# LASCON 2018

## Tutorial 4
## NEURON II

NEURON
for empirically-based simulations of neurons and networks of neurons

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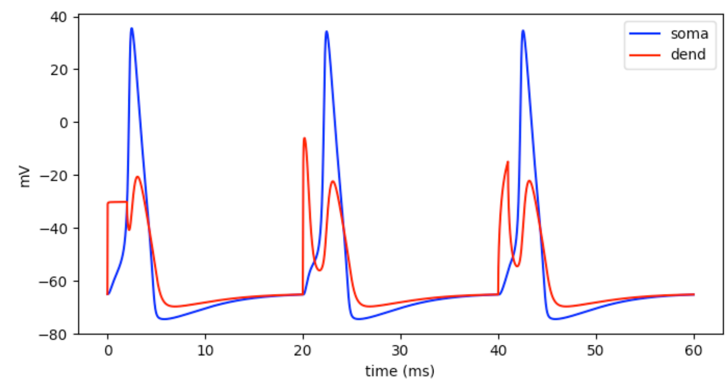
# Problem

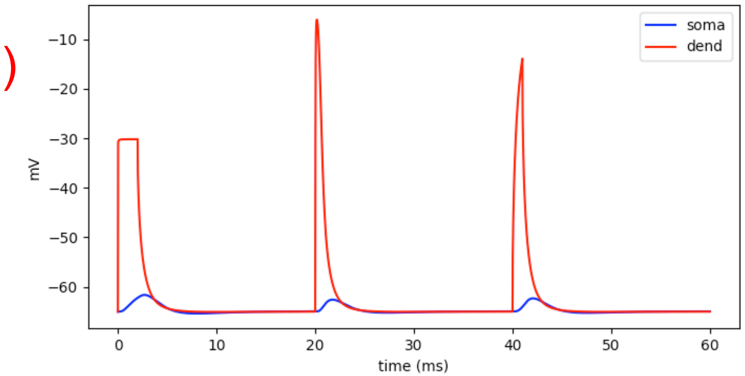
- Start with original *tut4_start.py* (available from LASCON Resources)

- Check that 3 action potentials are generated if dendrite length is 200 um: voltage clamp, synapse, and current clamp




- Change the dendrite length to 400 um

- Check that NO action potentials are generated:

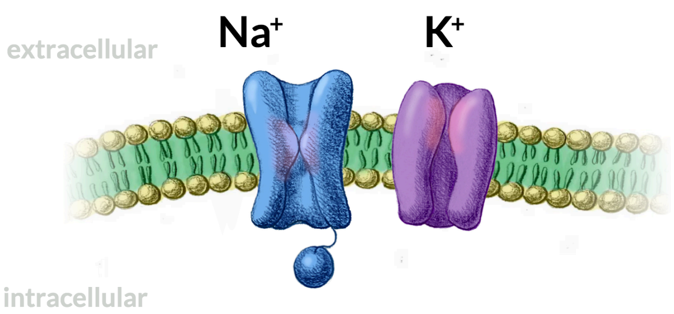



- Experiment and find ways to get them back!

(Write down numeric values – part of assessment!)

# Biophysics: Distributed mechanisms

- Distributed mechanisms modifies membrane properties eg. V or $g_{Na}$
- They are inserted in a *Section*, and automatically distributed to all of its *Segments*
- Hodgkin-Huxley sodium, potassium and leakage channels
  - sec.insert('hh')
  - sec(0.5).hh.ena (leak equilibrium potential)
  - sec(0.5).hh.gnabar (sodium conductance)

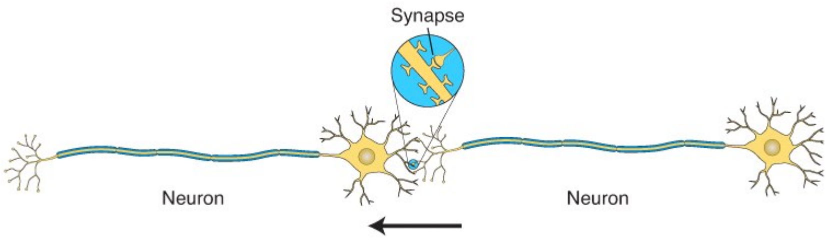



- Passive channels
  - sec.insert('pas')
  - sec(0.5).hh.gk (leak conductance)
- Other NMODL (.mod) mechanisms defined (eg. other ionic channels)

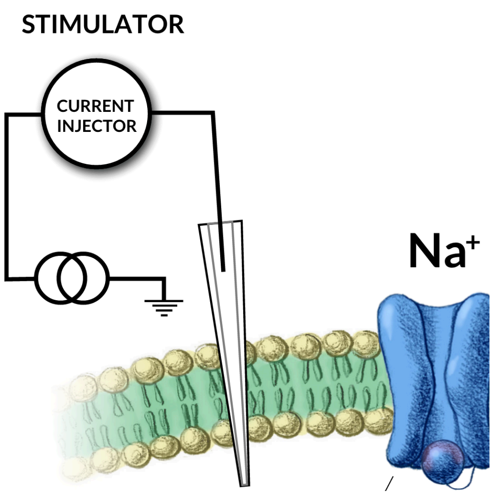
# Biophysics: Point Processes

- Point processes are sources of current in specific segment

- Synapses
  - syn = h.AlphaSynapse(soma(0.5))
  - syn = h.ExpSyn(dend(0.8))




