Dendritic computation

Dendrites as computational elements:

Passive contributions to computation

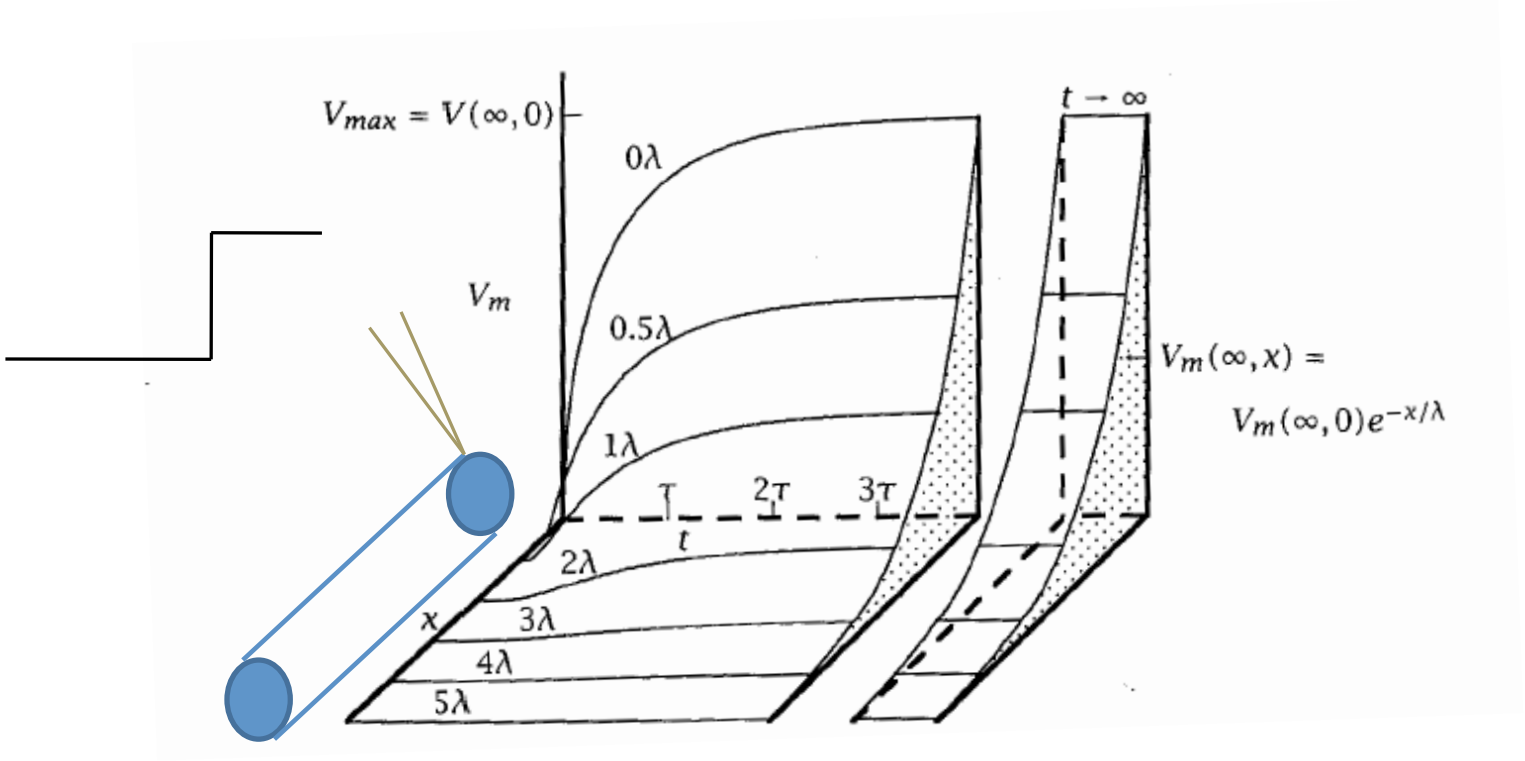
Active contributions to computation

Examples

Properties of passive cables

→ Electrotonic length $\lambda = \sqrt{\frac{r_m}{r_i}}$

Electrotonic length

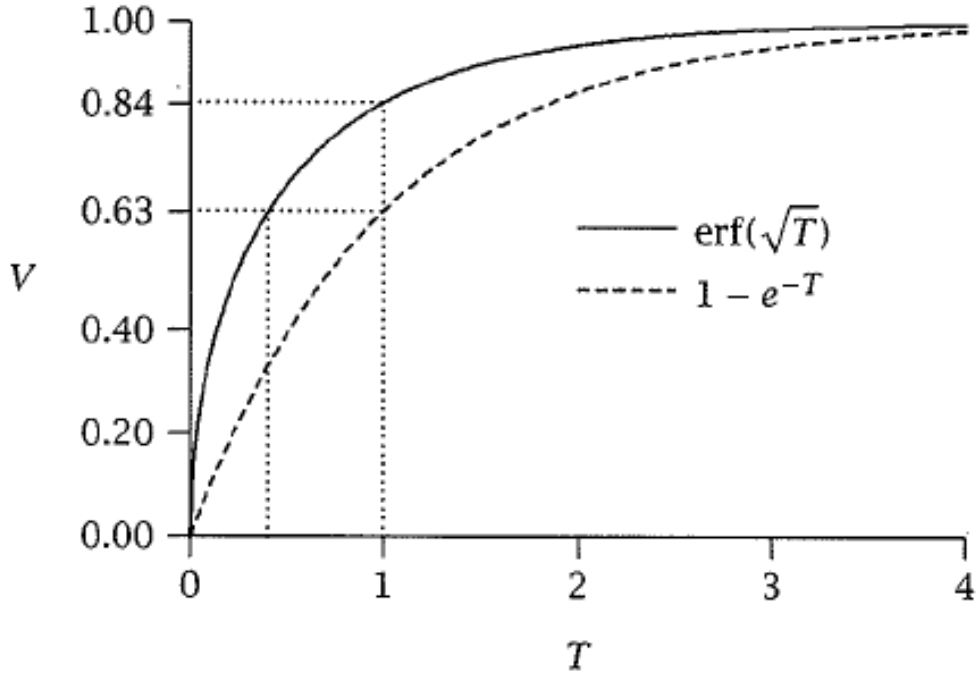


Johnson and Wu

Properties of passive cables

→ Electrotonic length $\lambda = \sqrt{\frac{r_m}{r_i}}$

→ Current can escape through additional pathways: speeds up decay

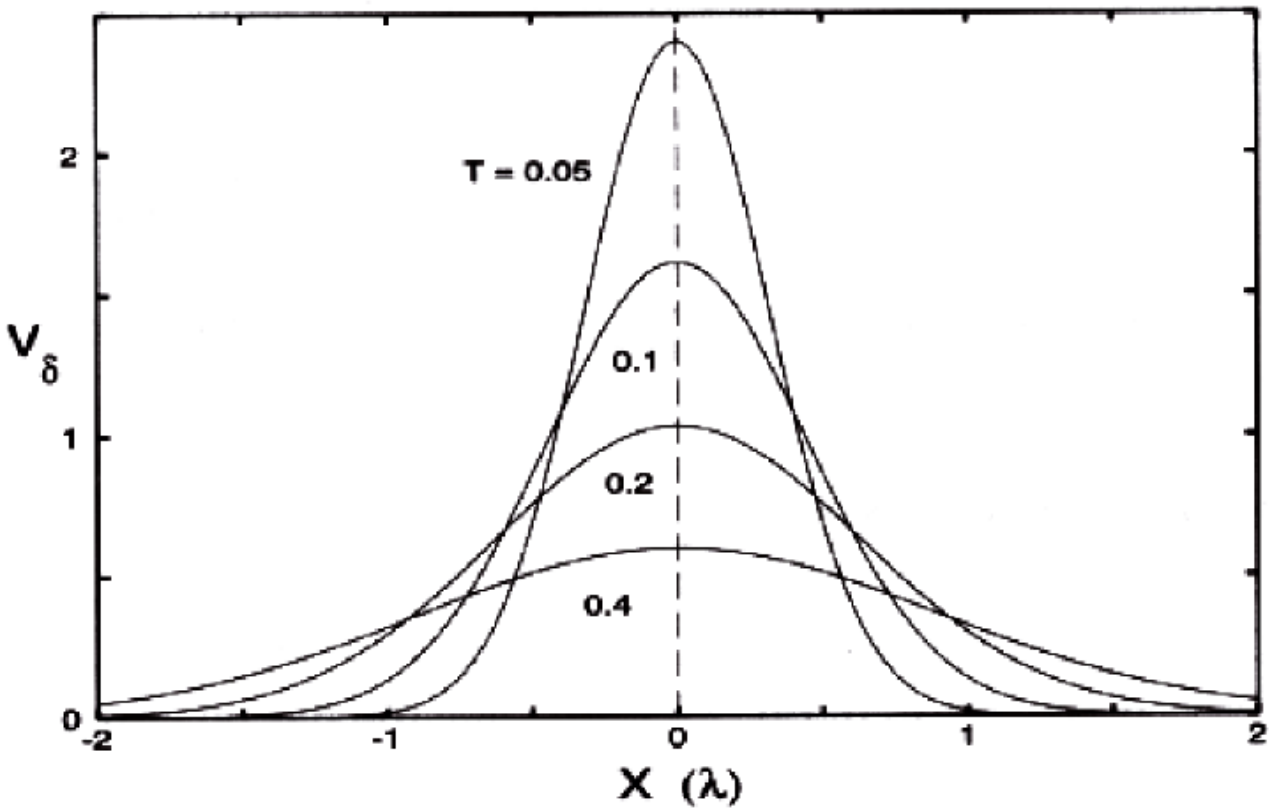


Johnson and Wu

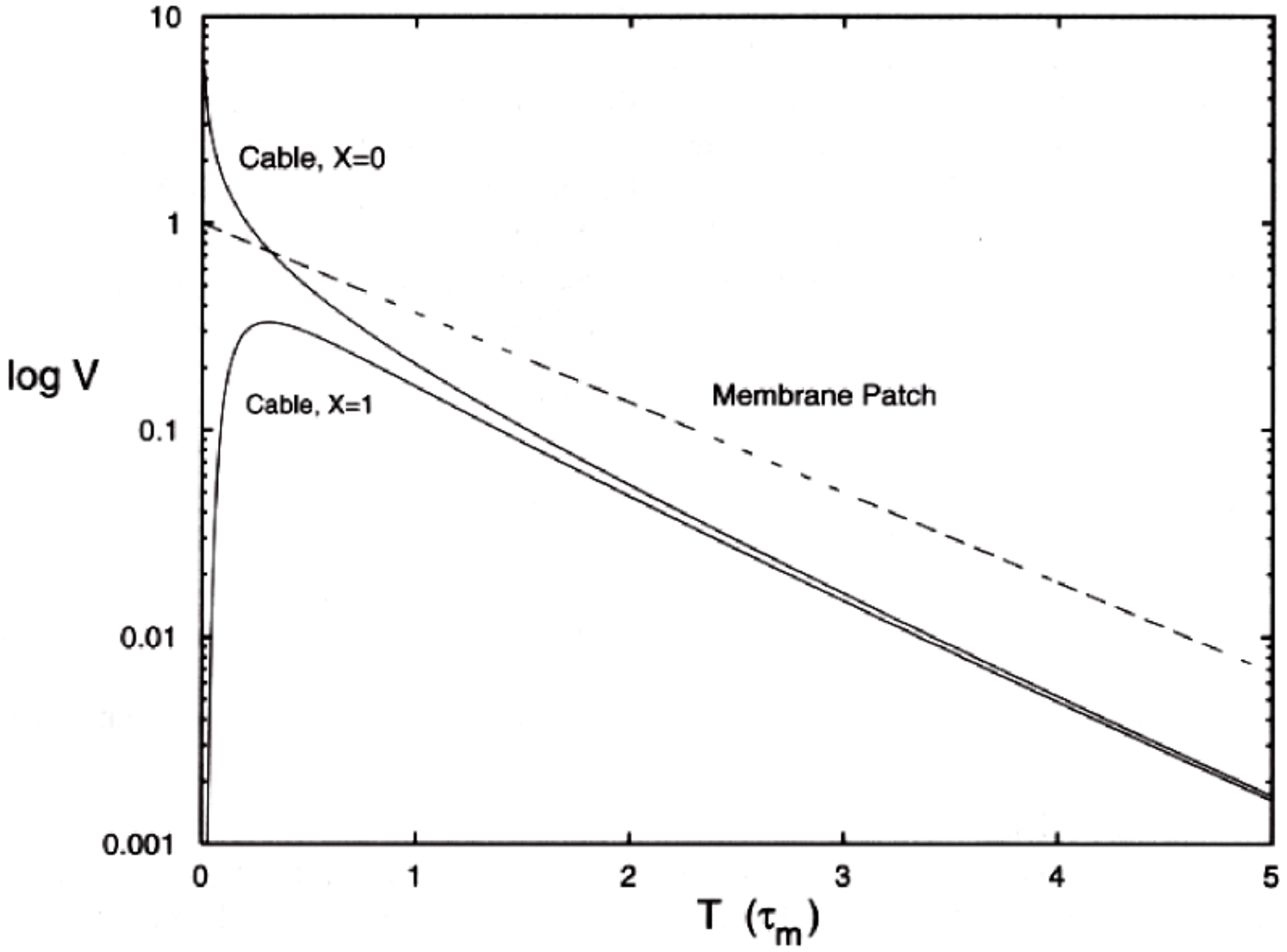
Pulse response

