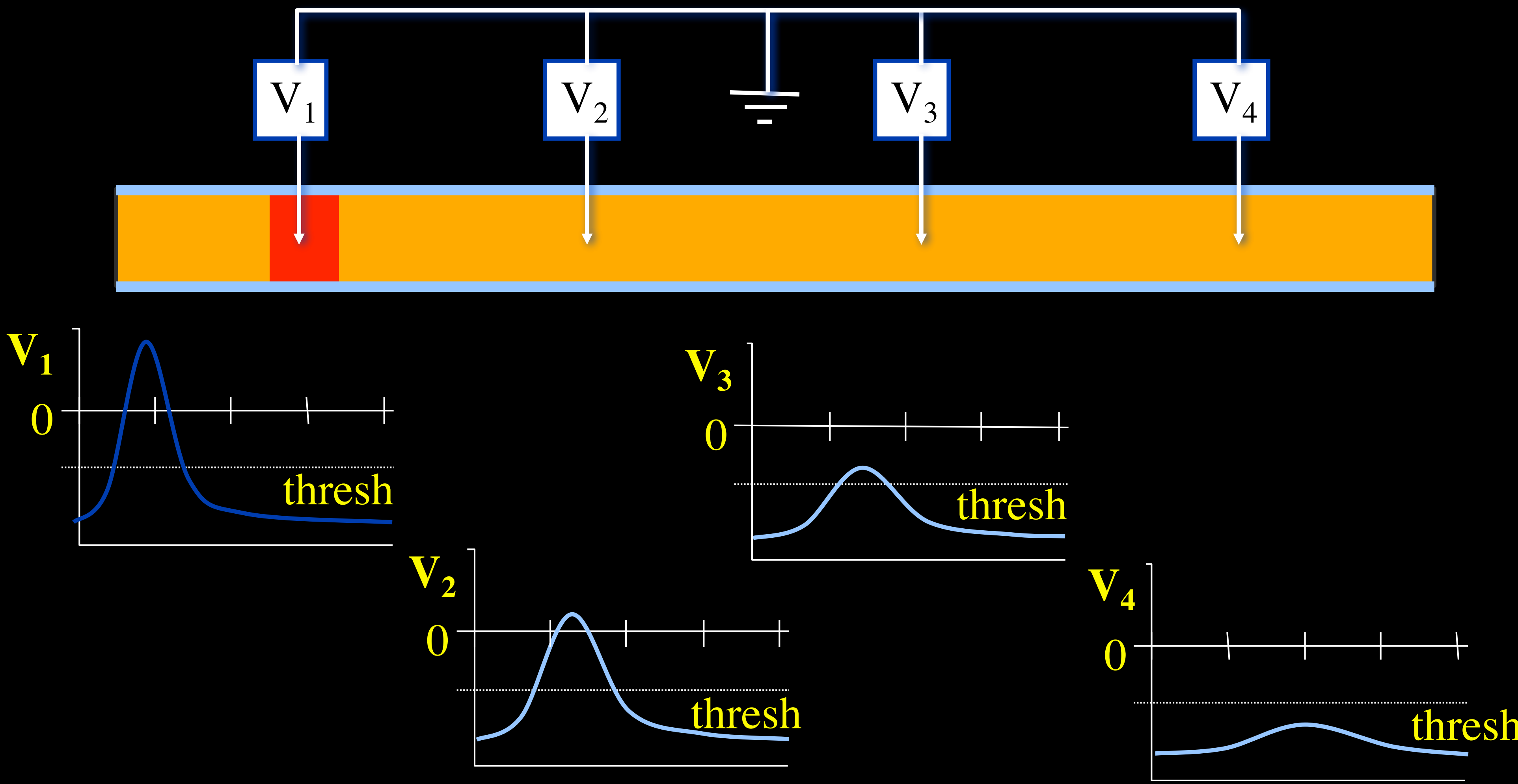
Resulting Velocity ~1-3m/sec

Propagation of the Action Potential



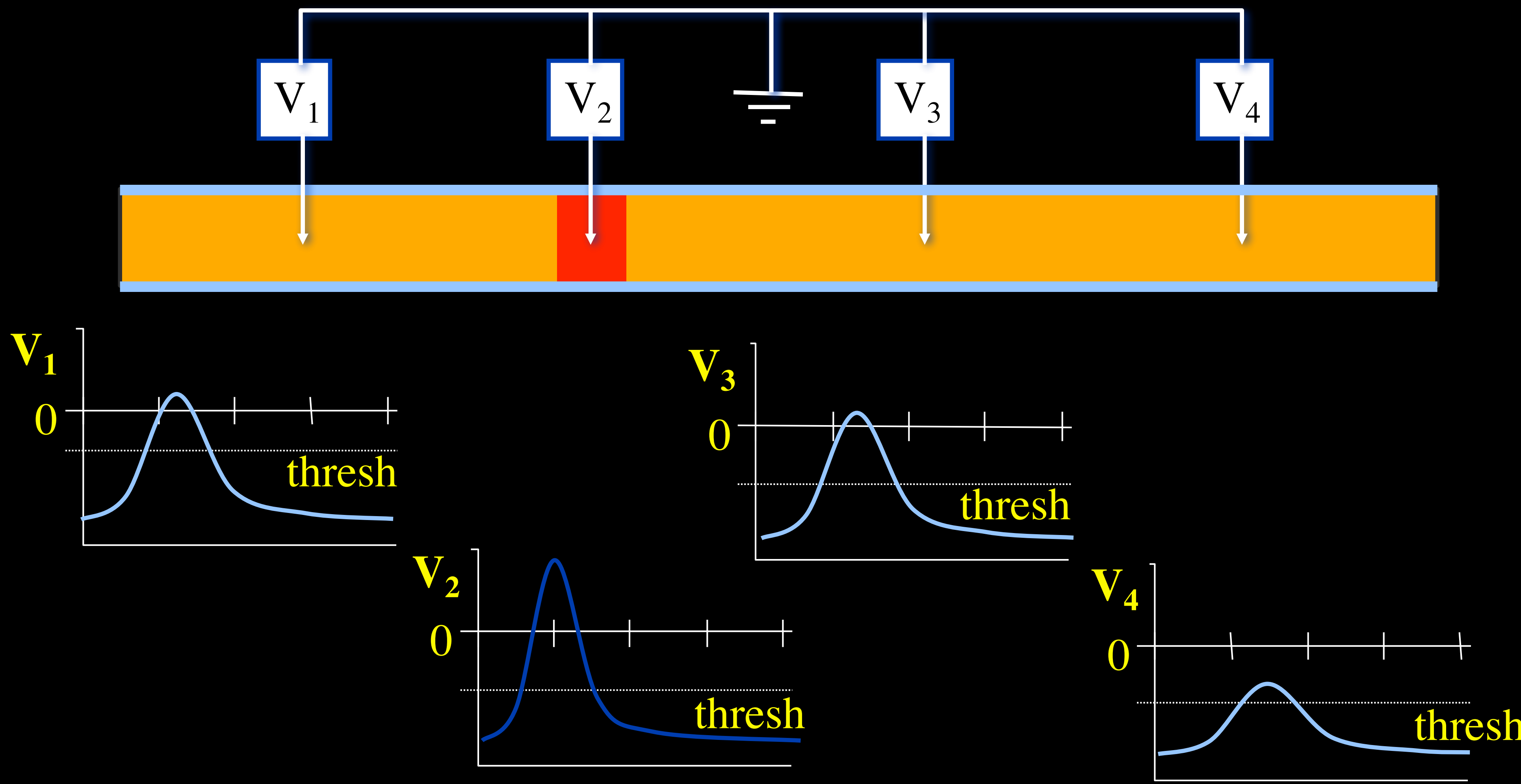
Resulting Velocity ~1-3m/sec

Propagation of the Action Potential



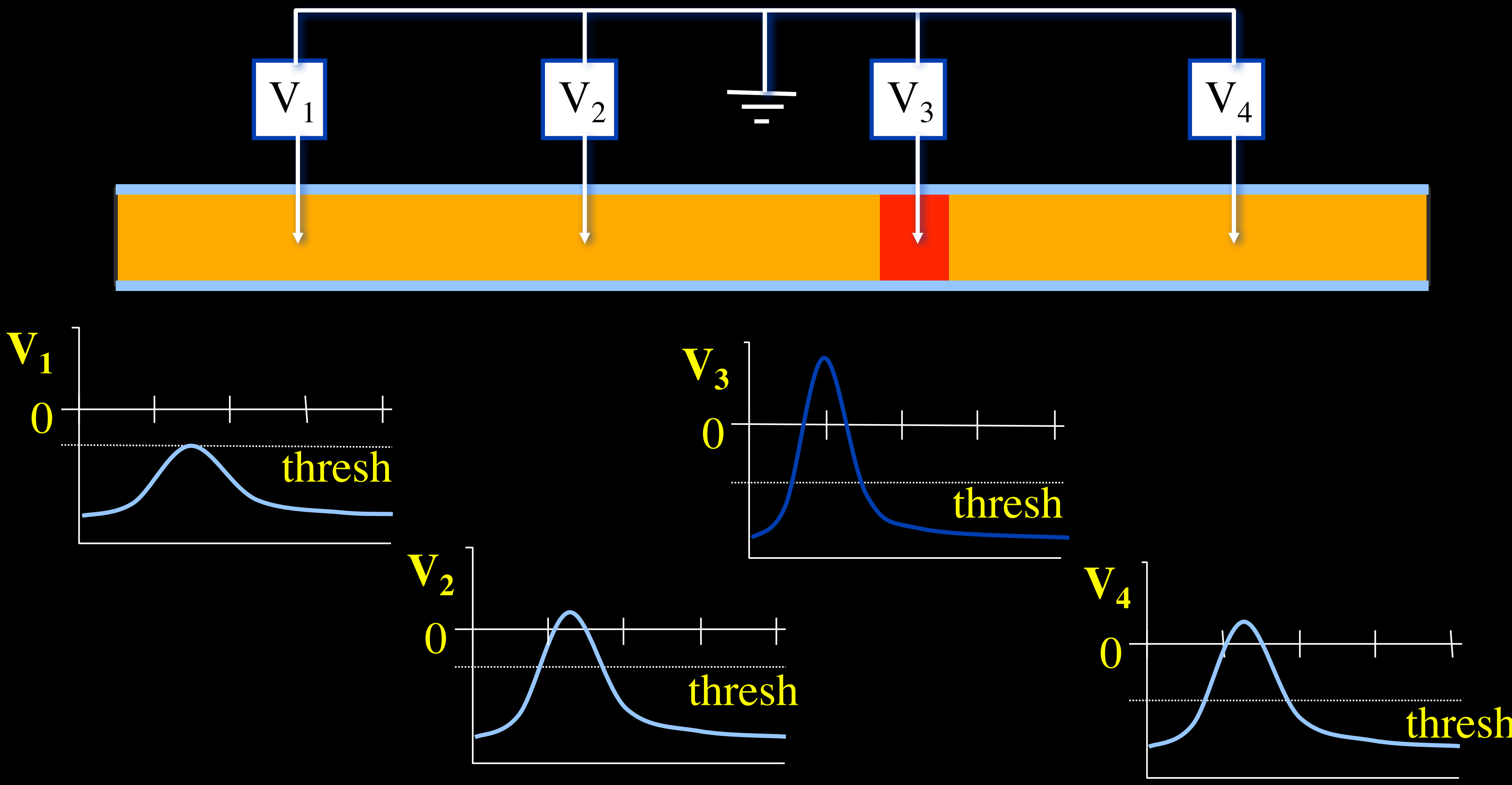
Resulting Velocity ~1-3m/sec

Propagation of the Action Potential



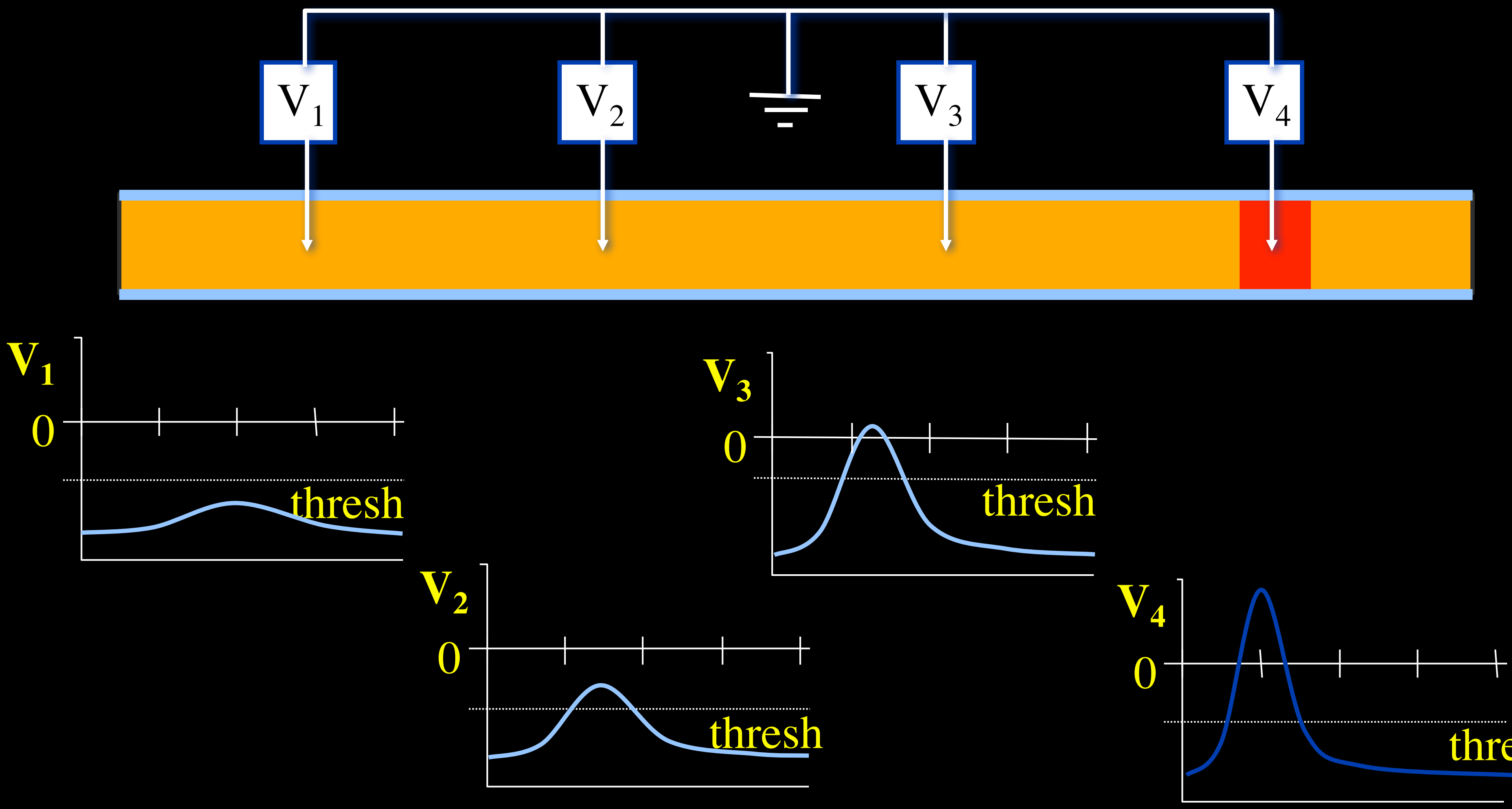
Resulting Velocity ~1-3m/sec

Propagation of the Action Potential