- Current Clamp
  - stim = h.IClamp(soma(0.5))

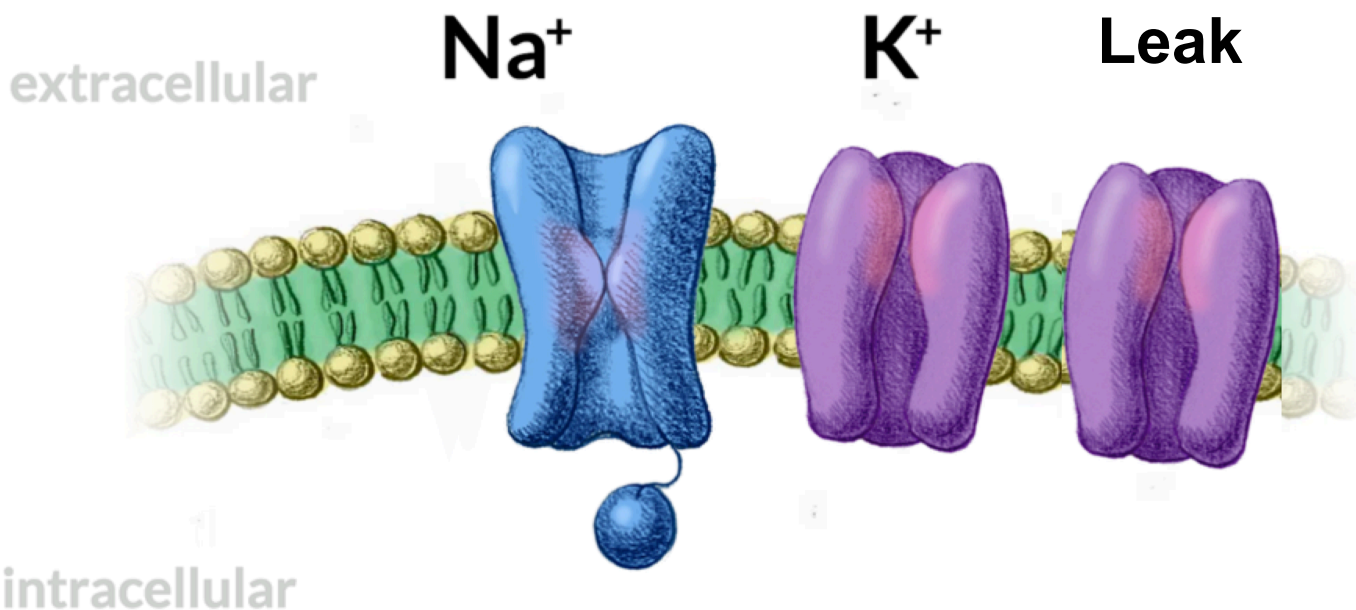



- Artificial Cells (special type of point process)
  - ns = h.NetStim()
  - cell = h.IntFire1()
  - cell = h.IntFire2()

# Membrane potential

Membrane potential at steady-state (ignoring $C_m$):

$$V_m \sim= (g_{Na}/g_m)\cdot V_{Na} + (g_K/g_m)\cdot V_K + (g_L/g_m)\cdot V_L$$




$V_m$: membrane potential
$g_m \sim= g_{Na}+g_K+g_L$ : membrane conductance

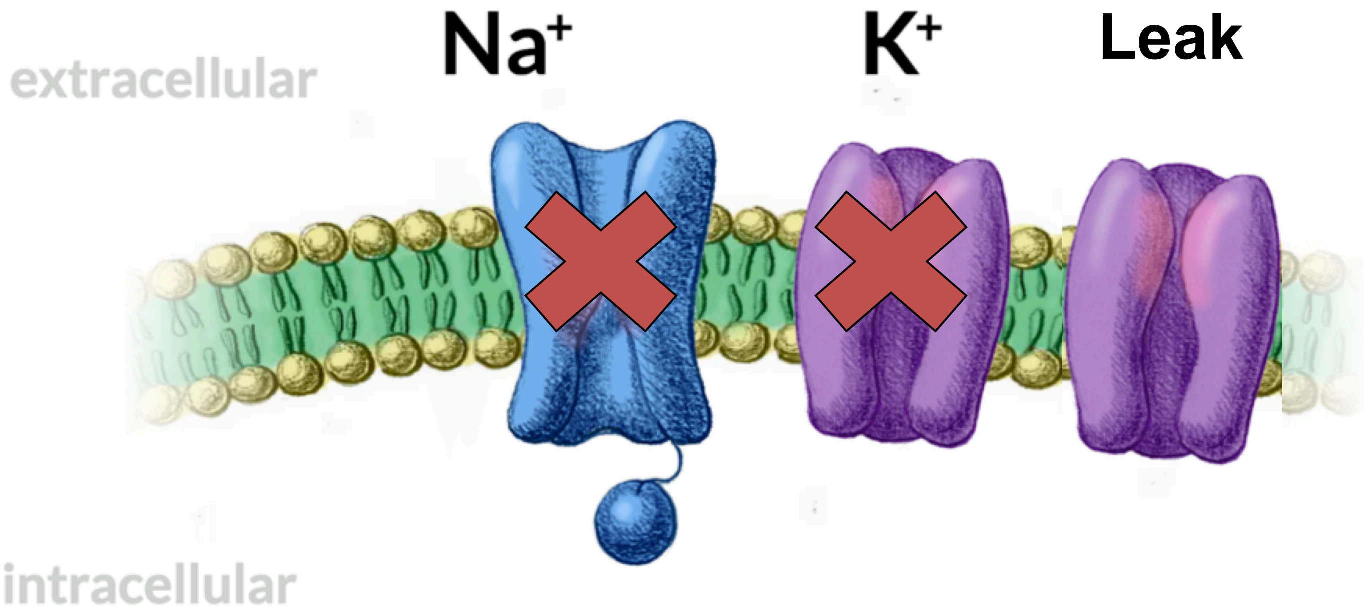
$V_{Na}$, $V_{K,}$ $V_L$ : sodium, potassium and leak equilibrium potential
$g_{Na}$, $g_{K,}$ $g_L$ : sodium, potassium and leak conductance