$$V(x,t) \propto \sqrt{\frac{\tau}{4\pi\lambda^2 t}} e^{-\frac{t}{\tau} - \frac{\tau x^2}{4\lambda^2 t}}$$

$$V(x,t) = V(0) e^{-\frac{1}{2}\ln t/\tau - \frac{t}{\tau} - \frac{s^2\tau}{4\lambda^2 t}}$$



Koch


10
1
0.1
0.01
0.001
log V
Cable, X=0
Cable, X=1
Membrane Patch
0
1
2
3
4
5
T (τm)

Koch

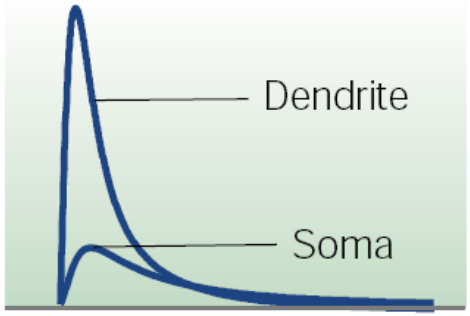
Properties of passive cables

→ Electrotonic length $\lambda = \sqrt{\frac{r_m}{r_i}}$

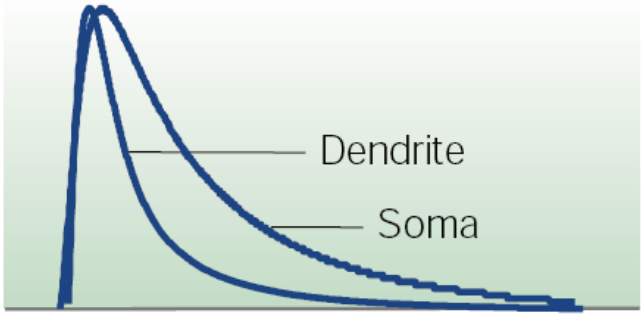
→ Current can escape through additional pathways: speeds up decay

→ Cable diameter affects input resistance $R_N = \frac{\sqrt{R_m R_i / 2}}{2\pi a^{3/2}}$