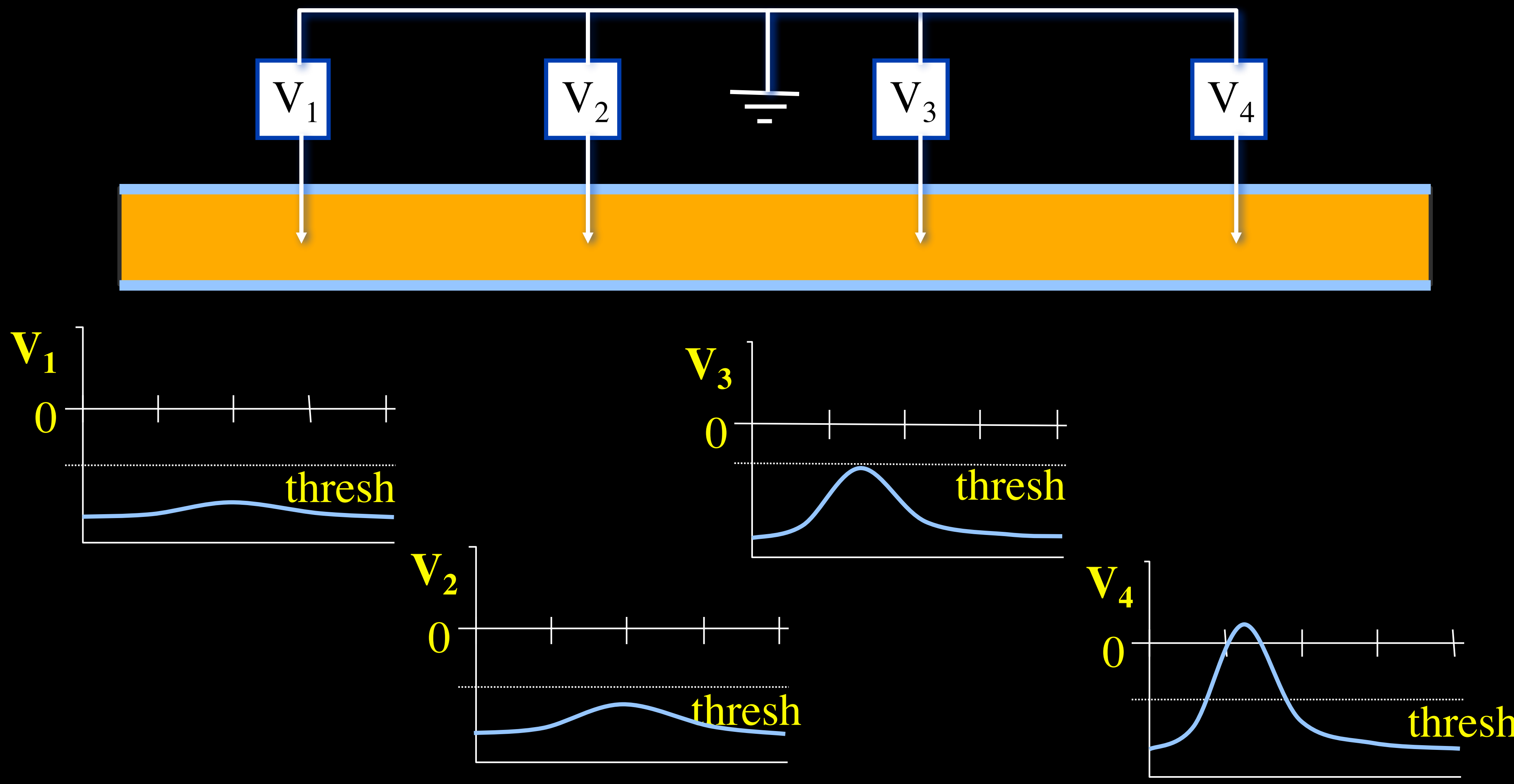
Resulting Velocity ~1-3m/sec

Propagation of the Action Potential



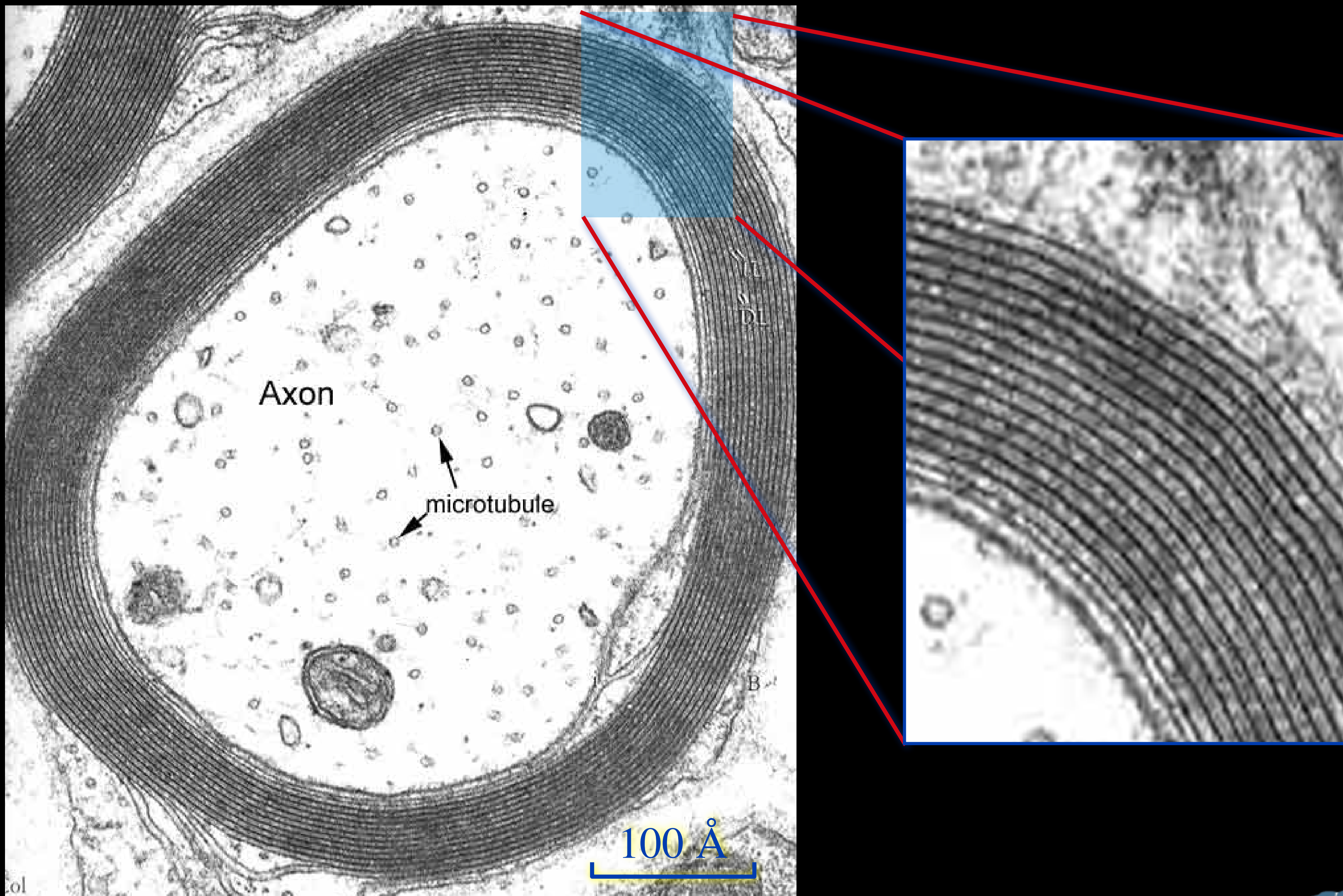
Resulting Velocity ~1-3m/sec

Propagation of the Action Potential

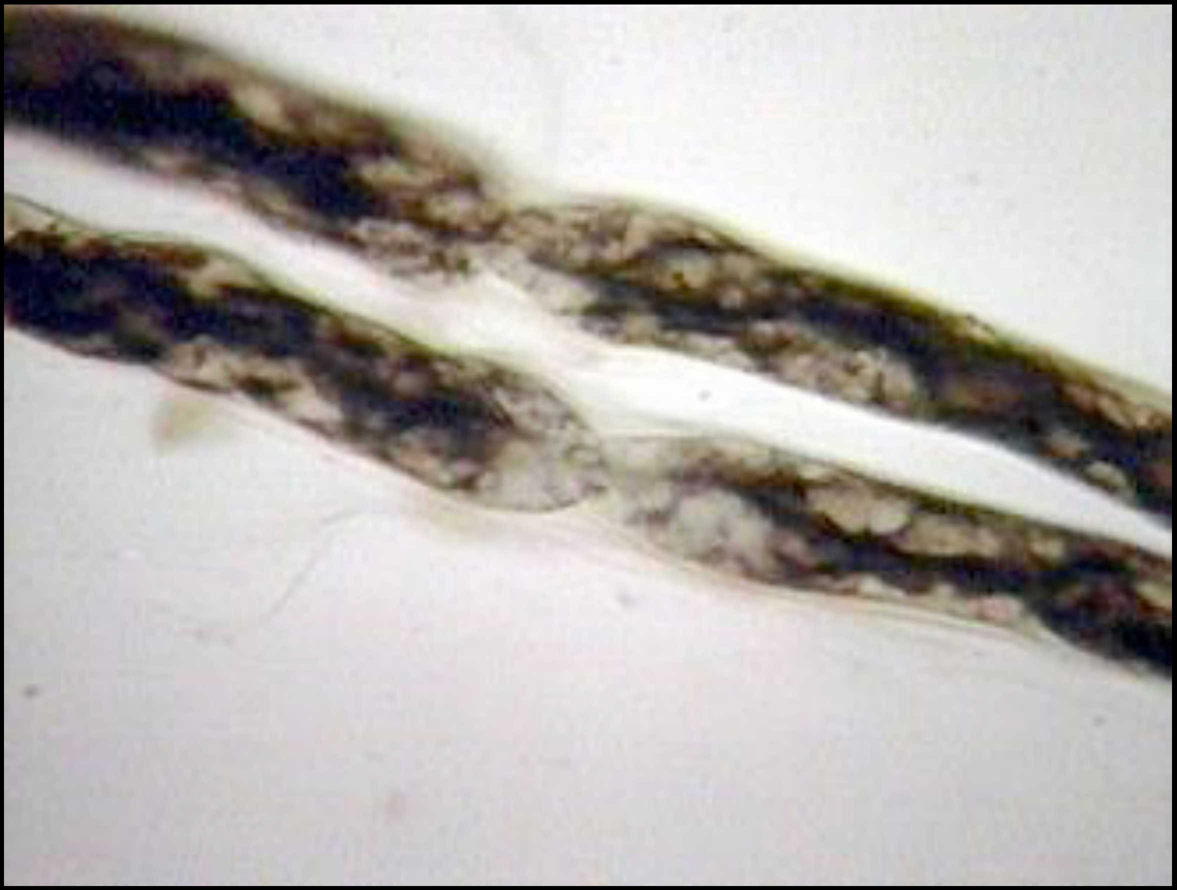


Resulting Velocity ~1-3m/sec

Myelin Sheath



Nodes of Ranvier



Saltatory Conduction

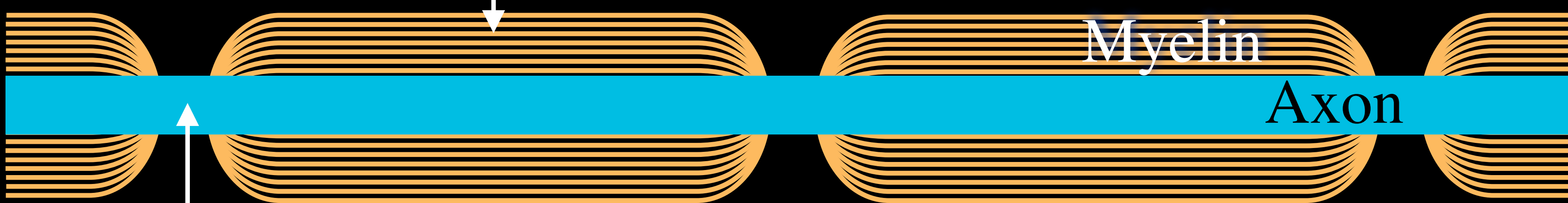
Internode:

High Membrane Resistance

Long Spatial Constant

Short Time Constant

Efficient Electrotonic Conduction



Node:

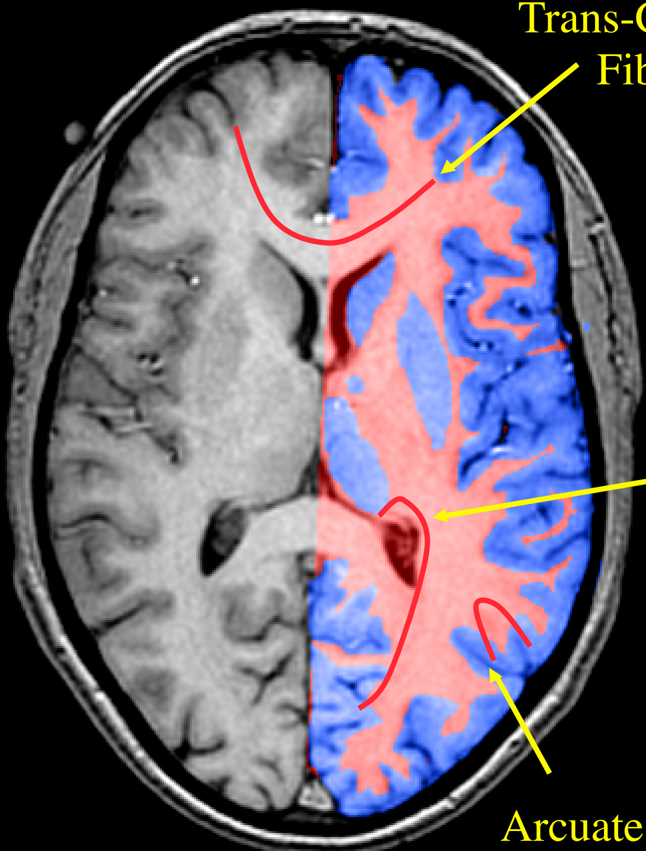
Low Membrane Resistance

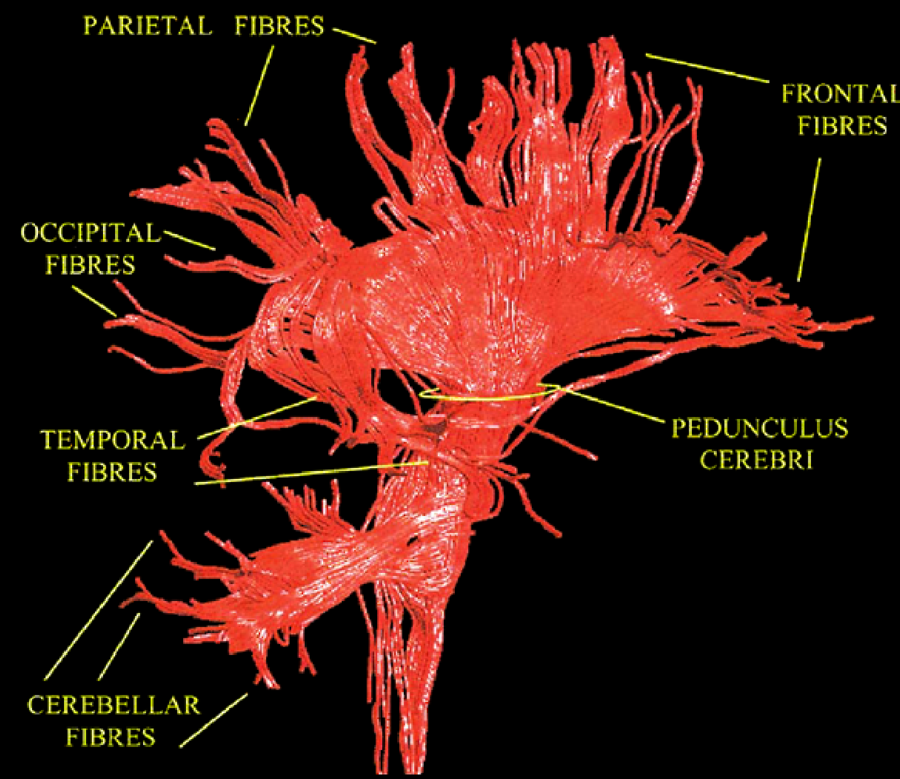
High Membrane Current Flow

Fires Action Potential

Action Potential Regeneration

White and Gray Matter

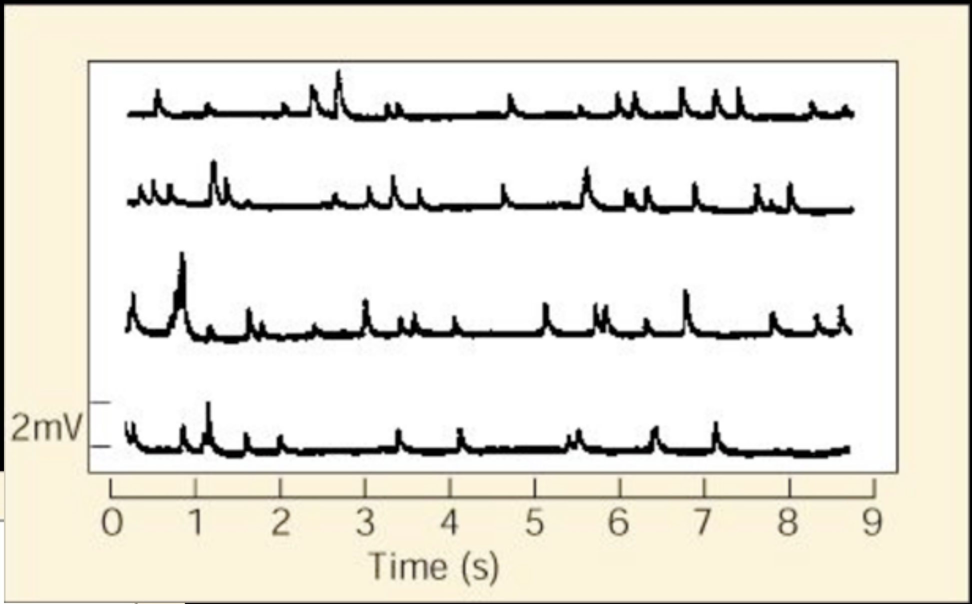


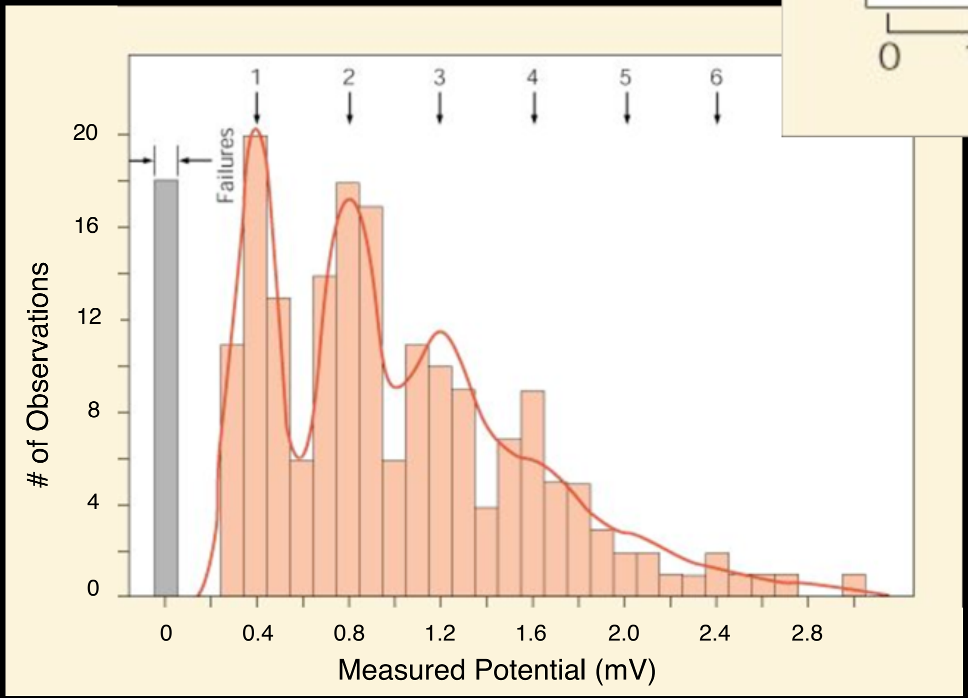


After: Catani, et al., NeuroImage 17:77, 2002

EPSP's: *Excitatory Post-Synaptic Potentials*

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

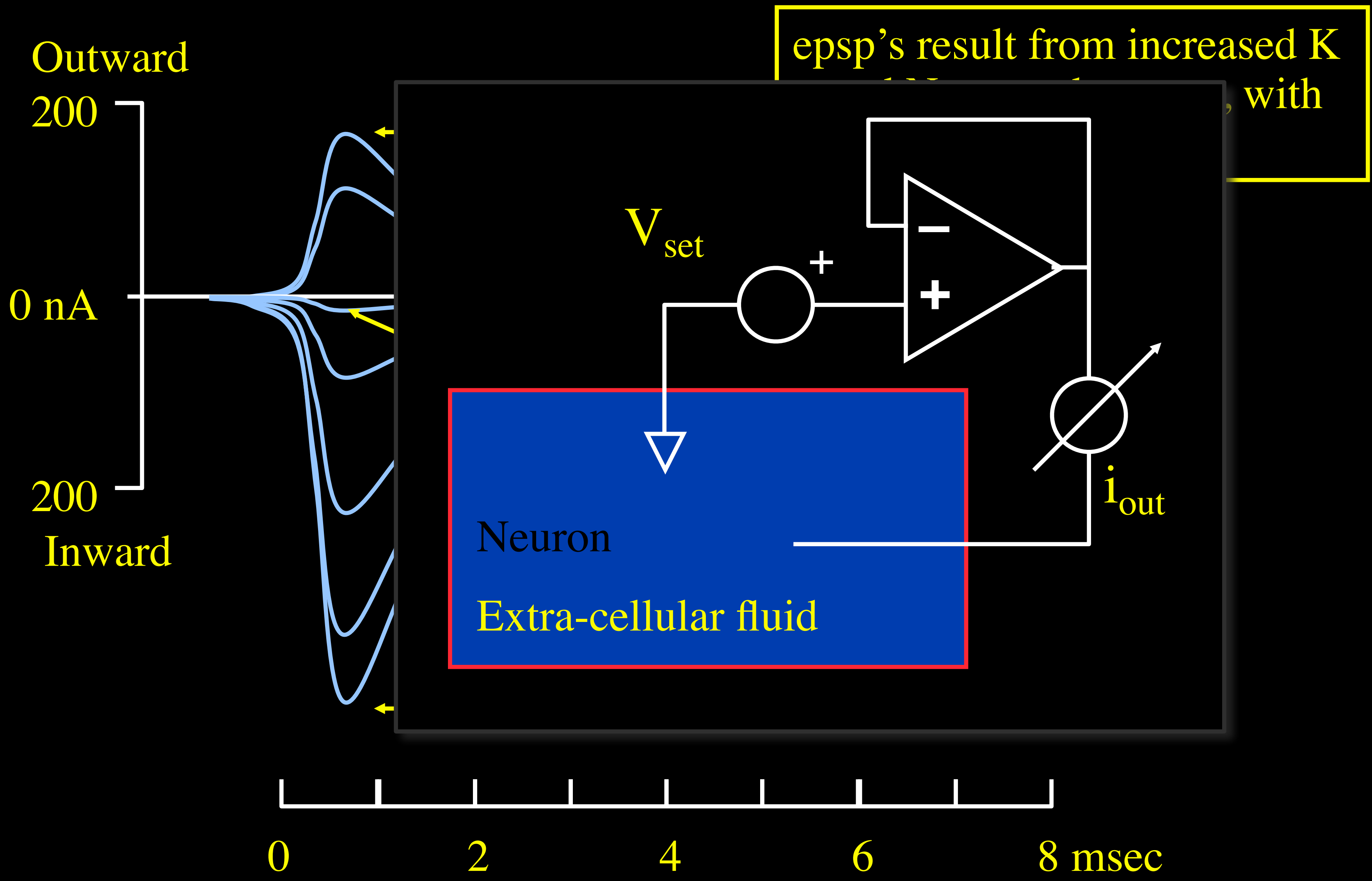




Amplitudes are *quantized* and display a Poisson distribution

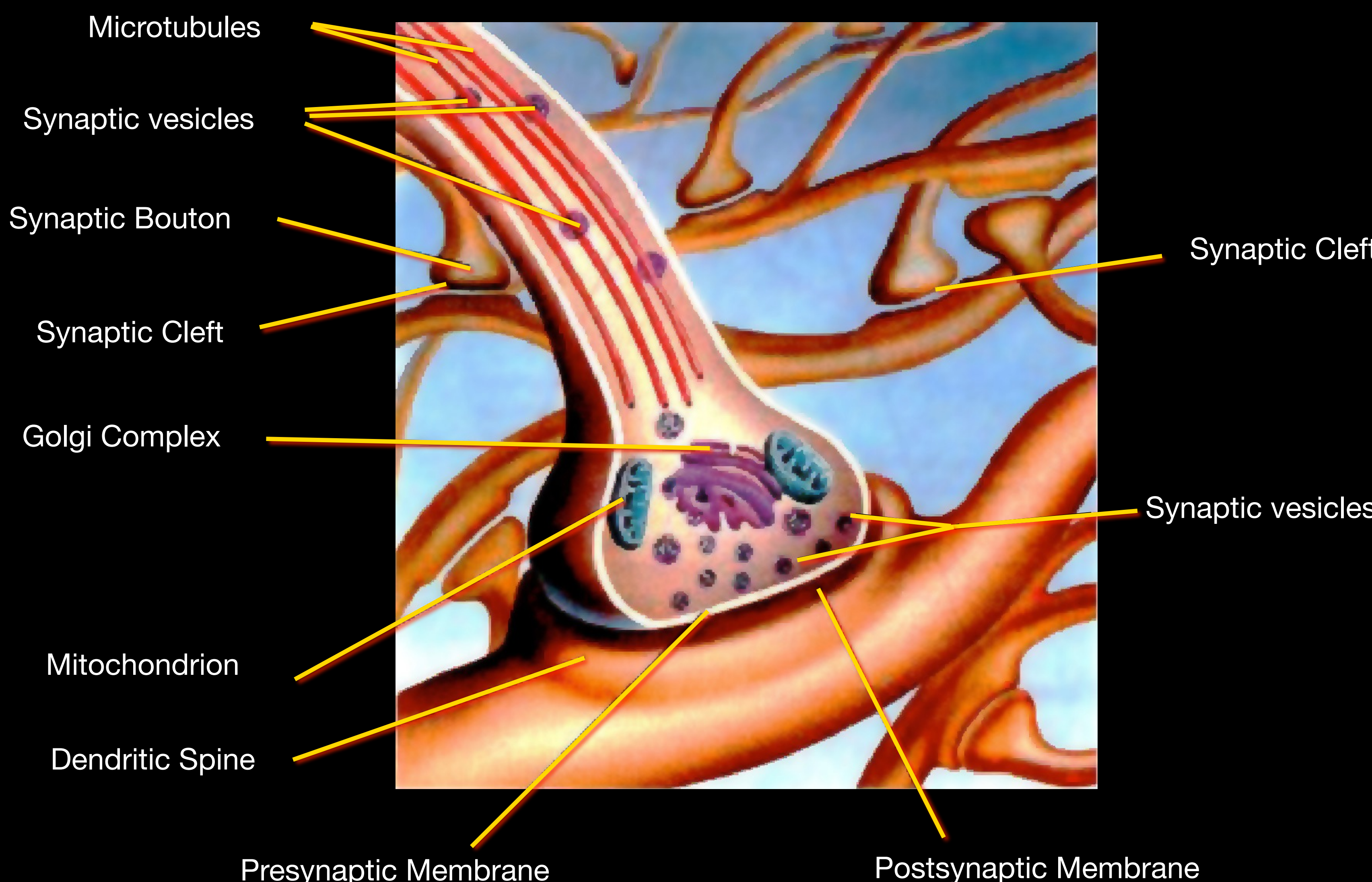
$$f(k;\lambda) = \frac{\lambda^k e^{-\lambda}}{k!}$$