# Membrane potential

Membrane potential at steady-state (ignoring $C_m$) and at rest:

$$V_m \sim= (0/g_m)\cdot V_{Na} + (0/g_m)\cdot V_K + (g_L/g_m)\cdot V_L$$

$$V_m \sim= (g_L/g_m)\cdot V_L$$



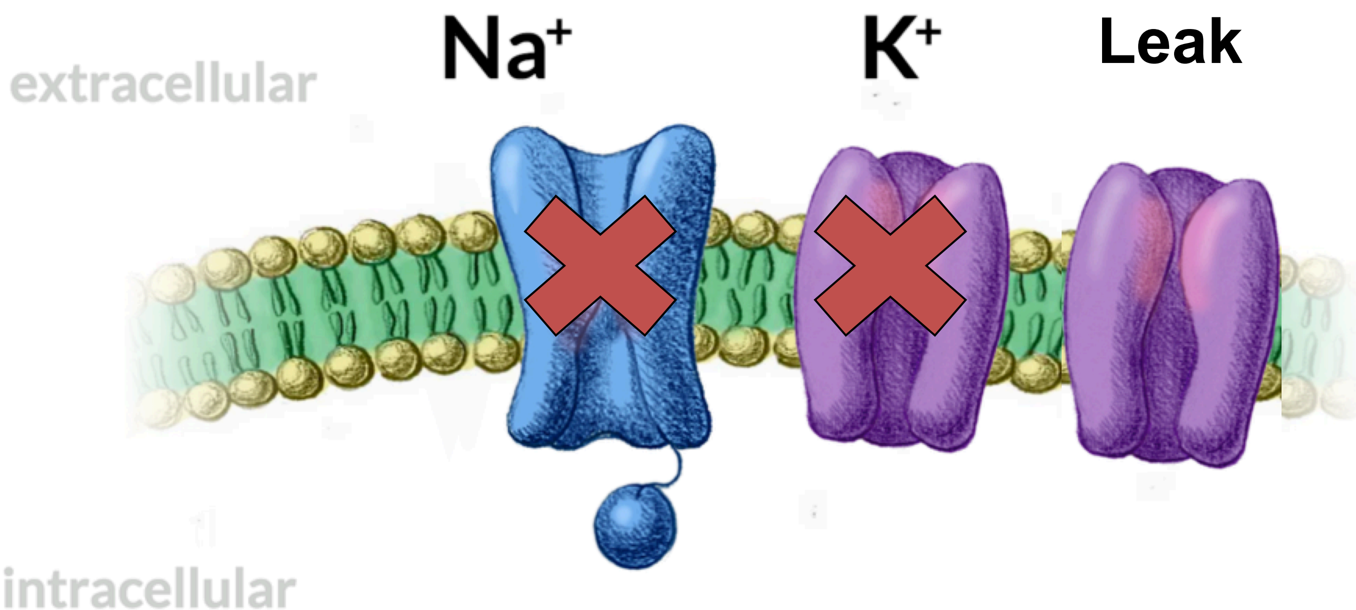

$V_m$: membrane potential
$g_m \sim= g_L$ : membrane conductance

$V_{Na}$, $V_{K,}$ $V_L$ : sodium, potassium and leak equilibrium potential
$g_{Na}$, $g_{K,}$ $g_L$ : sodium, potassium and leak conductance