Amplitude



Time course



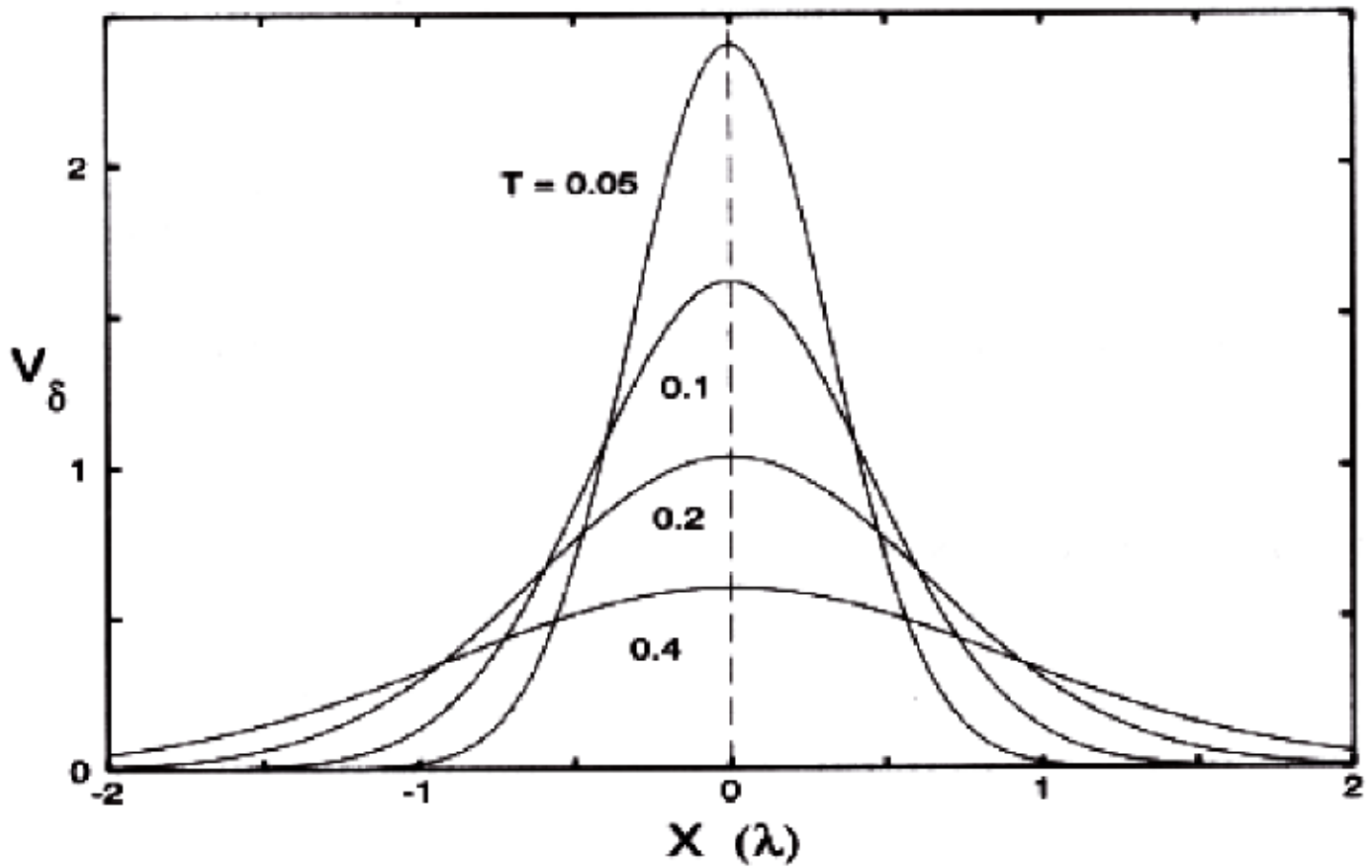
Properties of passive cables

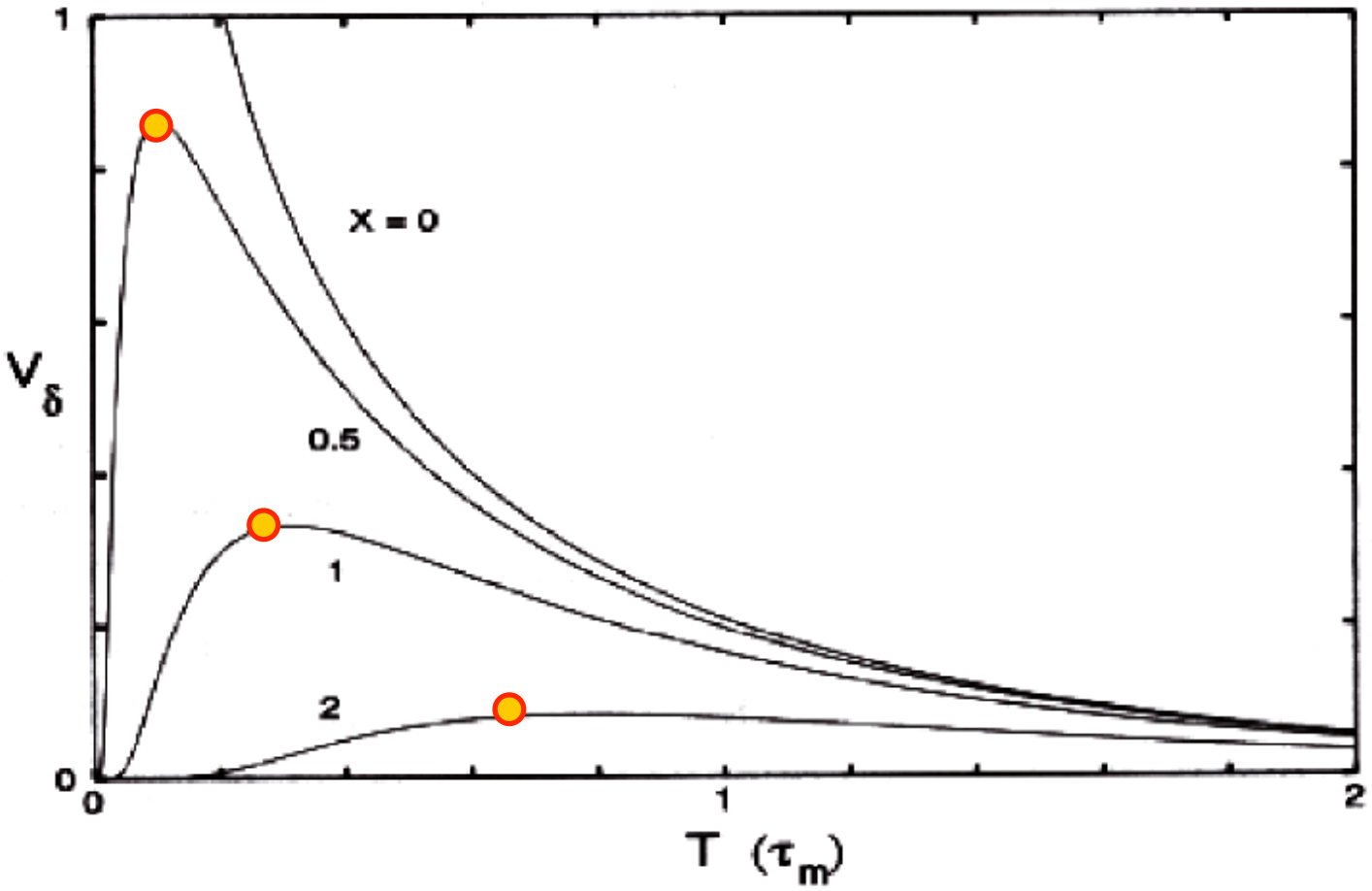
→ Electrotonic length $\lambda = \sqrt{\frac{r_m}{r_i}}$