Reversal Potential



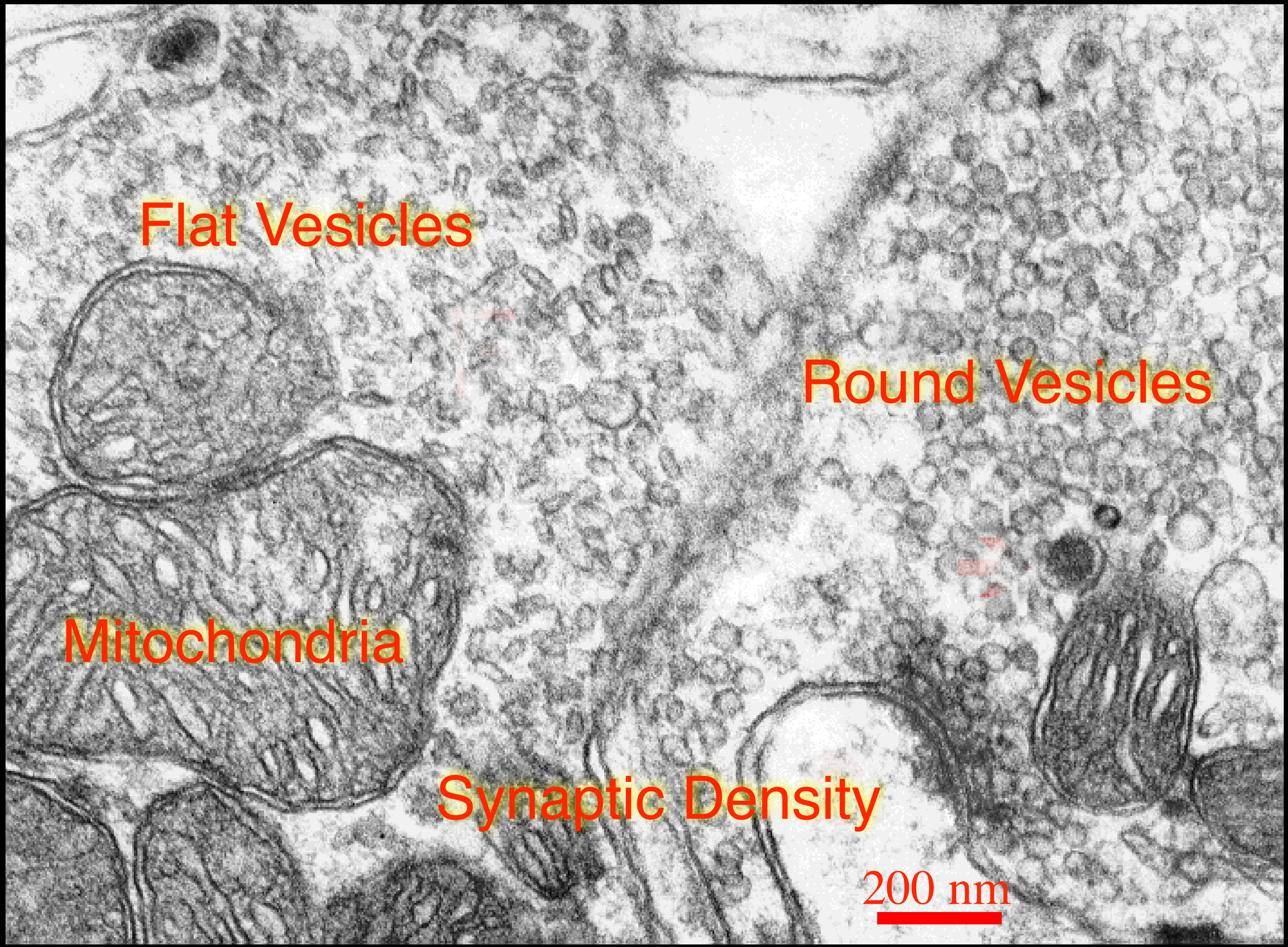
After Magleby and Stevens, 1972

Neural Synapse



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

Synapses by EM

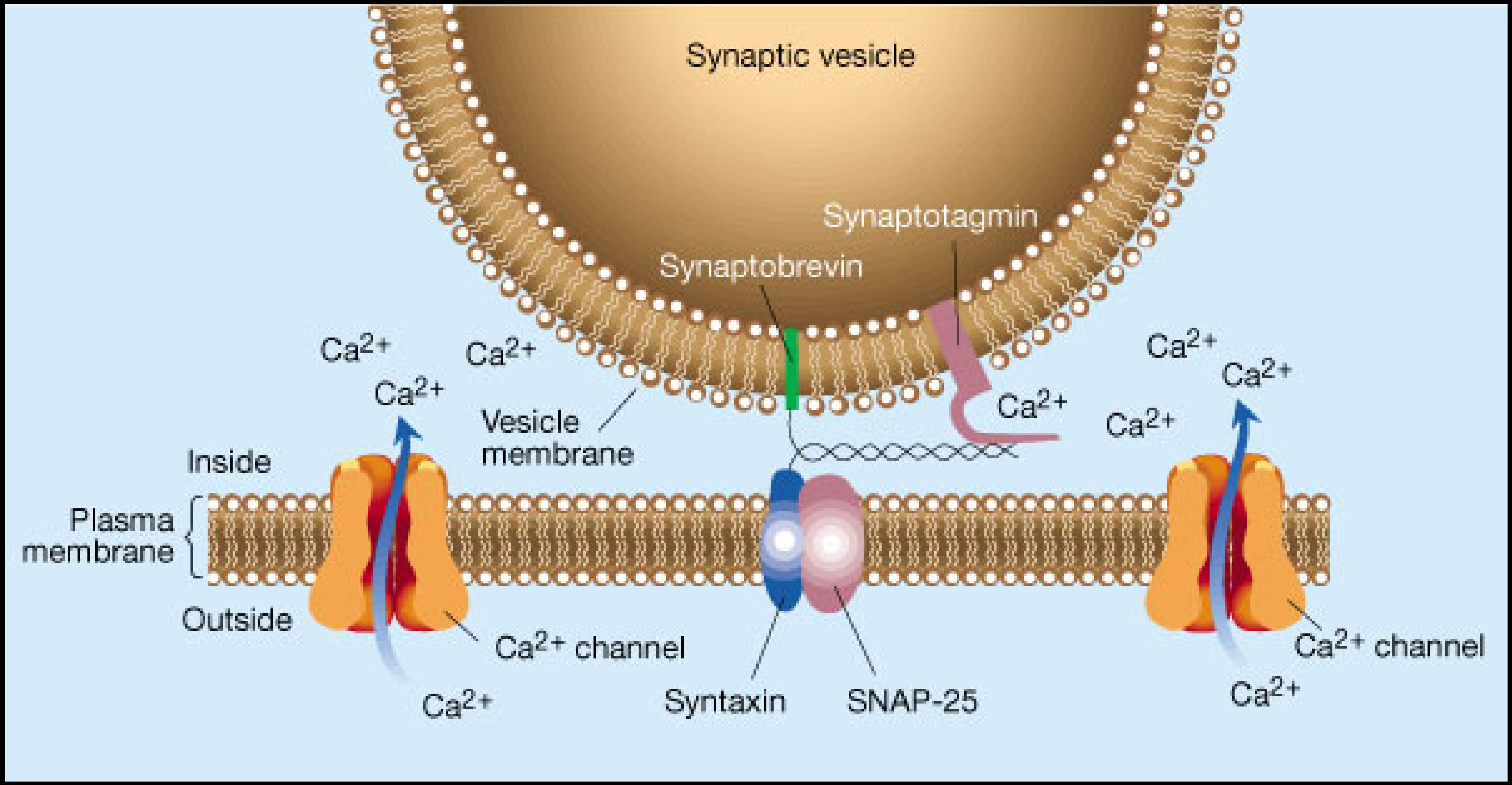


Atlas of Ultrastructural Neurocytology
http://synapses.mcg.edu/atlas/1_6_1.stm

Synaptic Mechanism (movie)

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

Synaptic Vesicles



Exocytosis of Transmitter requires Ca^{2+}

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

Neurotransmitters

Small Molecules:

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

Amino Acids

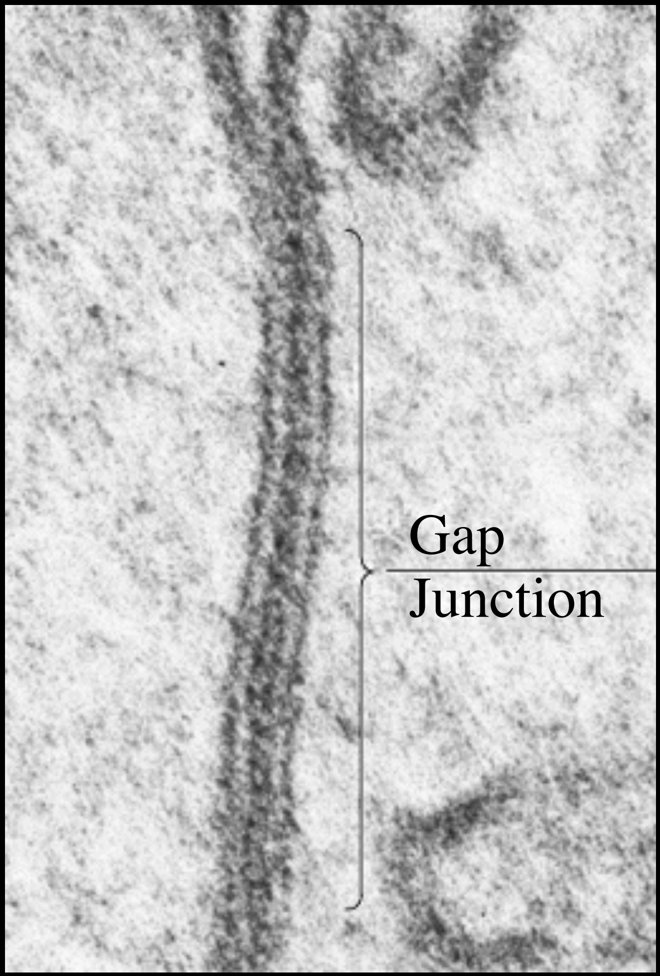
- Aspartate
- Gamma-aminobutyric Acid
- Glutamate
- Glycine