# Membrane potential

Membrane potential at steady-state (ignoring $C_m$) and at rest:

$$V_m \sim= (1) \cdot V_L$$



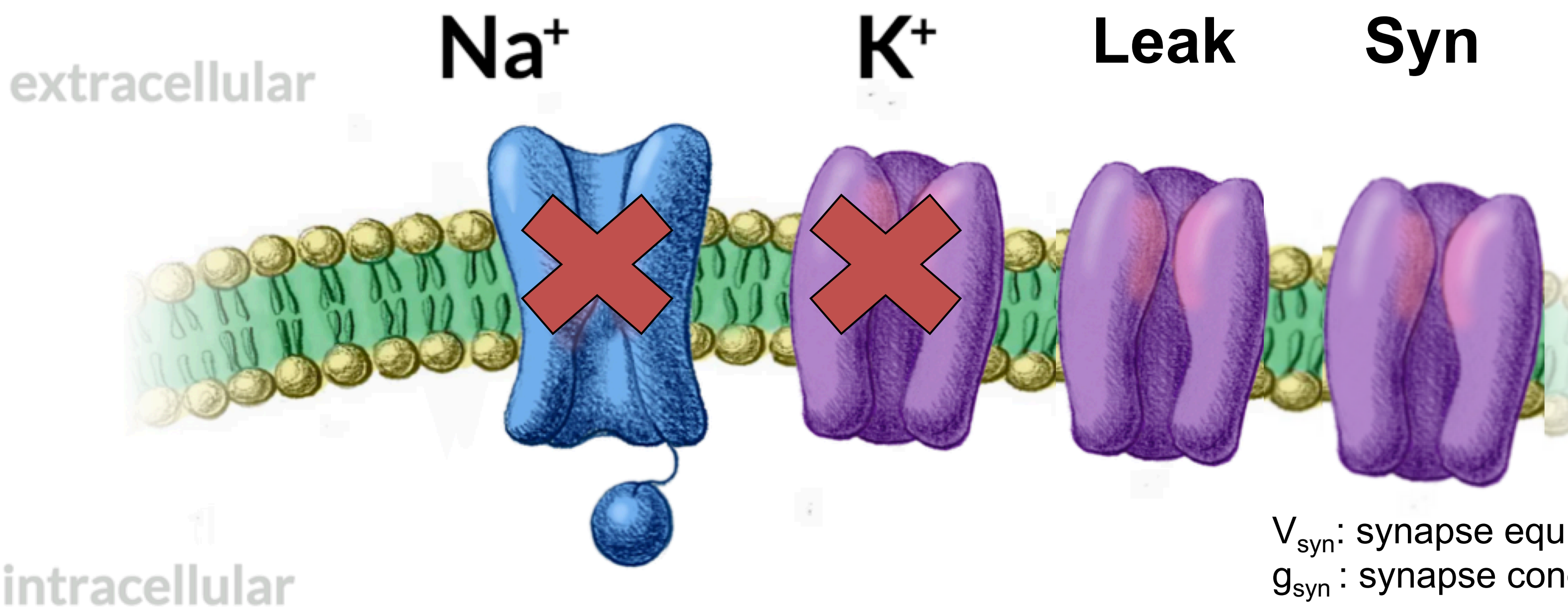

$V_m$: membrane potential
$g_m \sim= g_L$ : membrane conductance

$V_{Na}$, $V_{K,}$ $V_L$ : sodium, potassium and leak equilibrium potential
$g_{Na}$, $g_{K,}$ $g_L$ : sodium, potassium and leak conductance

# Synapse

Membrane potential at steady-state (ignoring $C_m$) and at rest:

$$V_m \sim= (g_L/g_m)\cdot V_L + (g_{syn}/g_m)\cdot V_{syn}$$



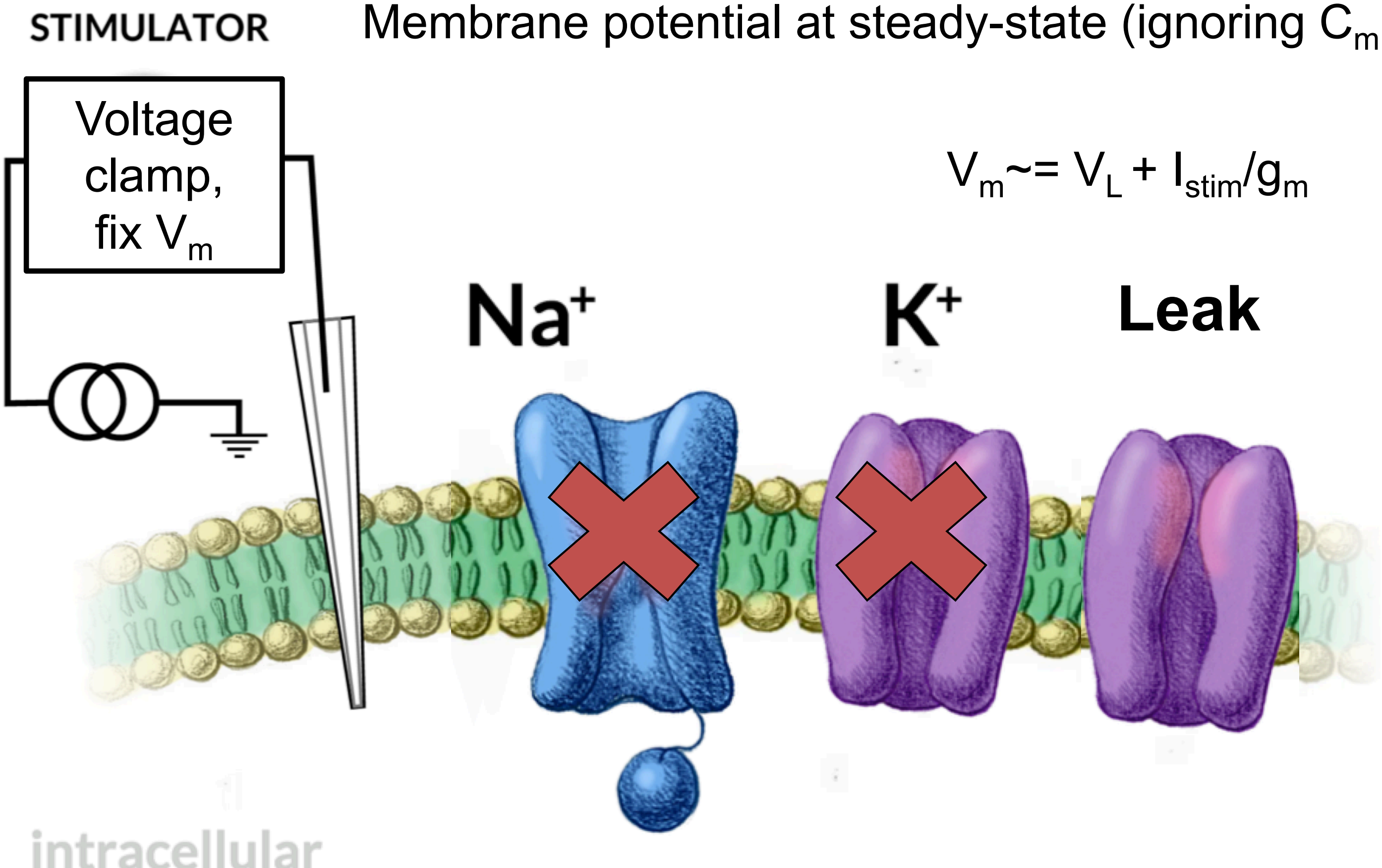

$V_{syn}$: synapse equilibrium potential
$g_{syn}$ : synapse conductance

$V_m$: membrane potential
$g_m \sim= g_L + g_{syn}$ : membrane conductance

$V_{Na}$, $V_{K,}$ $V_L$ : sodium, potassium and leak equilibrium potential
$g_{Na}$, $g_{K,}$ $g_L$ : sodium, potassium and leak conductance

# Voltage clamp

Membrane potential at steady-state (ignoring $C_m$) and at rest:




$$V_m \sim= V_L + I_{stim}/g_m$$

$V_m$: membrane potential
$g_m \sim= g_L$ : membrane conductance

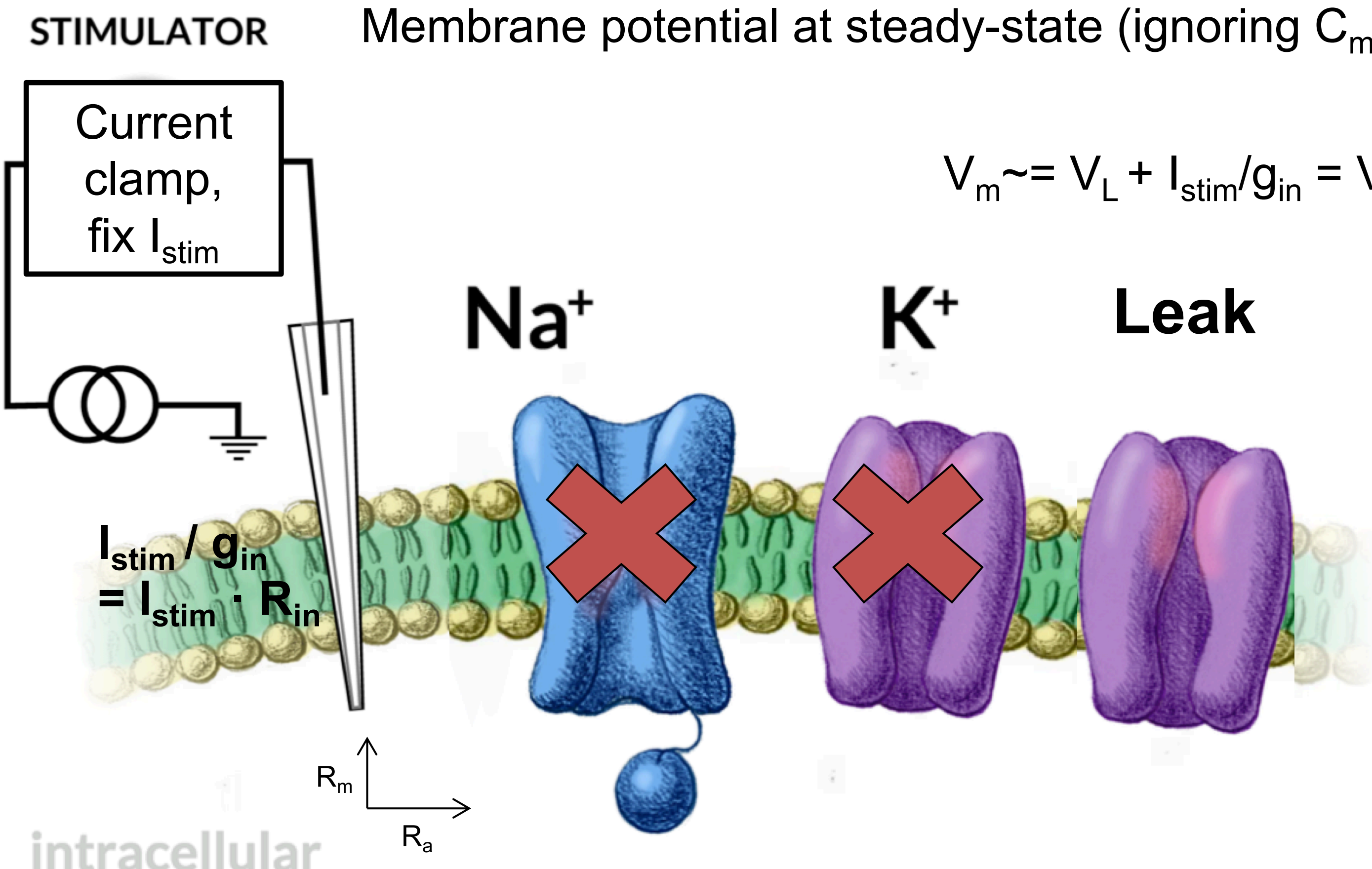
$V_{Na}$, $V_{K,}$ $V_L$ : sodium, potassium and leak equilibrium potential
$g_{Na}$, $g_{K,}$ $g_L$ : sodium, potassium and leak conductance