→ Current can escape through additional pathways: speeds up decay

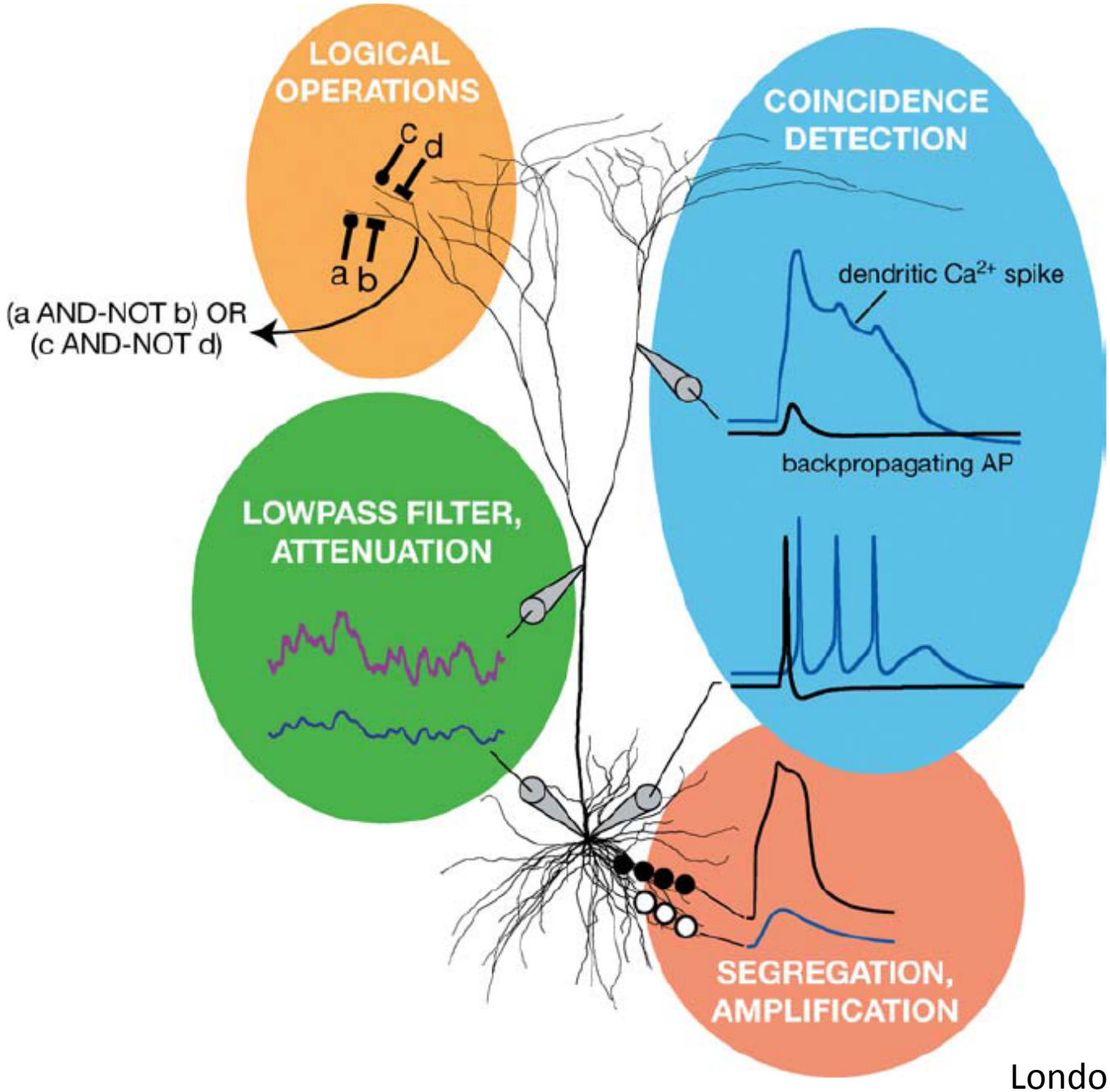
→ Cable diameter affects input resistance $R_N = \frac{\sqrt{R_m R_i / 2}}{2\pi a^{3/2}}$

→ Cable diameter affects transmission velocity


T = 0.05
0.1
0.2
0.4
V_δ
X (λ)
0
1
2
-2
-1
0
1
2



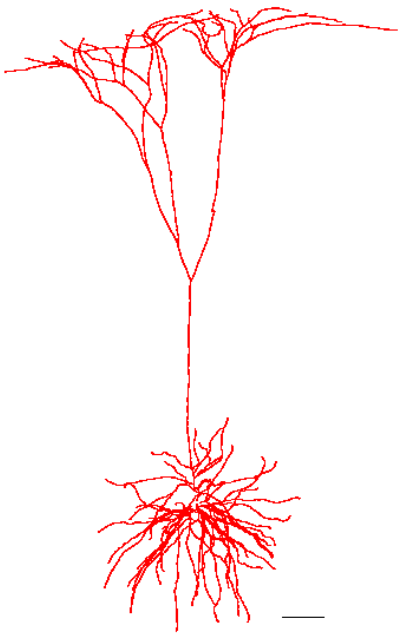
$$\theta = \frac{2\lambda}{\tau_m} = \sqrt{\frac{2a}{R_m R_i C_m^2}}$$



London and Hausser, 2005

Passive computations

Linear filtering:



→ Inputs from dendrites are broadened and delayed

→ Alters summation properties..
coincidence detection to temporal integration

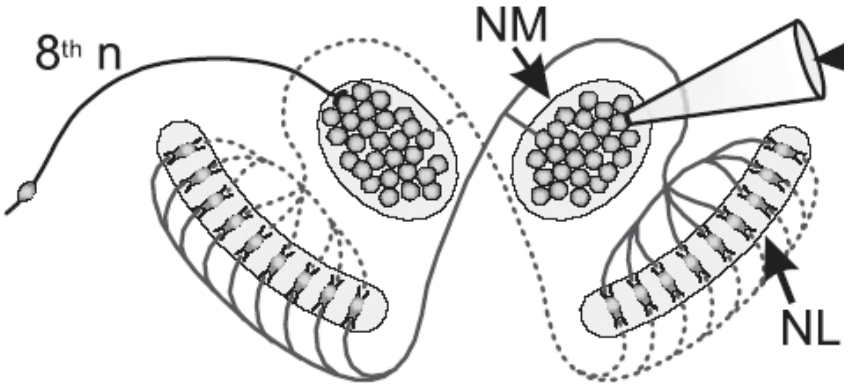
→ Delay lines

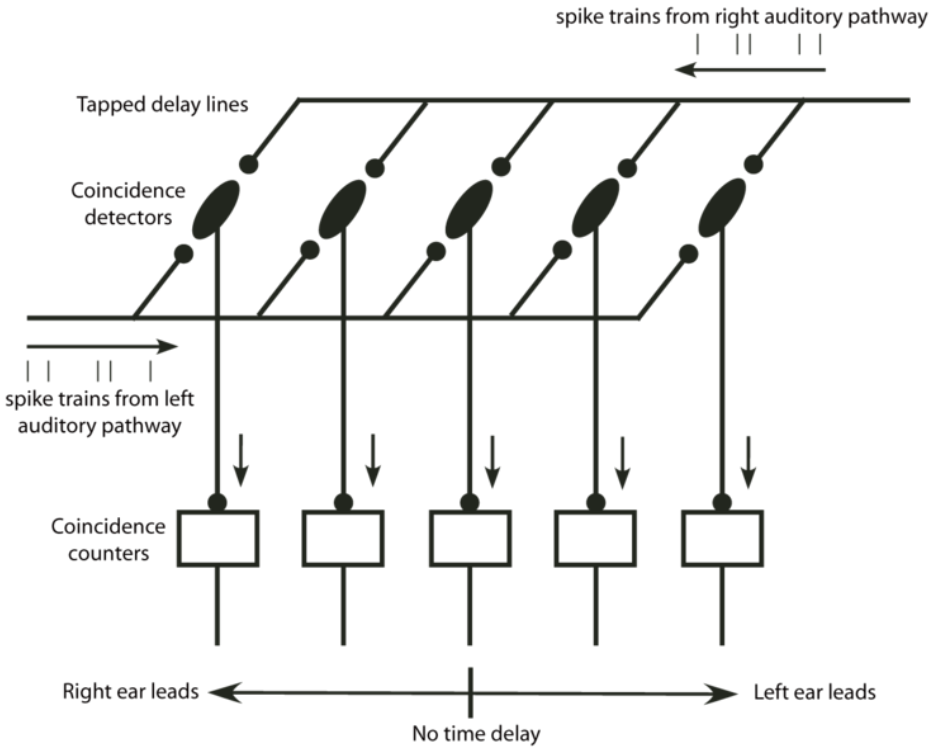
→ Segregation of inputs

→ Nonlinear interactions within a dendrite
-- sublinear summation
-- shunting inhibition