Peptides

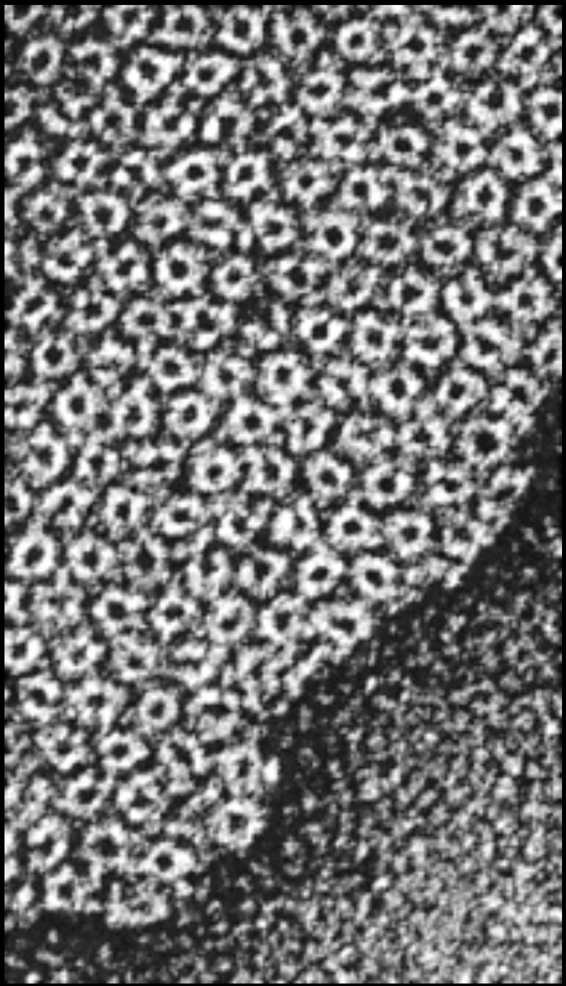
- Angiotensin II
- Bradykinin
- Beta-endorphin
- Bombesin
- Calcitonin
- Cholecystokinin
- Enkephalin
- Dynorphin
- Insulin
- Galanin
- Gastrin
- Glucagon
- GRH
- GHRH
- Motilin
- Neurotensin
- Neuropeptide Y
- Substance P
- Secretin
- Somatostatin
- Vasopressin
- Oxytocin
- Prolactin
- Thyrotropin
-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

…and many others

Electrical Synapses



50 nm



50 nm

Cohen

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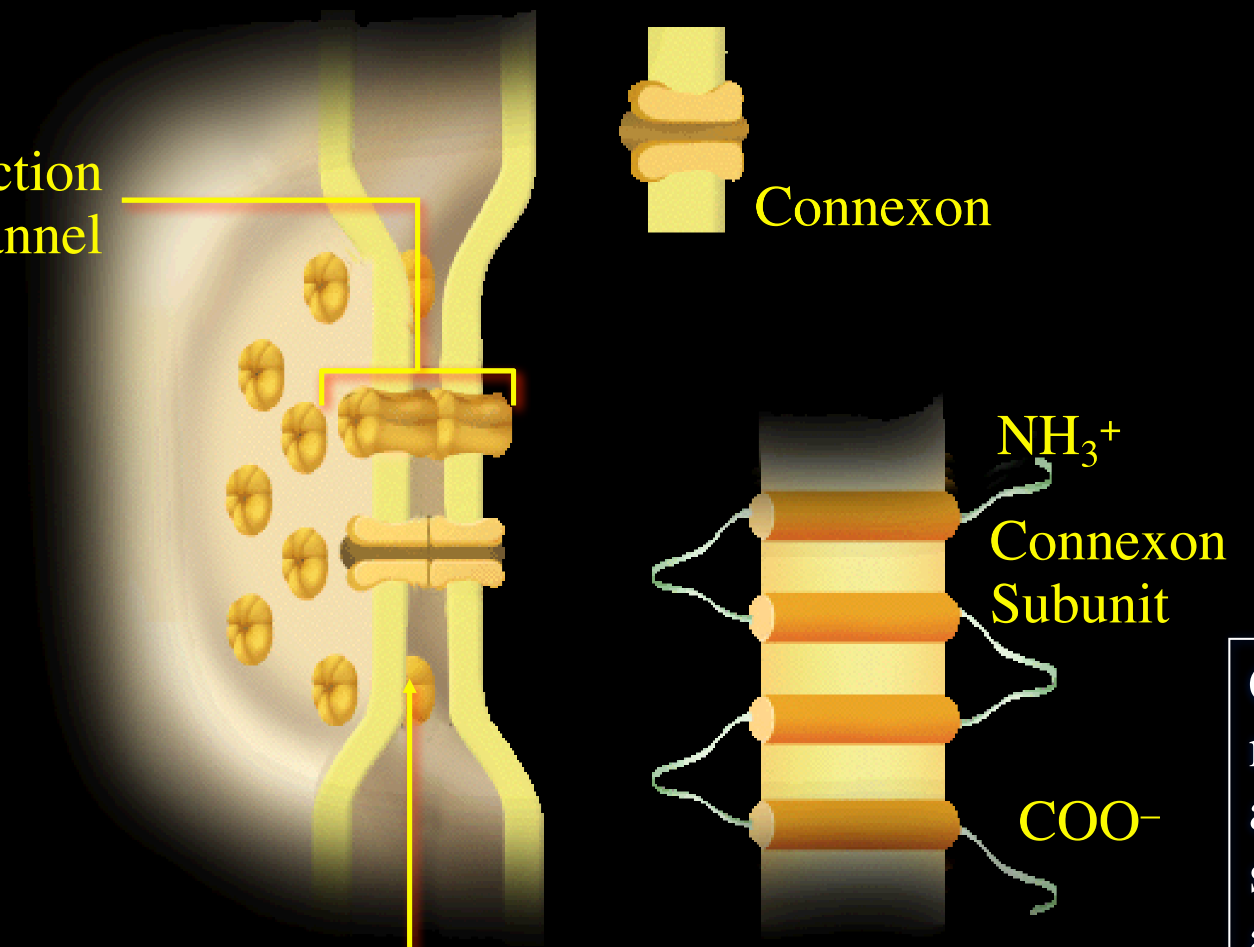
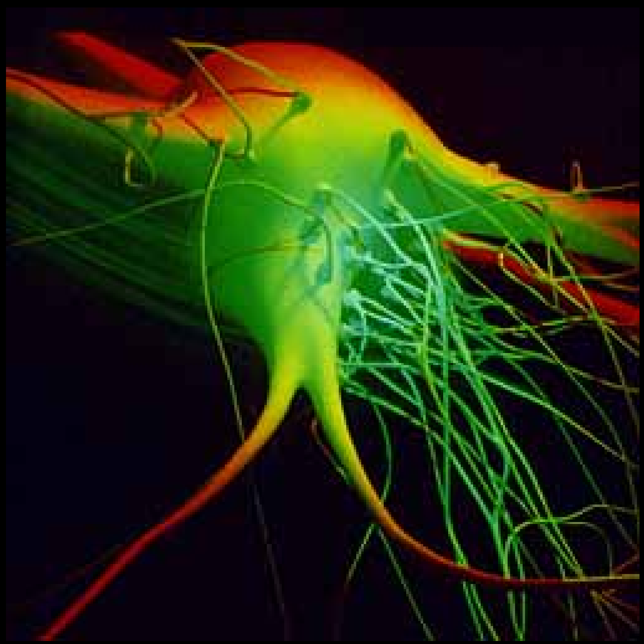
Gap Junction Microstructure

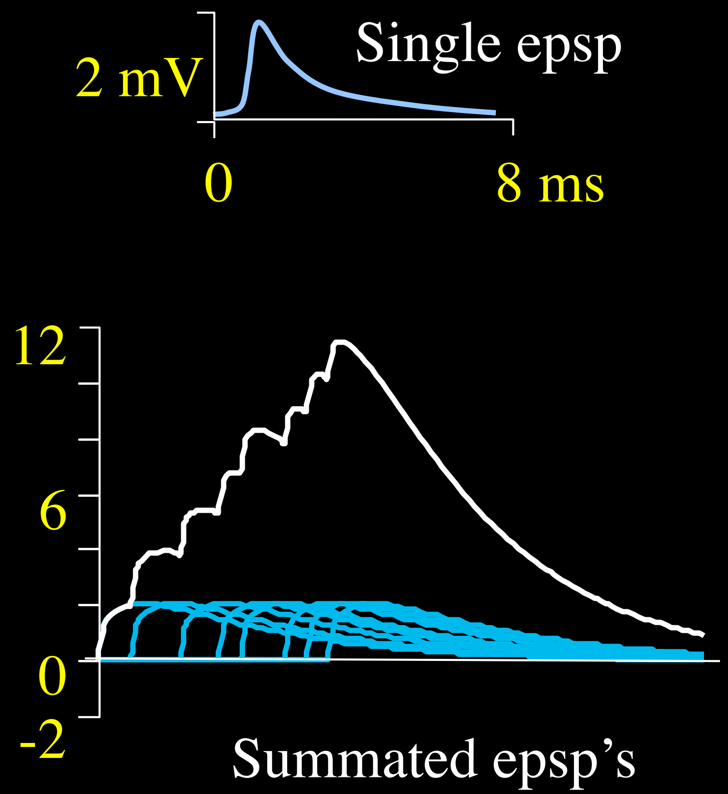


Gap Junctions have no synaptic delay, and may act as simple resistance or as electrical *rectifiers*