# Current clamp

Membrane potential at steady-state (ignoring $C_m$) and at rest:

$$V_m \sim= V_L + I_{stim}/g_{in} = V_L + I_{stim} \cdot R_{in}$$

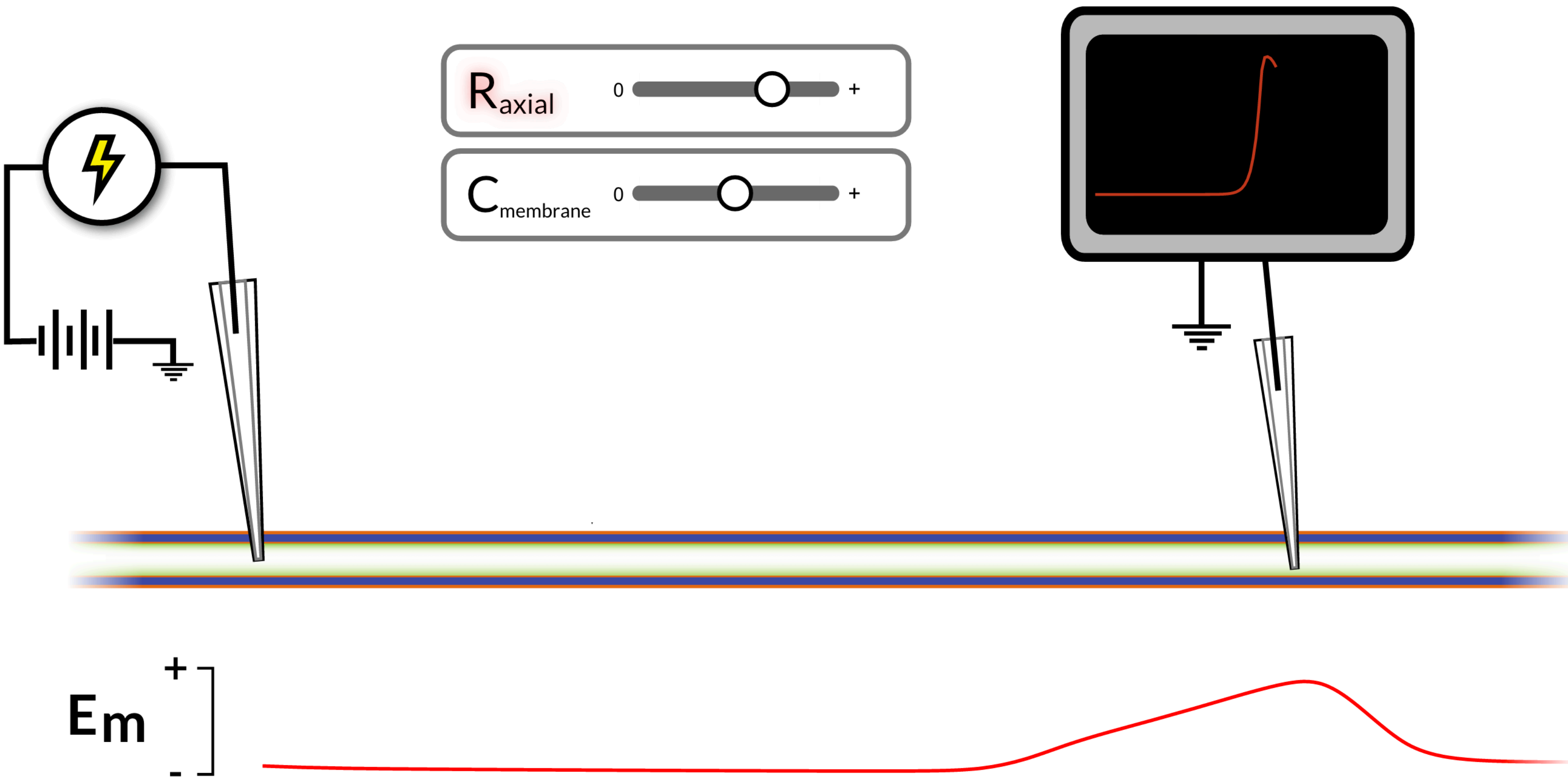
$$R_{in} = \frac{2\sqrt{R_m \cdot R_a}}{\pi \cdot d^{3/2} \cdot \tanh(l)}$$