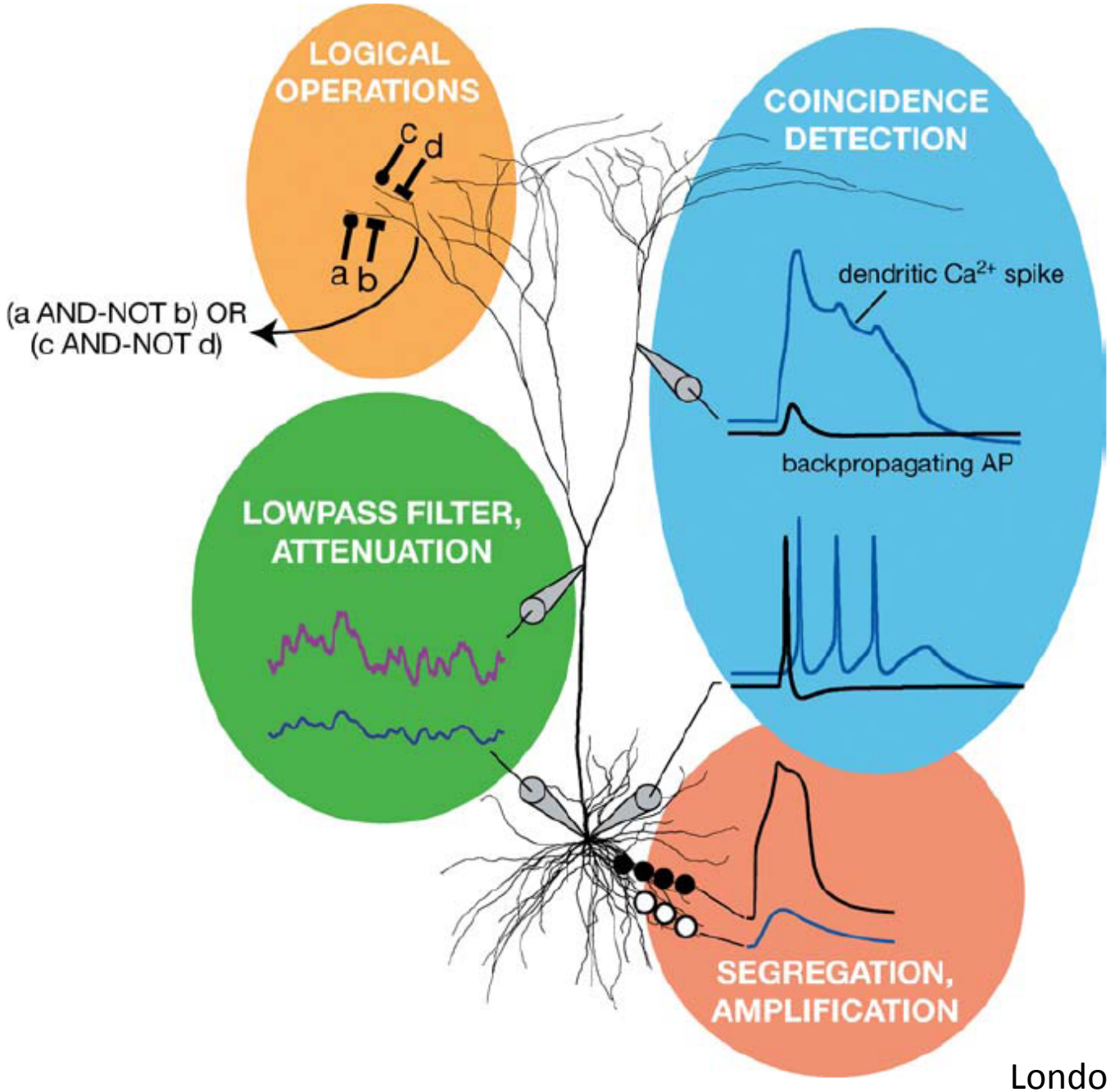
→ Dendritic inputs “labelled”

Delay lines: the sound localization circuit





Spain; Scholarpedia



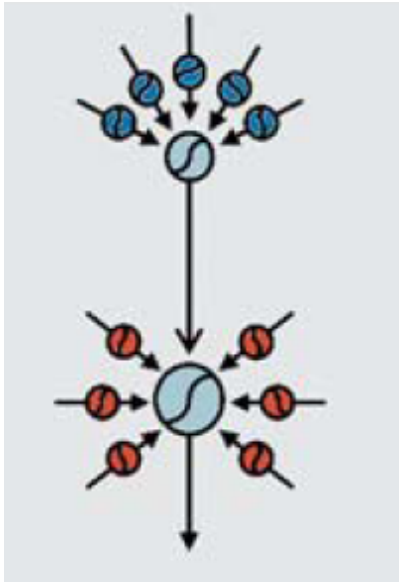
London and Hausser, 2005

Active dendrites

Mechanisms to deal with the distance dependence of PSP size

→ Subthreshold boosting: inward currents with reversal near rest
Eg persistent Na^+