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

SpatioTemporal Summation of psp's



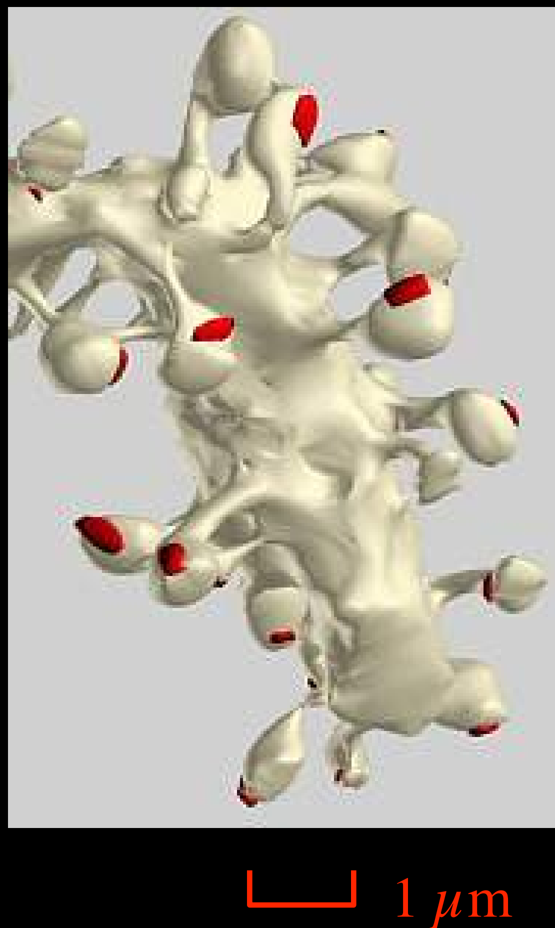


http://www.oseplus.de/Images/jpg/Synapse1.jpg

Integration of Inputs

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

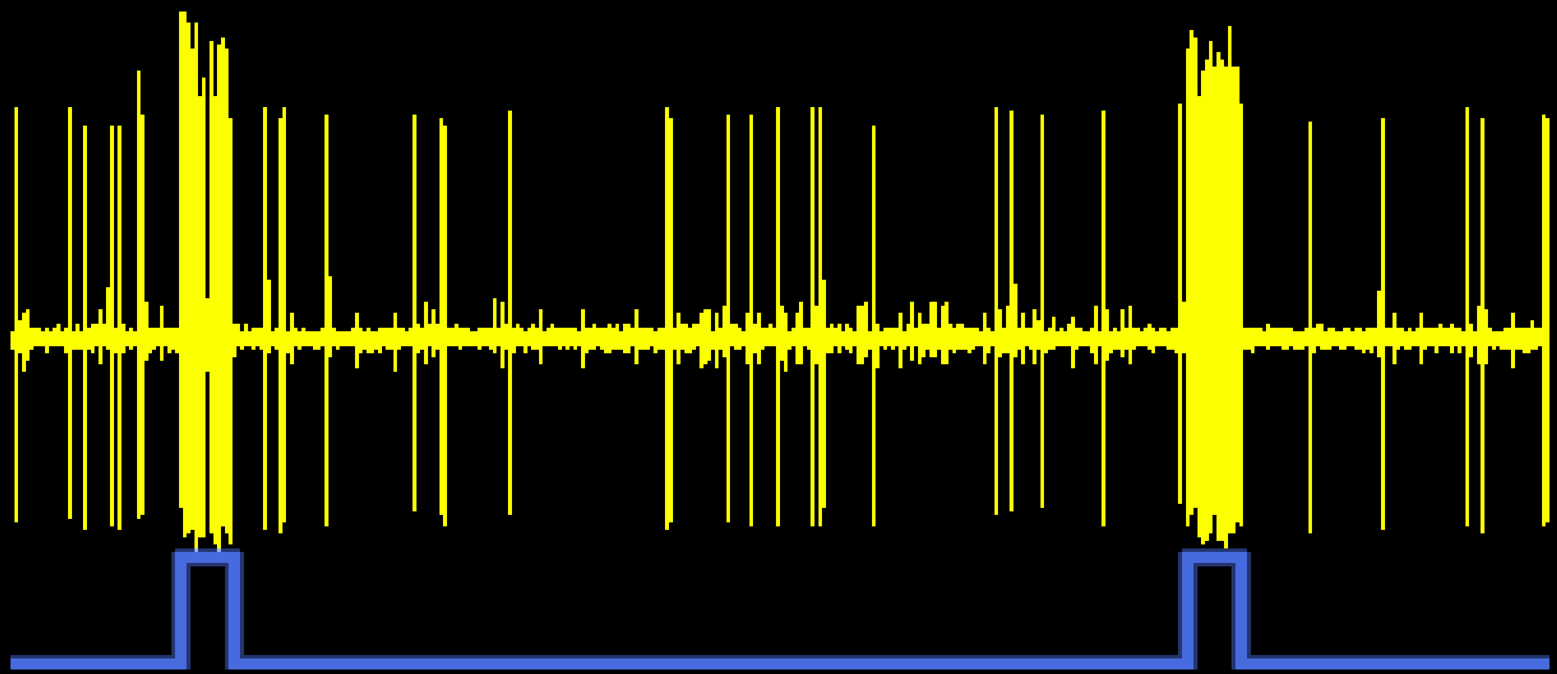
Dendritic Spines



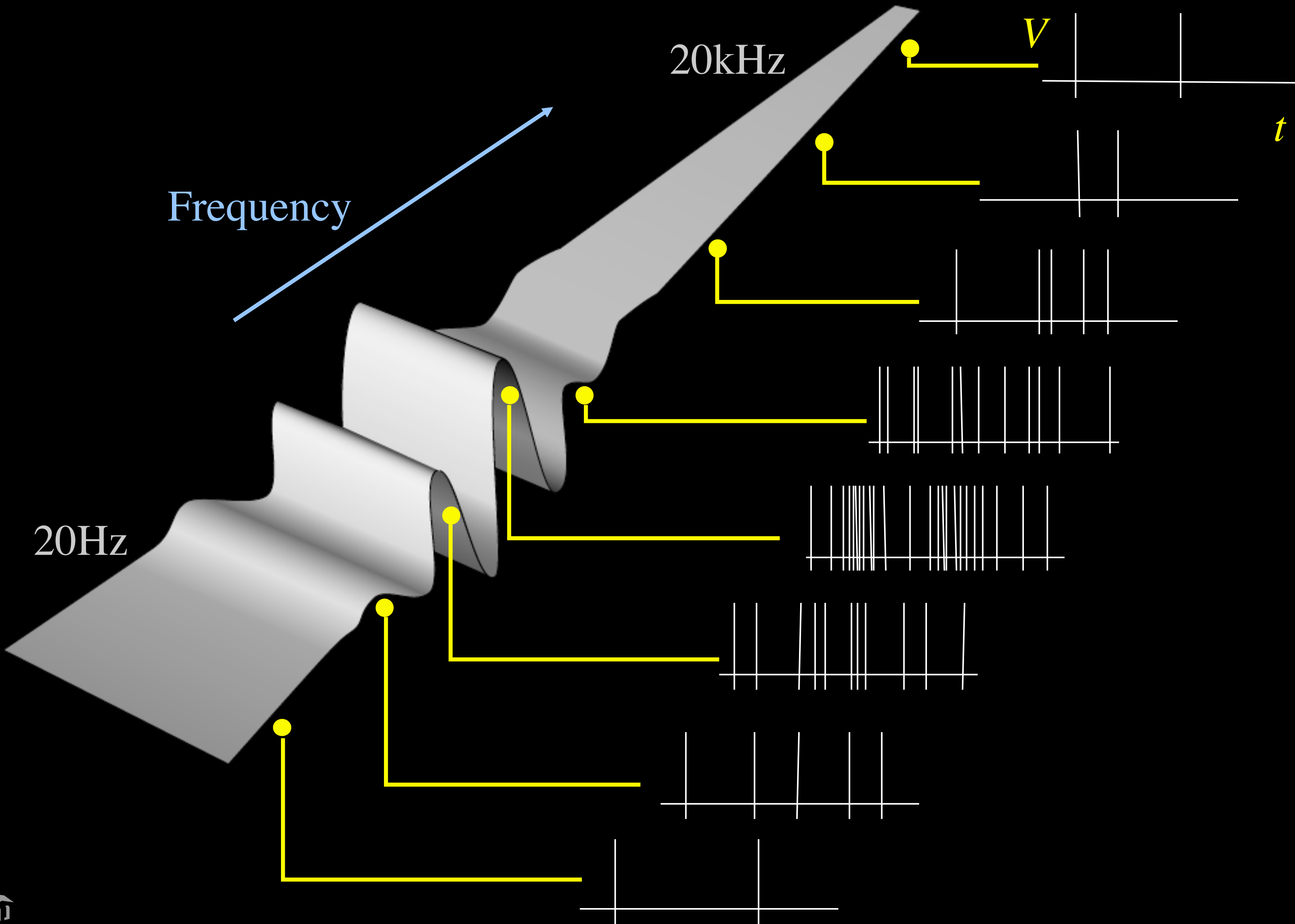
Atlas of Ultrastructural Neurocytology

How Do Neurons Encode Information?

Action Potentials are Identical!



Place Encoding - Basilar Membrane



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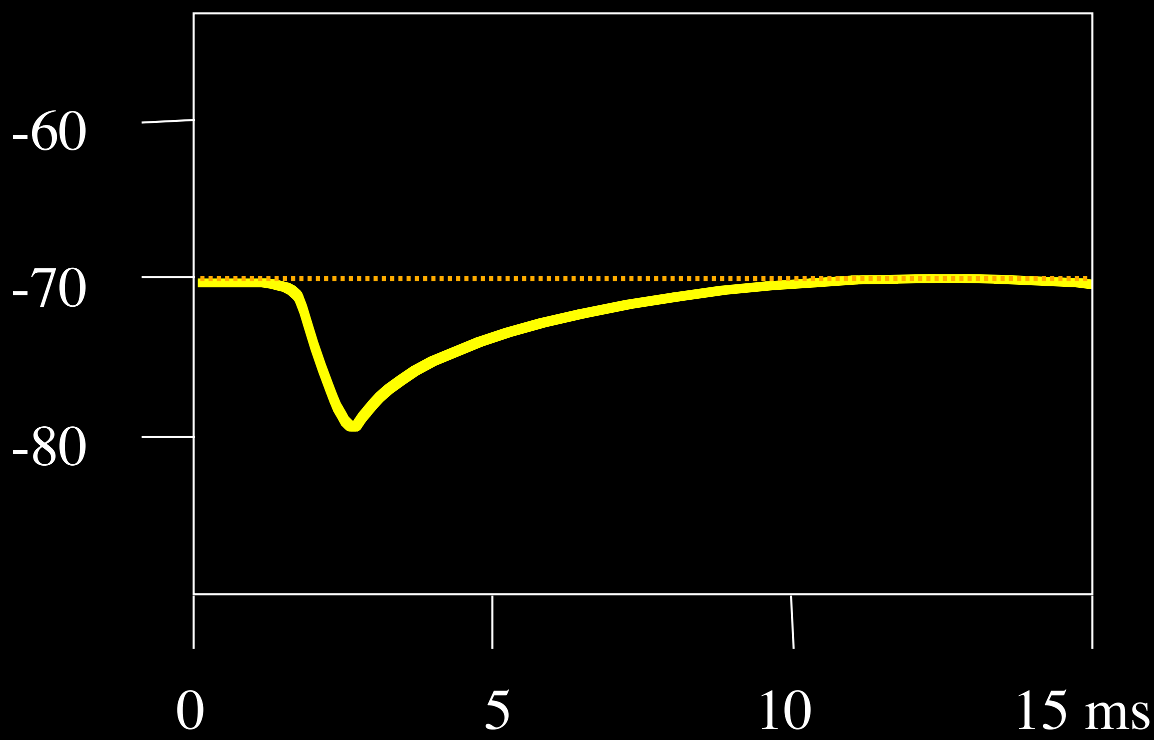
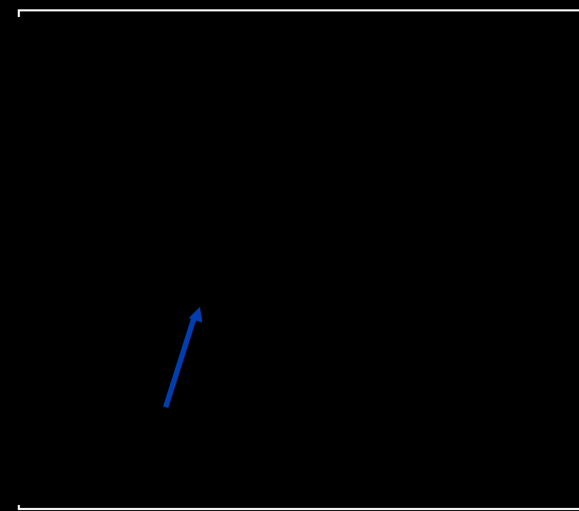
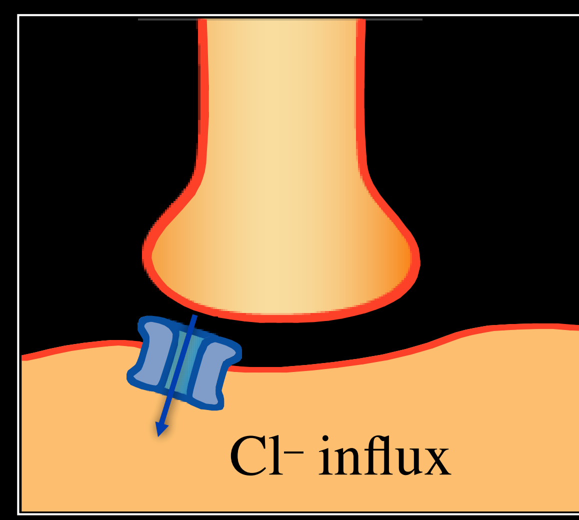
Inhibition

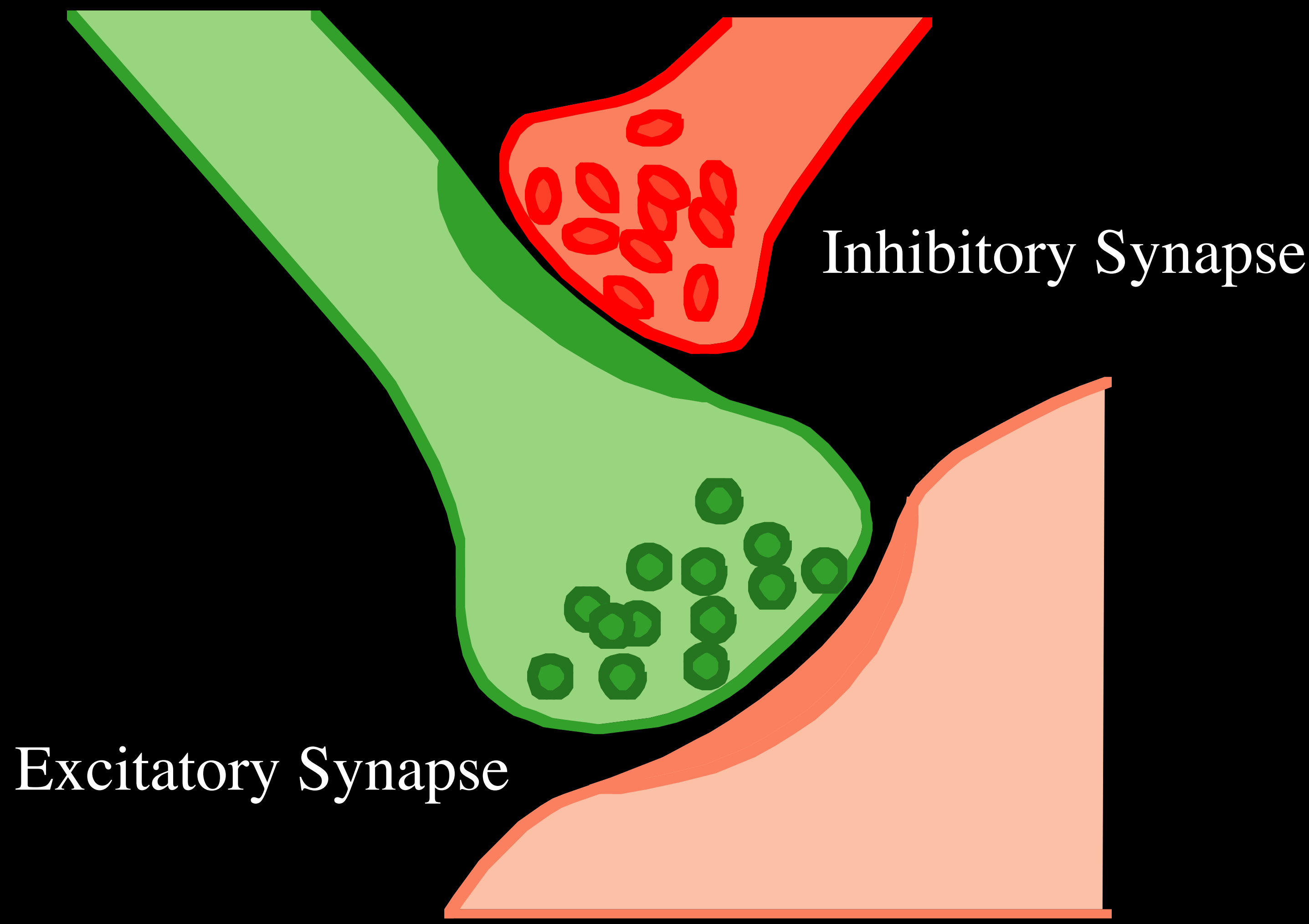






Reversal potential of Cl^- is near the resting potential. Therefore, its inhibition may be silent.