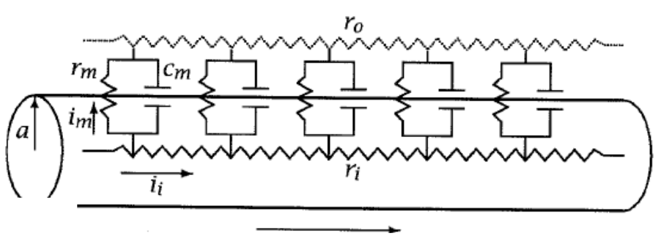



$V_m$: membrane potential
$g_m \sim= g_L$ : membrane conductance

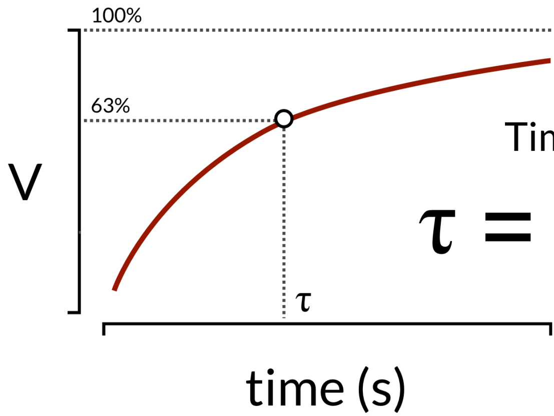
$V_{Na}$, $V_{K,}$ $V_L$ : sodium, potassium and leak equilibrium potential
$g_{Na}$, $g_{K,}$ $g_L$ : sodium, potassium and leak conductance