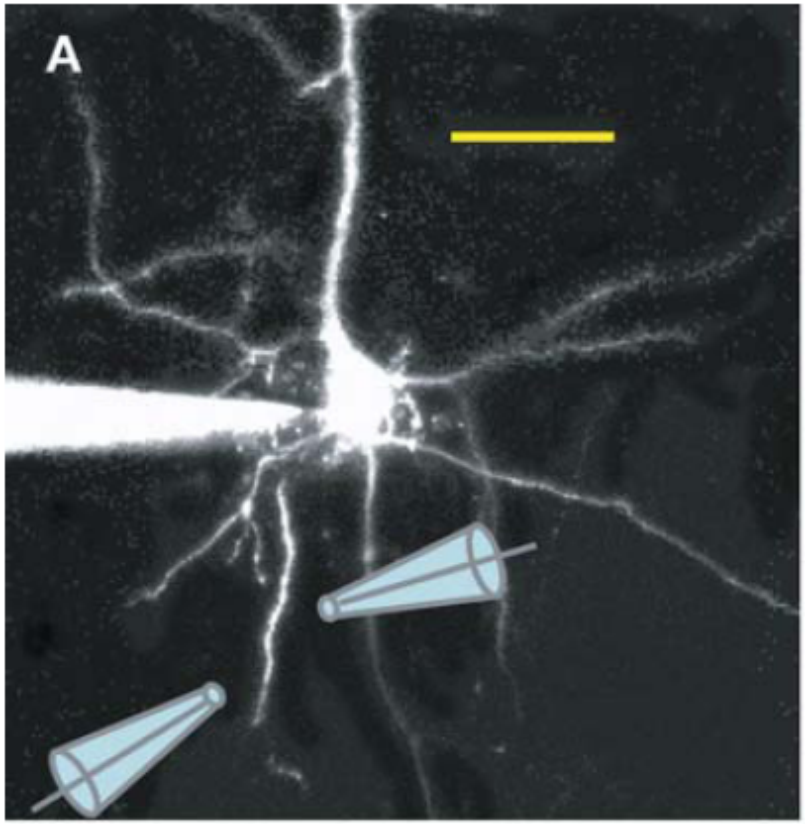
→ Synaptic scaling

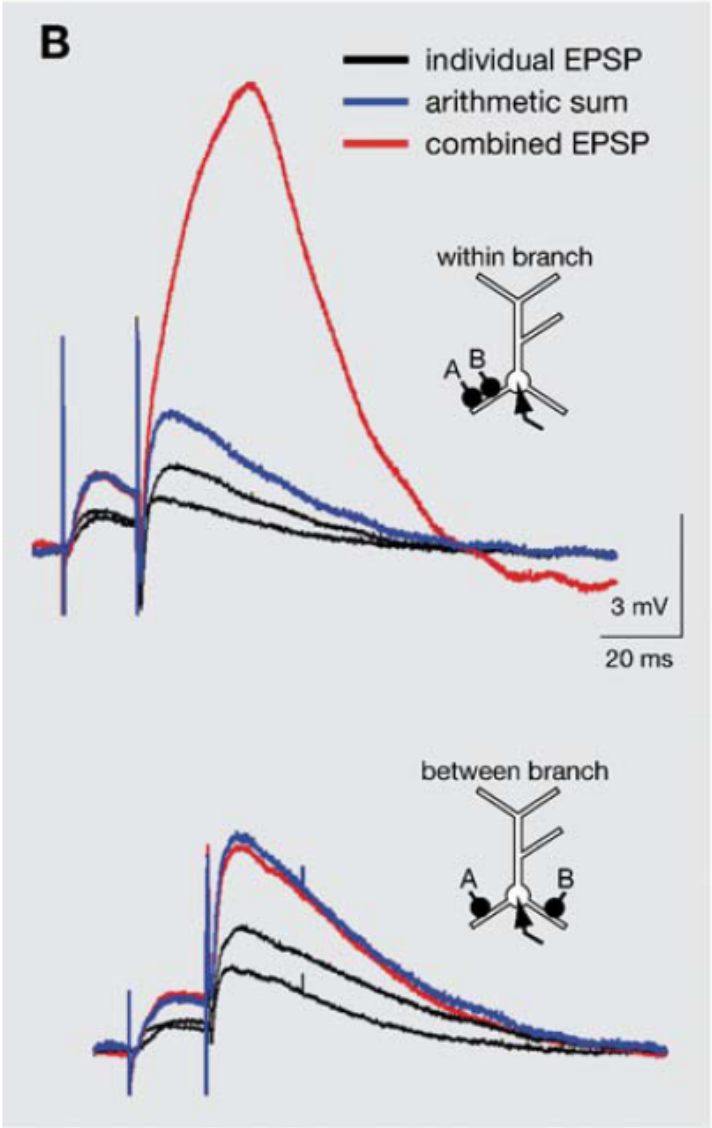


→ Dendritic spikes
Na^+, Ca^{2+} and NMDA
Dendritic branches as
mini computational units

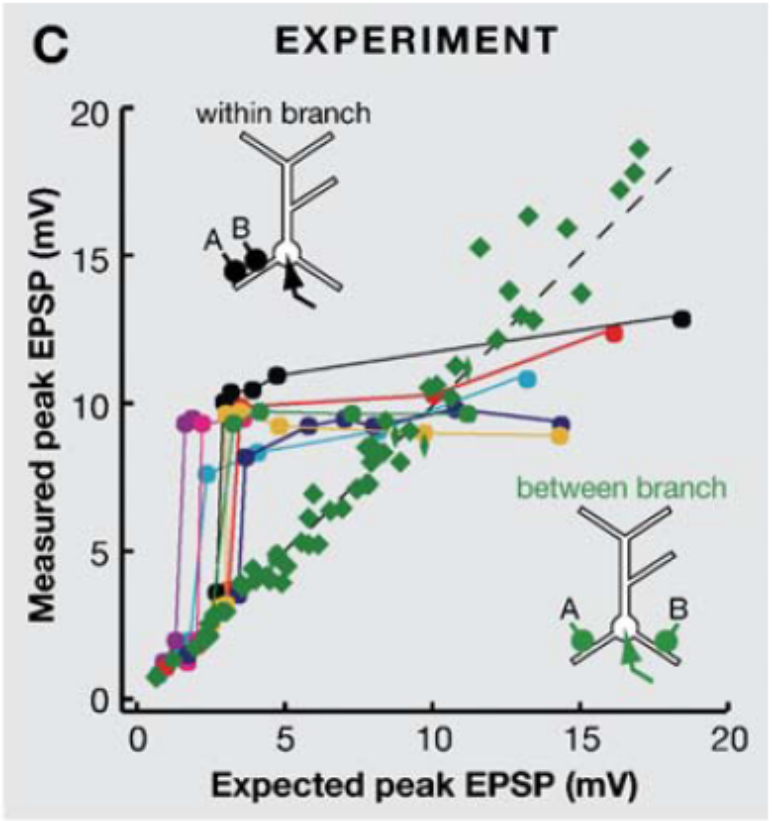
→ backpropagation:
feedback circuit
Hebbian learning through
supralinear interaction of backprop spikes with inputs