Pre-Synaptic Inhibition



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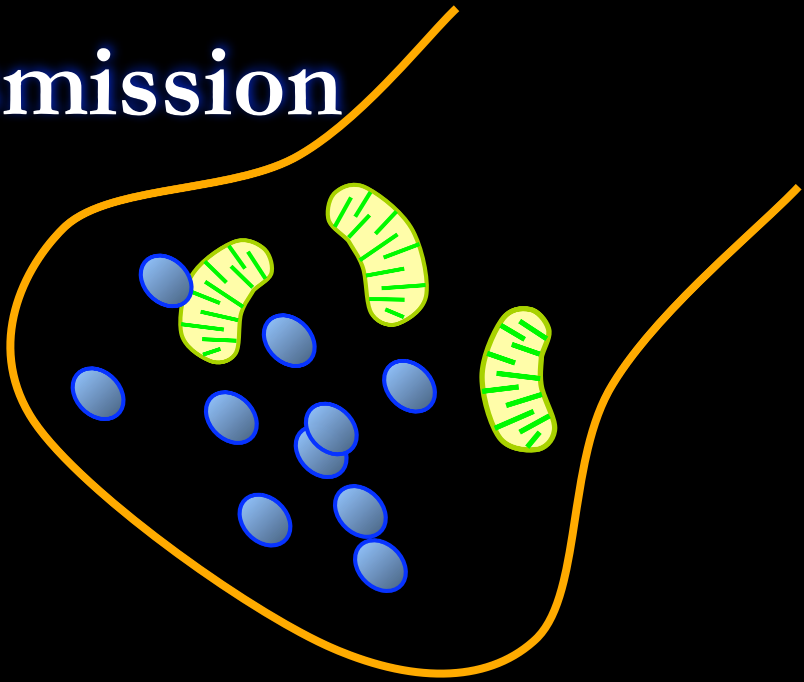
What Might We Detect?

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

How does BOLD relate to neural firing?

Energy Demands in Transmission



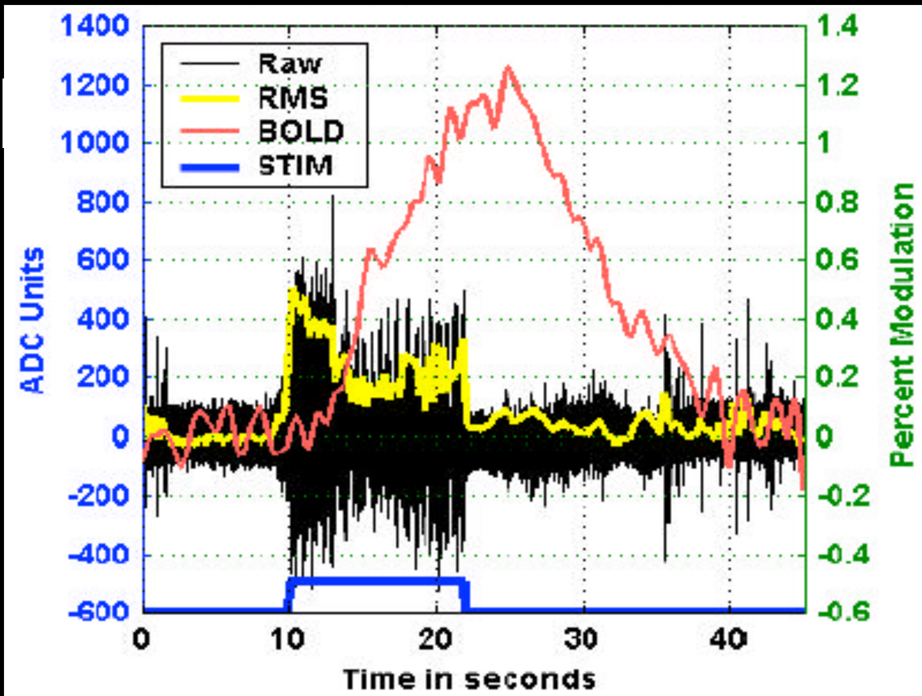
Pre-synaptic:

- *Transmitter Synthesis*
- *Exocytosis*
- *Transmitter re-uptake*

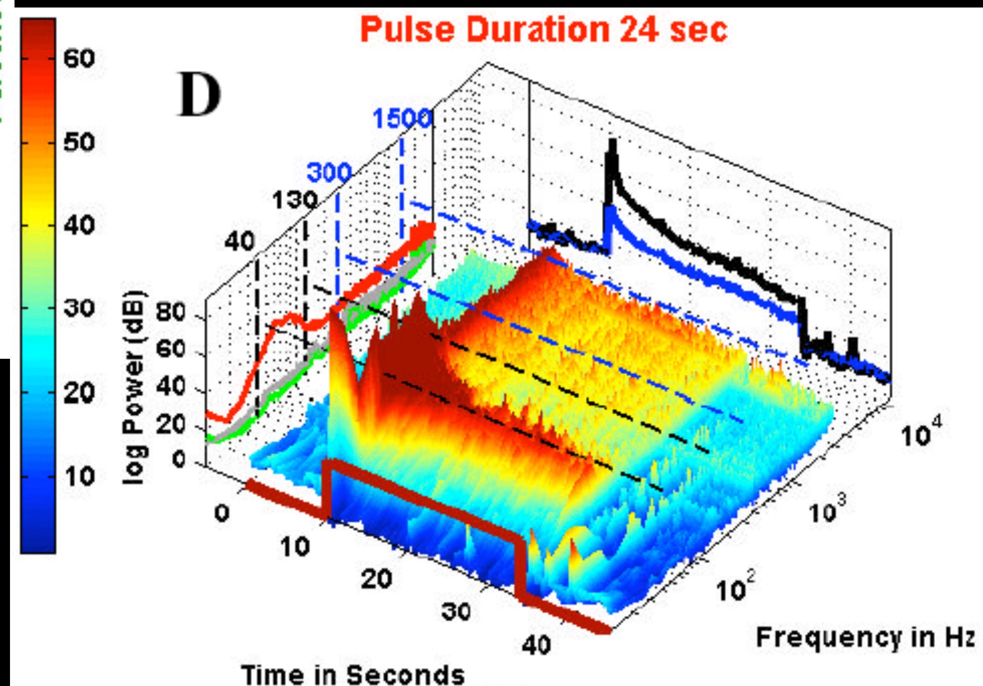
Post-Synaptic

- *Maintenance of membrane potential after ion leakage*
- **Excitatory**: *Removal of Sodium (Na/K pump)*
- **Inhibitory**: *???*