# Passive Propagation



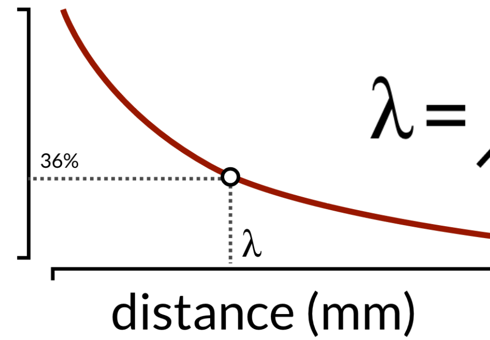



# Passive Propagation

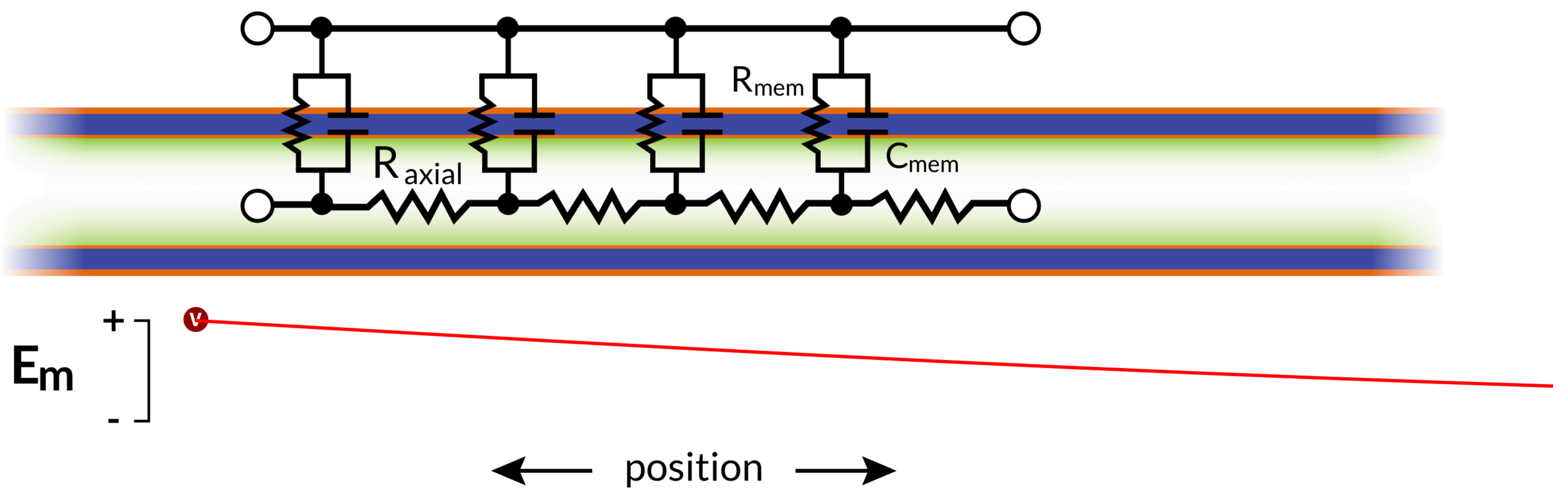



Time Constant

$$\tau = R_{mem} C_{mem}$$




$$\lambda = \sqrt{\frac{R_{membrane}\ (\text{Ohm}\cdot\text{cm})}{R_{axial}\ (\text{Ohm / cm})}}$$



# Passive Propagation

$$V(x) = V_0 \cdot e^{-x/\lambda}$$

$$V_0 = I \cdot r_{in}$$

$$r_m(ohm) = \frac{R_m(ohm \cdot m)}{l(m)} = \frac{R_M(ohm \cdot m^2)}{\pi \cdot d(m) \cdot l(m)}$$

$$\lambda = \sqrt{\frac{R_m(ohm \cdot m)}{R_a(ohm/m)}} = \sqrt{\frac{d(m)}{4} \cdot \frac{R_M(ohm \cdot m^2)}{R_A(ohm \cdot m)}}$$

$$c_m(F) = C_m(F/m) \cdot l(m) = C_M(F/m^2) \cdot \pi \cdot d(m) \cdot l(m)$$

$$r_a(ohm) = R_a(ohm/m) \cdot l(m) = \frac{R_A(ohm \cdot m) \cdot 4 \cdot l(m)}{\pi \cdot d^2(m^2)}$$

$$V(t) = V_0 \cdot (1 - e^{-t/\tau})$$

$r_m$ = membrane resistance in cylinder of diameter *d* and length *l* (ohm)

$$\tau_m = r_m c_m = R_M C_M = R_m C_m$$

$R_m$ = membrane resistance in section of diameter *d* (ohm·m)

$R_M$ = specific membrane resistance (ohm·m$^2$)

$r_a$ = axial resistance in cylinder of diameter *d* and length *l* (ohm)

$R_a$ = axial resistance in section of diameter *d* (ohm/m)

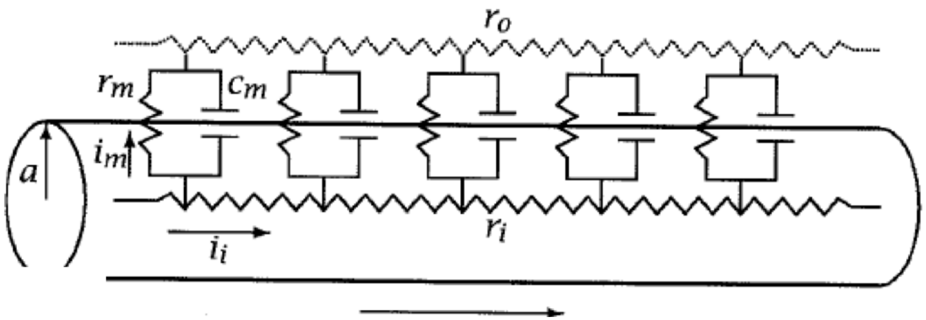
$R_A$ = specific axial resistance (ohm·m)

$c_m$ = membrane capacitance in cylinder of *d* · *l* (F)

$C_m$ = mebrane capacitance in section of diam *d* (F/m)

$C_M$ = specific membrance capacitance (F/m$^2$)

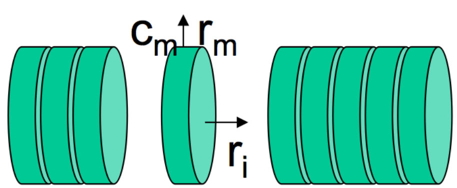
# Passive Propagation




$$C_m = c_m l = \pi d l C_M,$$

$$R_m = r_m / l = \frac{R_M}{\pi d l}$$

$$R_a = r_i l = \frac{4 l R_A}{\pi d^2}.$$




e *space constant,*

$$\lambda = \sqrt{r_m / r_i} = \sqrt{(d/4) R_M / R_A}$$

*me constant,*

$$\tau_m = r_m c_m = R_M C_M = R_m C_m.$$

| | Unmyelinated Axon (UA) | Myelinated Axon (MA) |
|---|---|---|
| axoplasm resistivity | $\rho_{axoplasm} = 2.0\ \Omega\cdot m$ | $\rho_{axoplasm} = 2.0\ \Omega\cdot m$ |
| wall resistivity | $\rho_{UA} = 0.20\ \Omega\cdot m^2$ | $\rho_{MA} = 40.0\ \Omega\cdot m^2$ |
| wall capacitance/area | $C/A = 10^{-2}\ F/m^2$ | $C/A = 5\cdot 10^{-5}\ F/m^2$ |

Table 1. Useful constants.

Note: different notation from previous slide