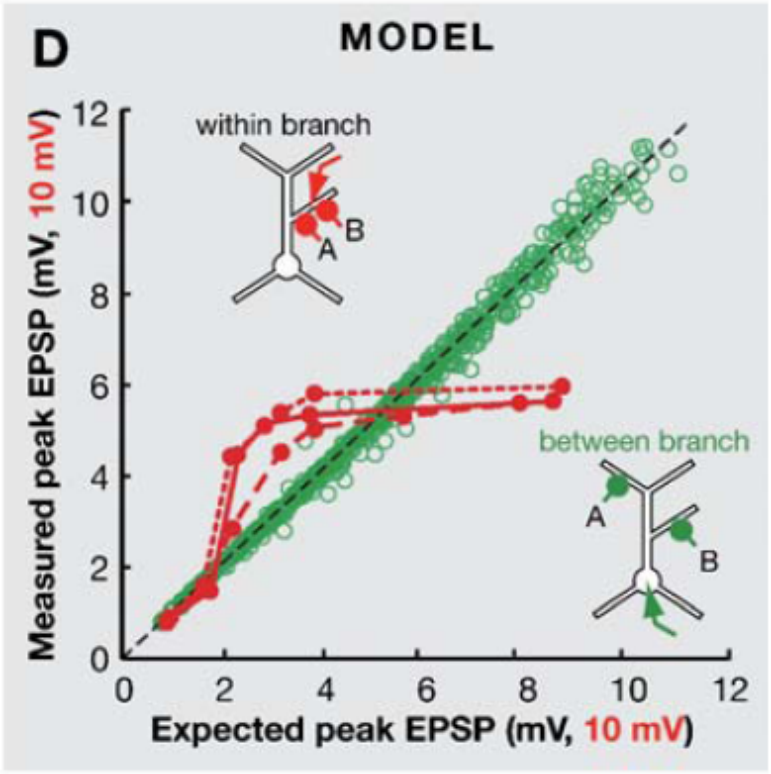
Segregation and amplification





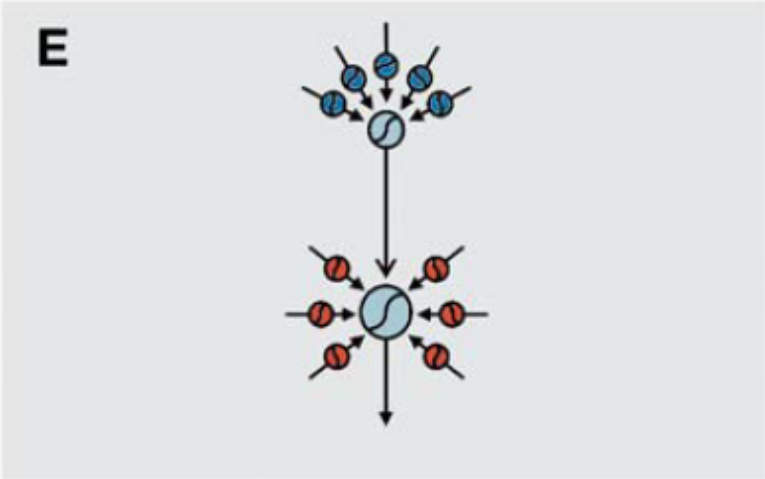
Segregation and amplification



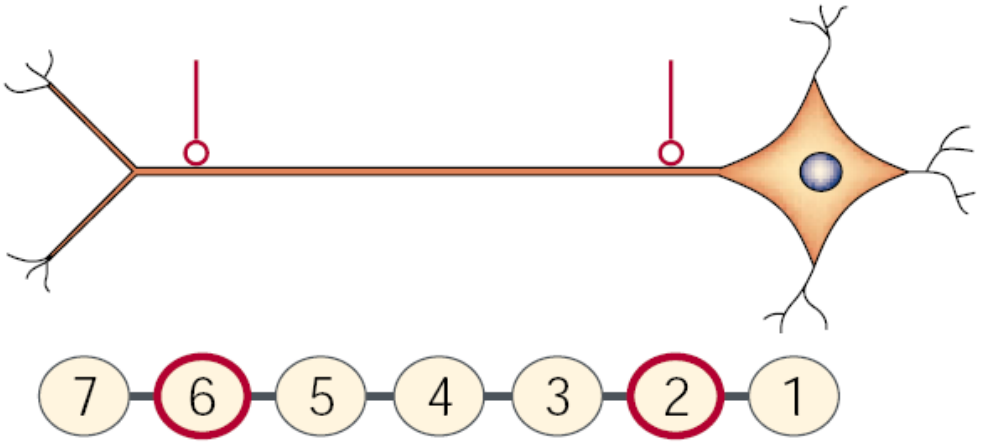


Segregation and amplification

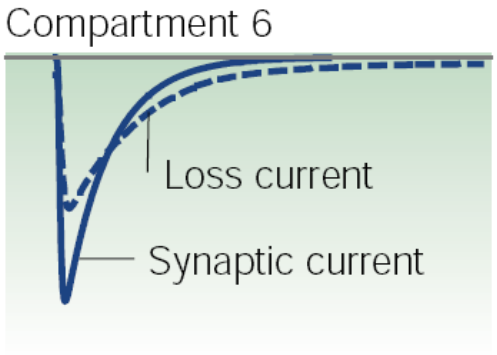
The single neuron as a neural network

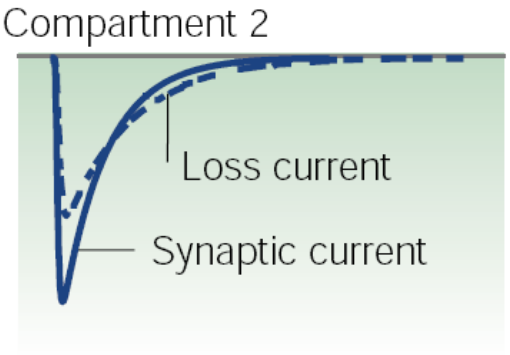


Synaptic scaling

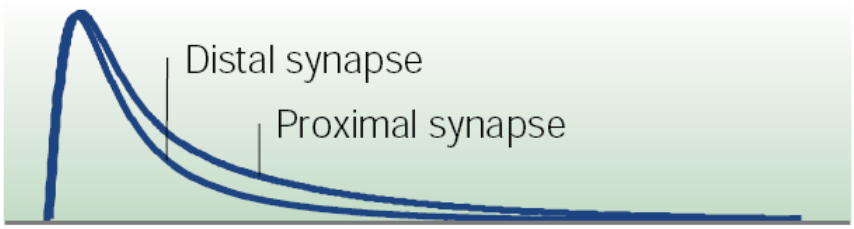


Currents





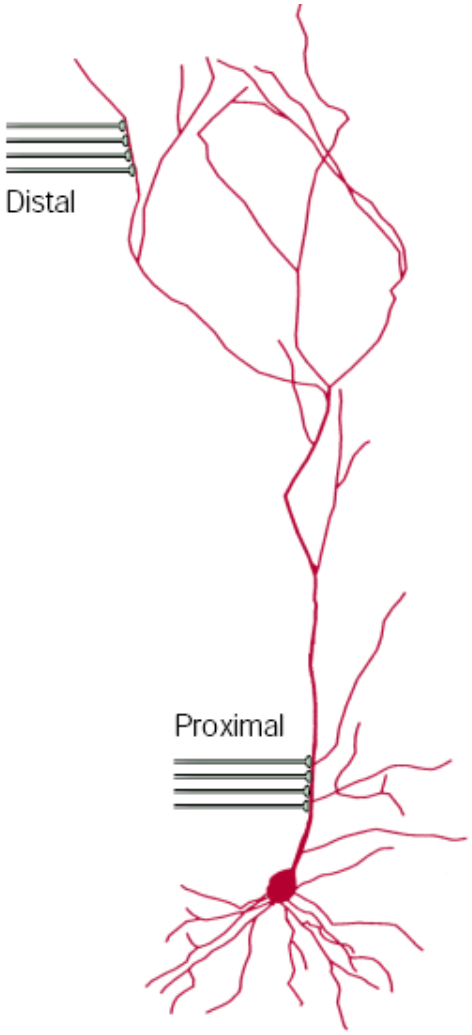
Potential



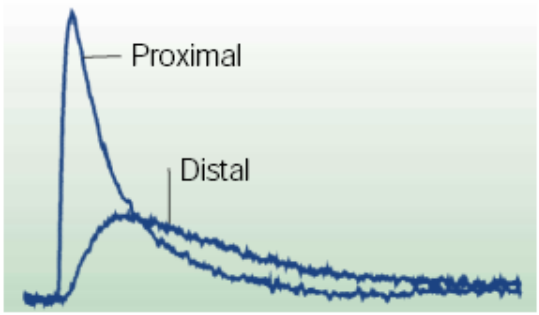
Distal: integration
Proximal: coincidence