Logothetis Results



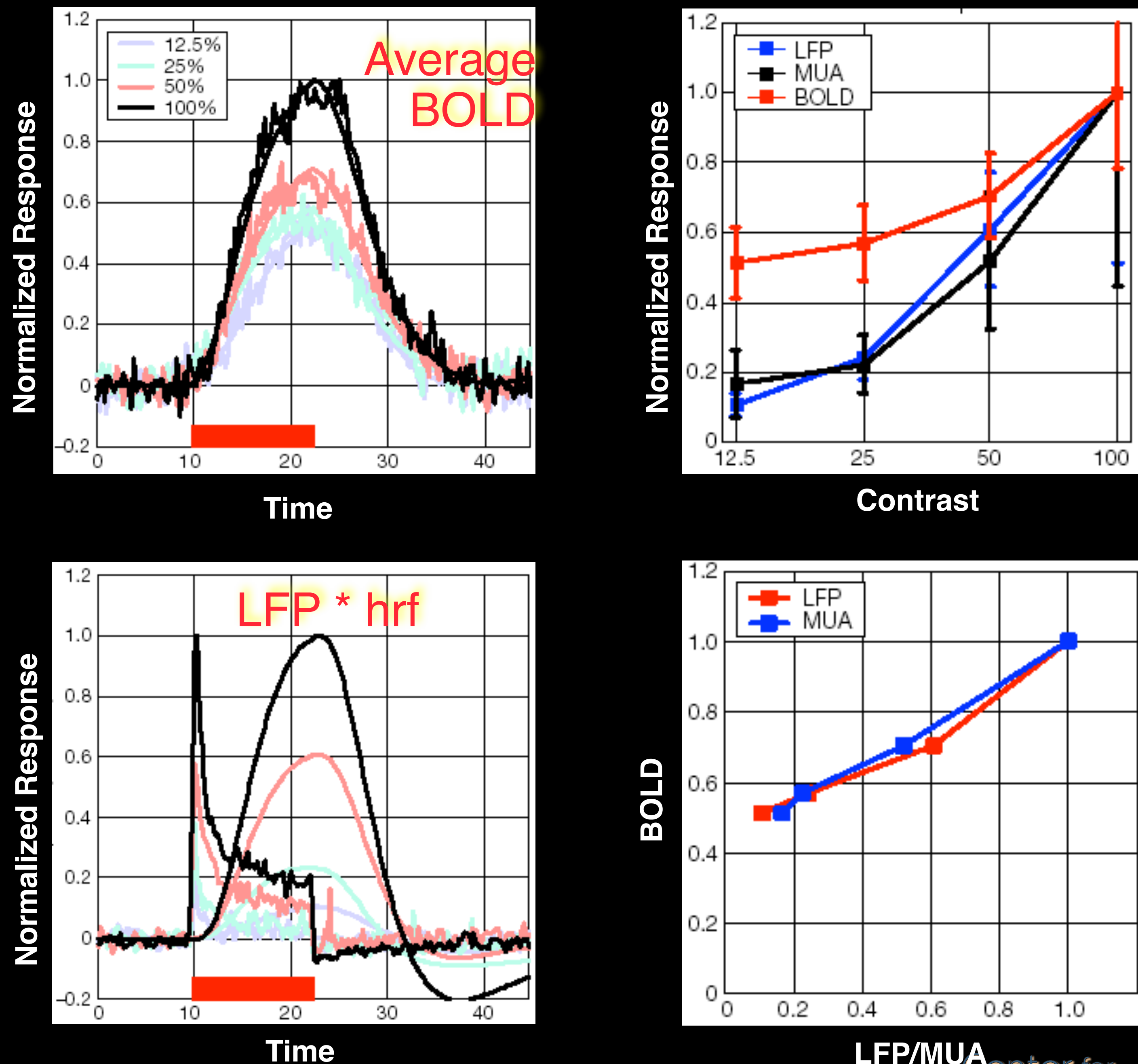
LFP = 40-130 Hz
MUA = 300-1500 Hz



Pre On Post
Stim

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

Logothetis results



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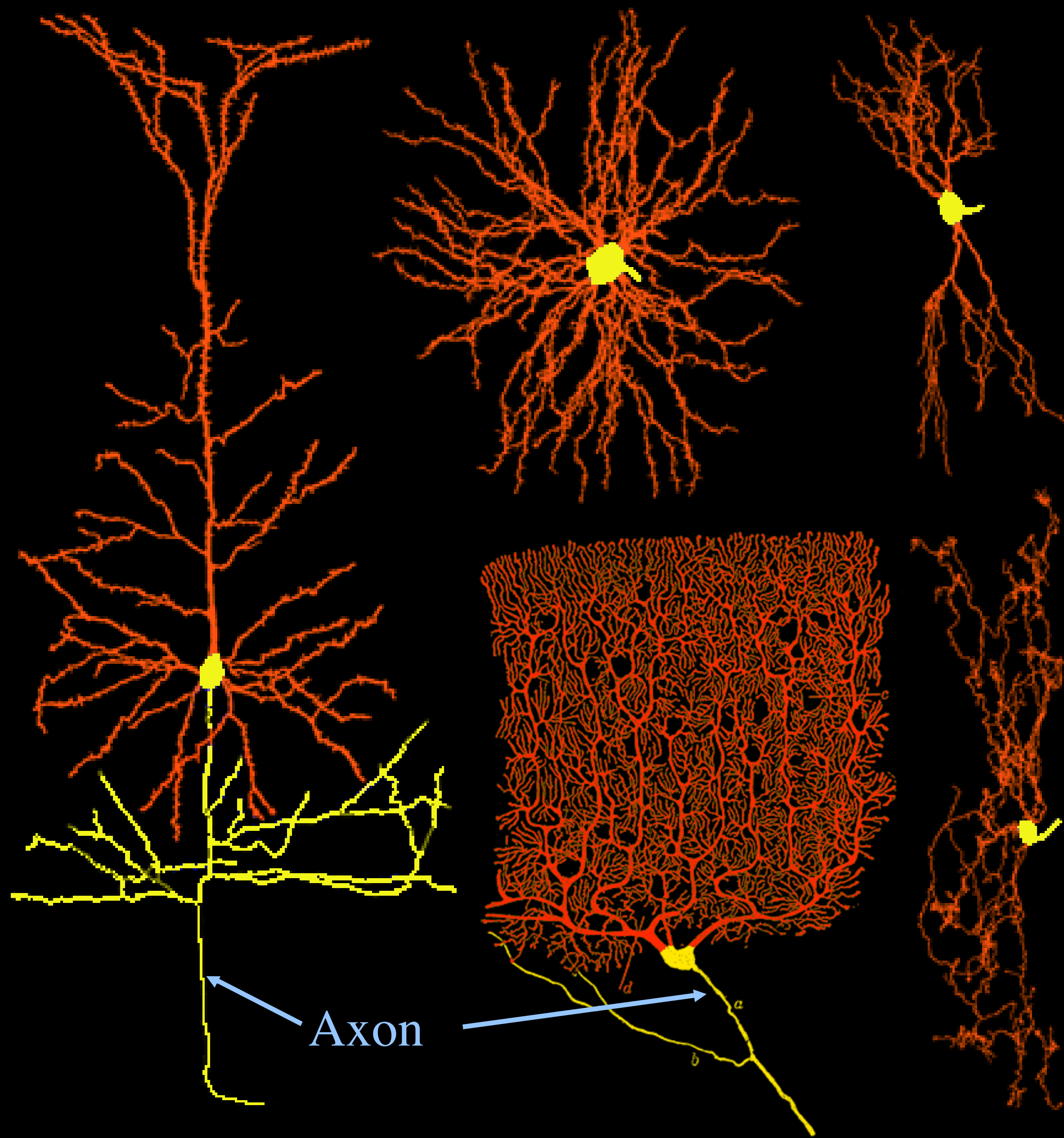
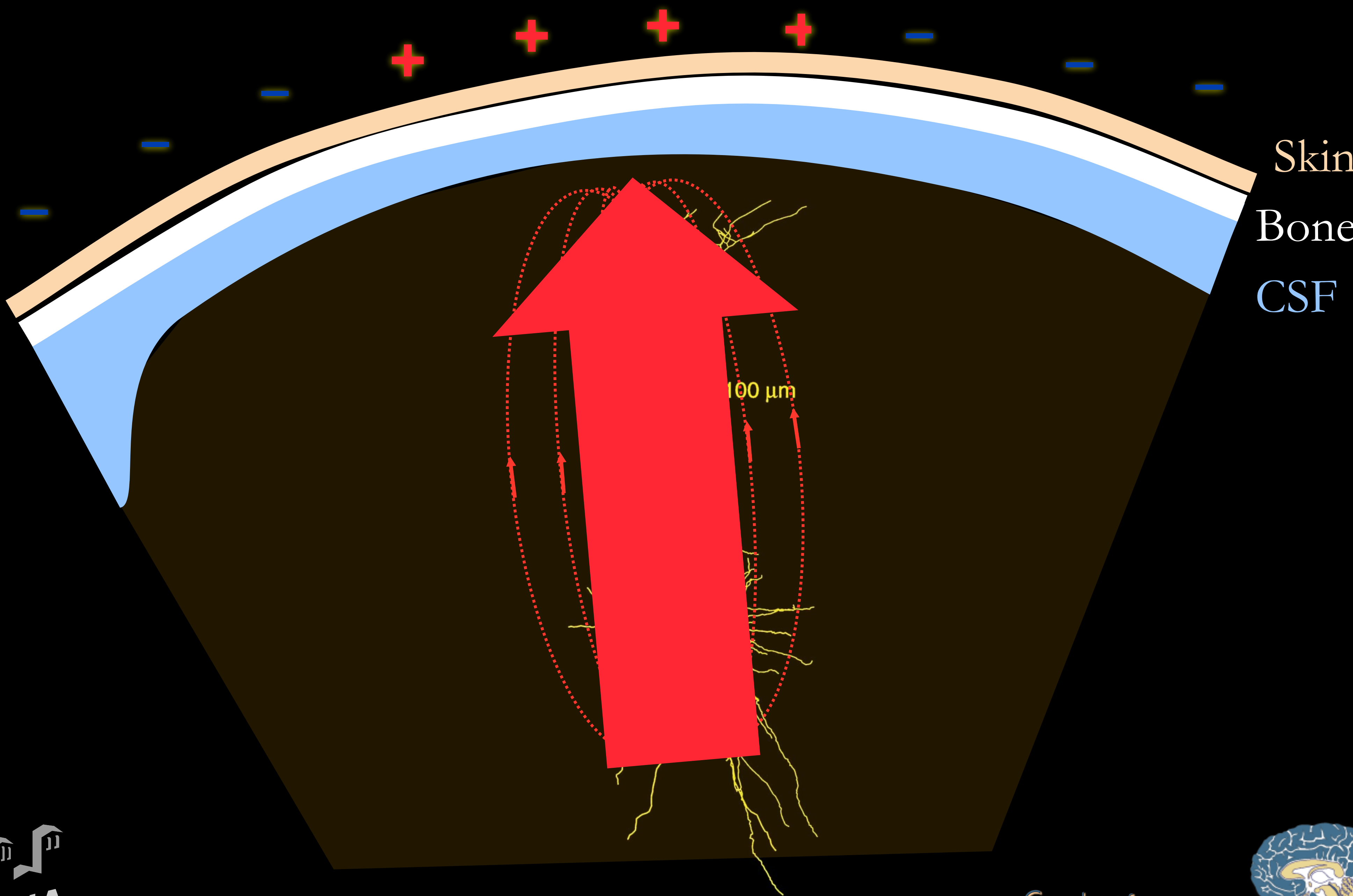
Types of Neurons



Presumed Origin of the EEG



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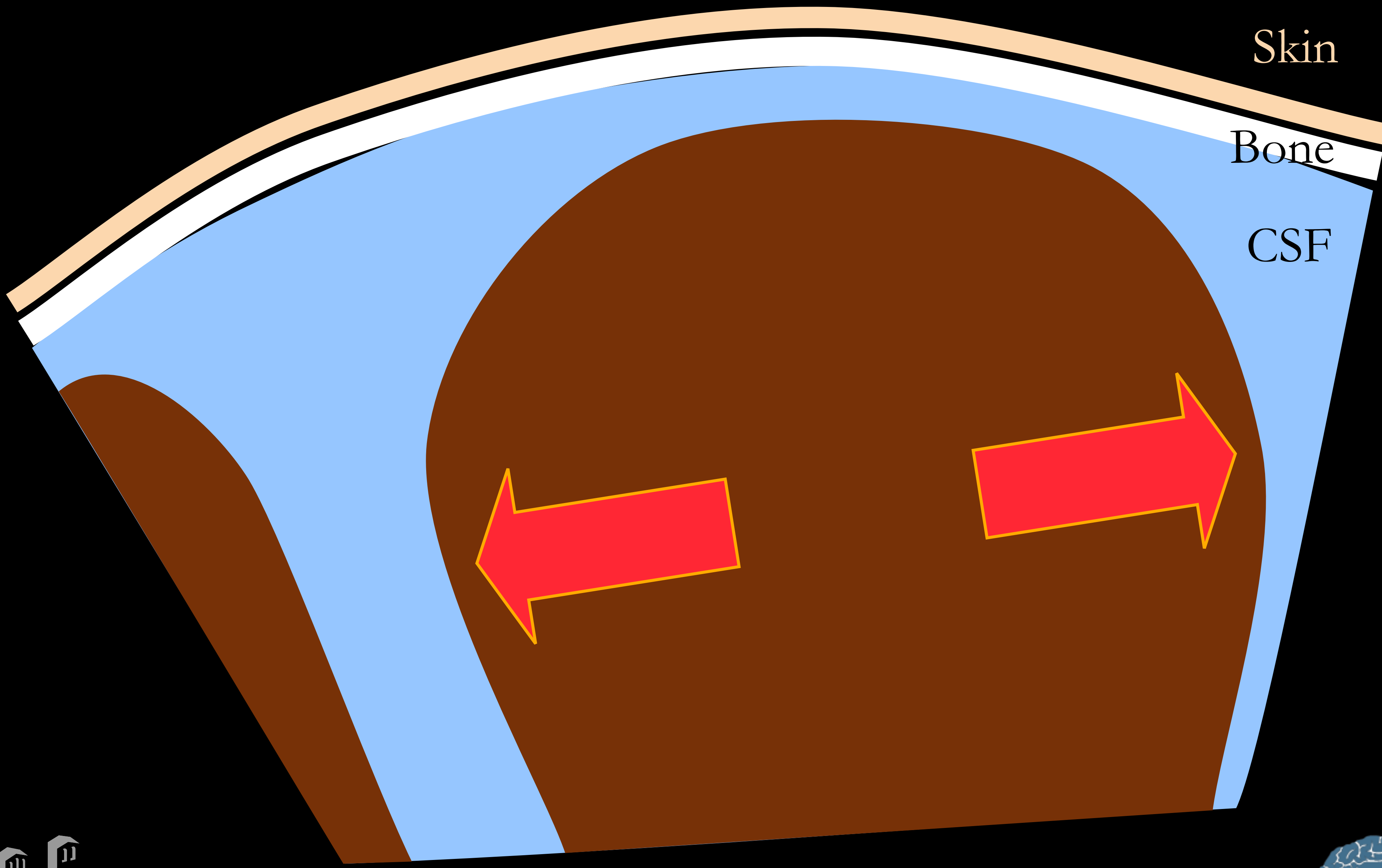
Many Neurons are Not "Seen" by EEG



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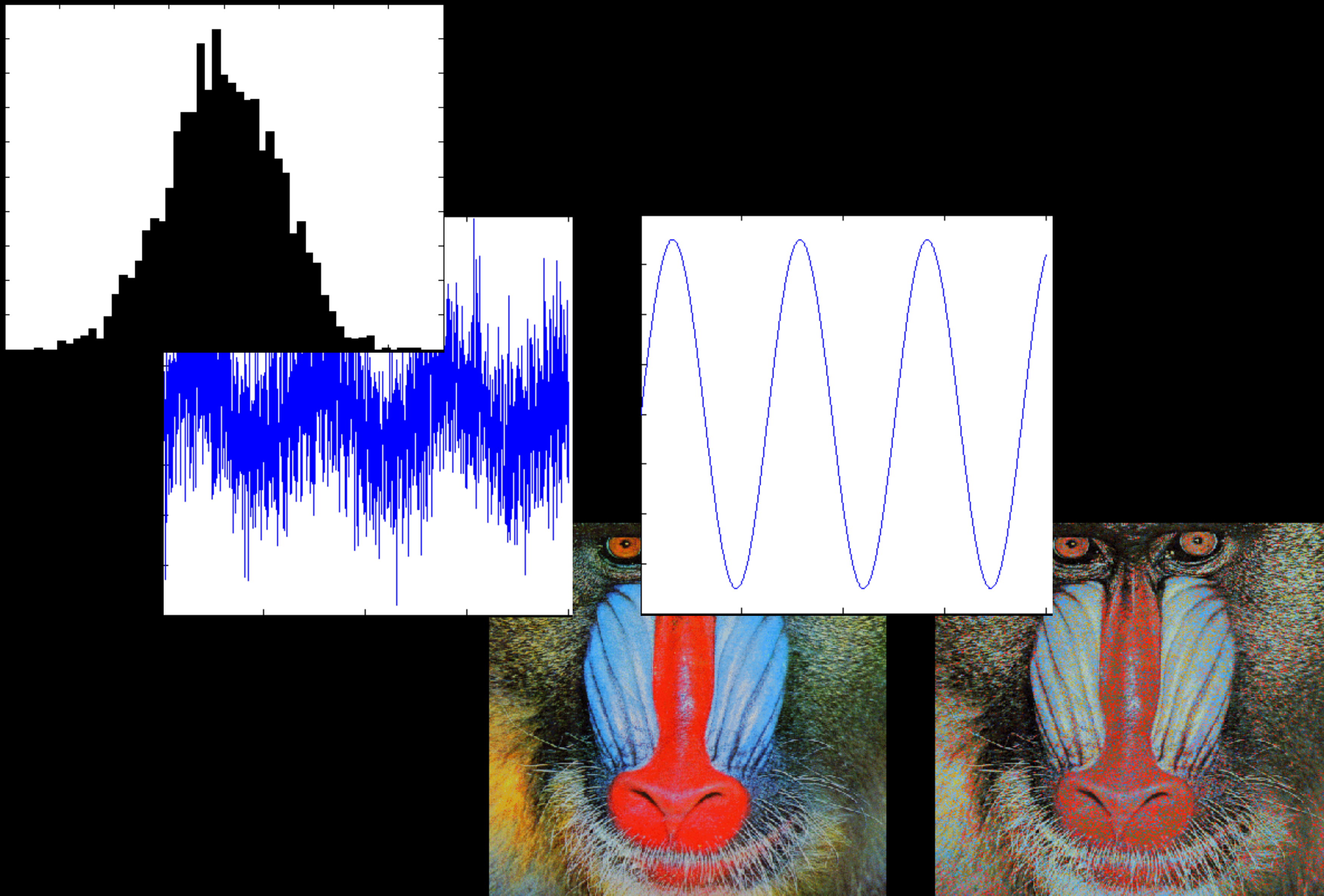
General Limitations in EEG Localization

- 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

The problem of Noise



Blurring and Filtering