This PowerPoint shows circuit diagrams superimposed on the membrane in order to illustrate current flow in four of the Neurons in Action tutorials:

- The Membrane Tutorial (diagrams of current flow that accompany the steps of the tutorial)
- The Passive Axon Tutorial
- The Unmyelinated Axon Tutorial
- The Myelinated Axon Tutorial
Current may be injected through a microelectrode.
stimulating electrode inserted

outside

inside

C

Vm
Patch Membrane Tutorial

Current may also be injected by the opening of a channel.
Ach-gated channels

outside

inside

C

Vm
Larger soma, more membrane area, more capacitance

Smaller soma, less membrane area, not as much capacitance

Current from an invading action potential
Patch Membrane Tutorial steps 1 & 2

electrode injects positive charge (20nA current pulse)

Vm = 200 mV at end of current pulse

What will the voltage trace look like?

Vm

injected current pulse
Patch Membrane Tutorial steps 1 & 2

electrode injects positive charge (20nA current pulse)

$V_m = 200 \text{ mV at end of current pulse}$
Patch Membrane Tutorial steps 1 & 2

$V_m = 200 \text{ mV at end of pulse}$

$I_{cap} = C \left[\frac{dV}{dt}\right]$
Patch Membrane Tutorial step 3: add leak channel

\[ r_{\text{leak}} \]

\[ V_m \]

\[ I_m \]
Patch Membrane Tutorial step 3: add leak channel

$V_m$  \hspace{1cm} \text{Im}  \hspace{1cm} t$
Time constant

\[ \text{tau} = R_m \cdot C_m \]

\text{tau} = the time it takes for voltage to rise to 67\% (1-1/e) or fall to 33\% (1/e) of its final value
Patch Membrane Tutorial step 4: add HH Na & K channels

Depolarizing (positive) current is injected.

The current first flows out through the capacitance C.

As the voltage builds up across C, current flows out through leak channels.

Na channels open, allowing the Na battery to drive positive current inward through these channels (outward Icap).

K channels then open, allowing the K battery to drive positive current out through these channels (inward Icap).

Na channels (fast)

K channels (slow)
Depolarizing (positive) current is injected.

The current first flows out through the capacitance $C$.

As the voltage builds up across $C$, current flows out through leak channels.

Na channels (fast) open, allowing the Na battery to drive positive current inward through these channels (outward $I_{cap}$).

K channels (slow) then open, allowing the K battery to drive positive current out through these channels (inward $I_{cap}$).

K channels then open, allowing the K battery to drive positive current out through these channels (inward $I_{cap}$).
Passive Axon Tutorial: add longitudinal resistances

$r_o$ (usually negligible)

$r_m$ ($= r_{\text{leak}}$)

$r_i$

$r_i$
**Length constant (L)**

- \( L = \) the distance over which a voltage step decays to \( 1/e \) (33%) of its original value.
- \( L \) tracks the (square root of the) \( r_m/r_i \) ratio: \( L = \sqrt{r_m / r_i} \)
- If \( r_m \) is large compared to \( r_i \), current will flow down the inside of the axon and \( L \) will be large.
Lambda (the length constant) of an axon =
the distance over which a voltage step decays
to $1/e$ (about 33%) of its original value.

\[ \lambda = \sqrt{\frac{r_m}{r_i}} \]
Unmyelinated Axon Tutorial: add HH Na & K channels

the AP
Myelinated Axon Tutorial: add myelin

time constant:  \[ \tau = R_m C_m \]
Cm decreases because of many capacitors in series
Rm increases because of equivalent # of resistors in series
\( \tau \) does not change

length constant:  \[ L = \sqrt{r_m/r_i} \]
r\(_m\) becomes very much larger
L becomes very much longer