Magee, 2000

Expected distance dependence

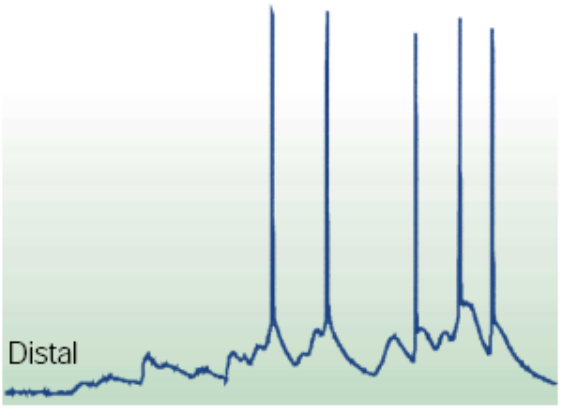


Localized output

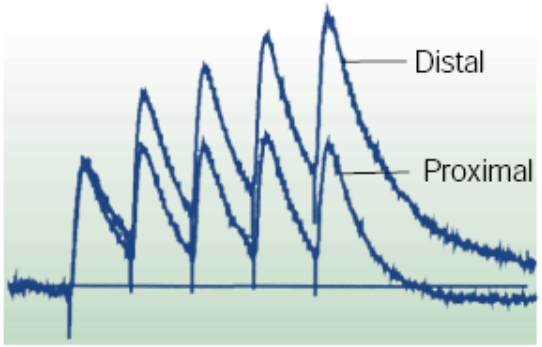


Amplitude and kinetics

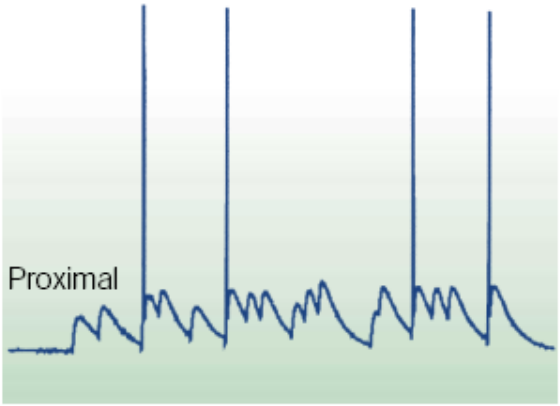
Synaptic potentials



Somatic action potentials

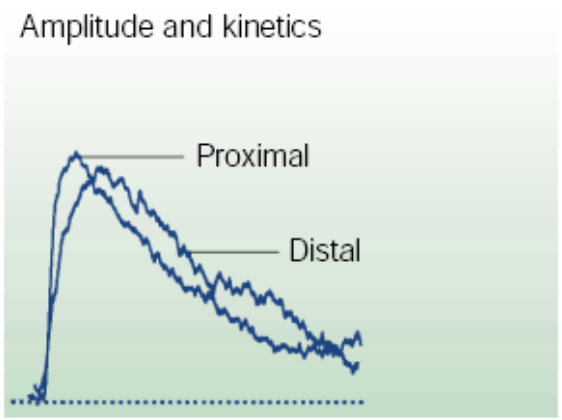


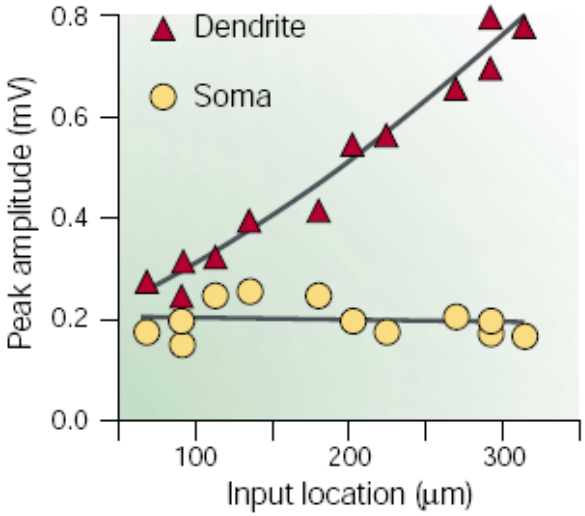
Temporal summation

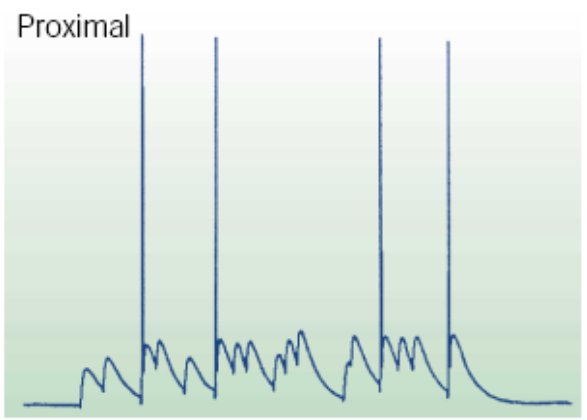


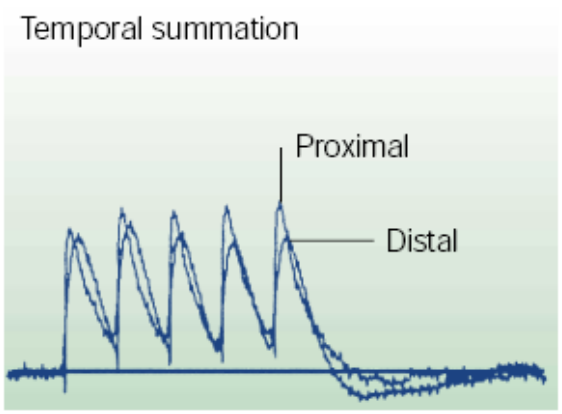
Magee, 2000

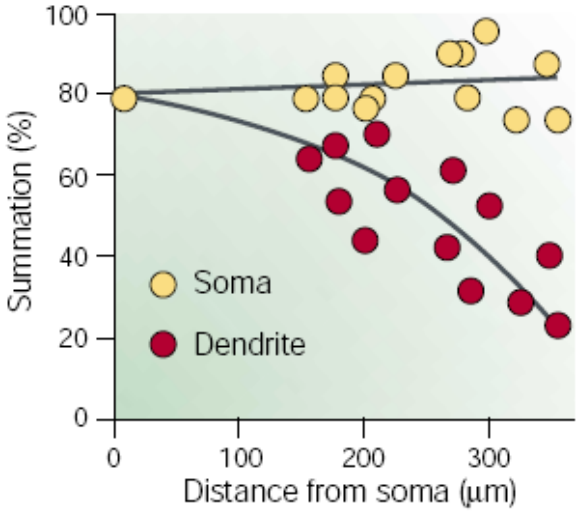
CA1 pyramidal neurons

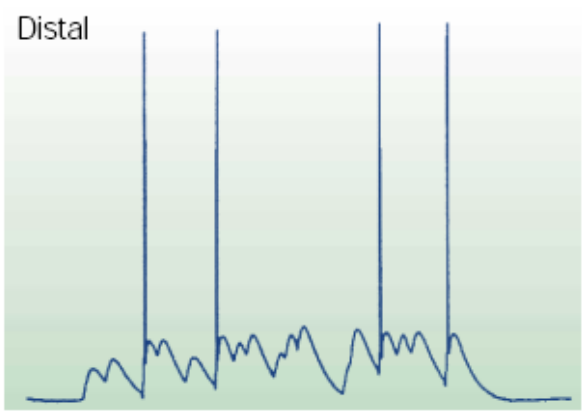




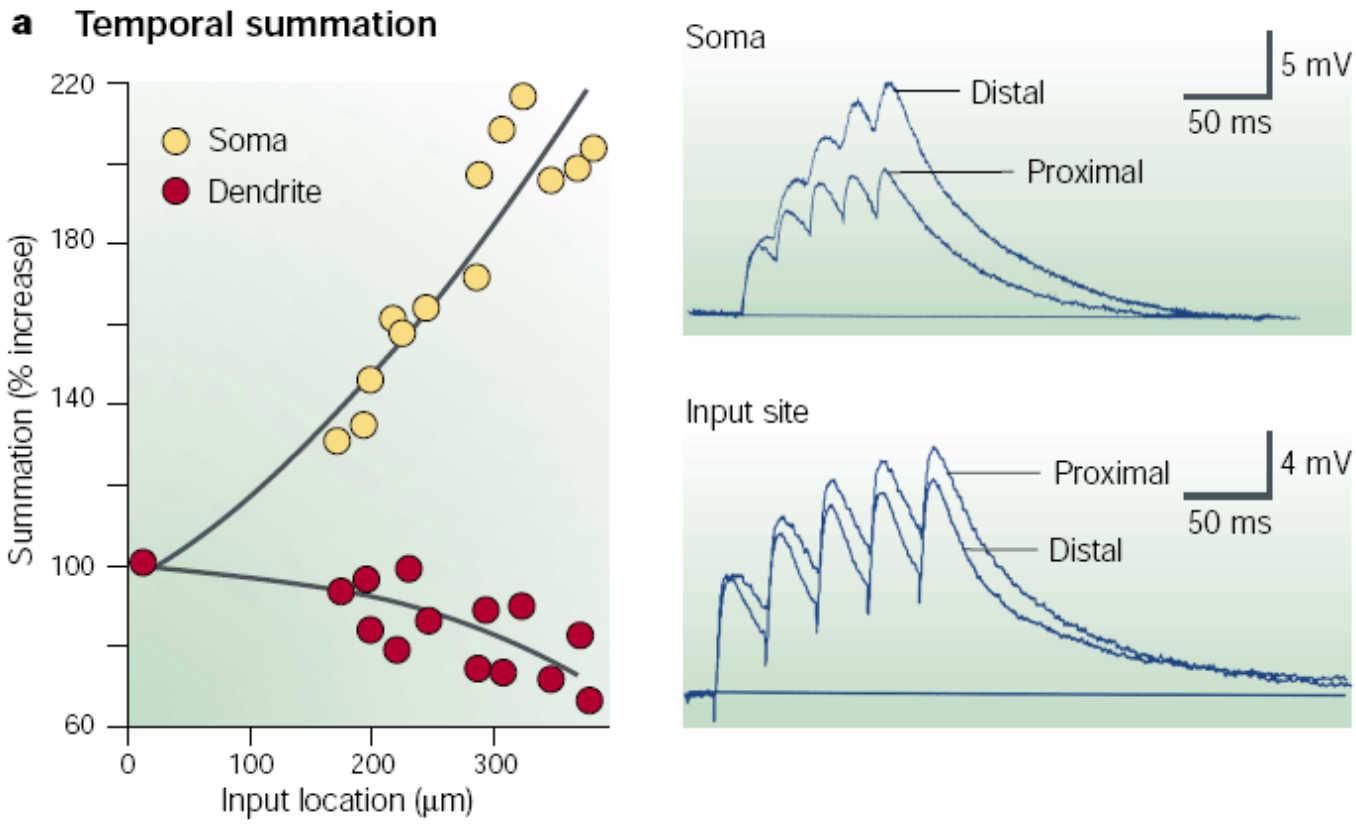




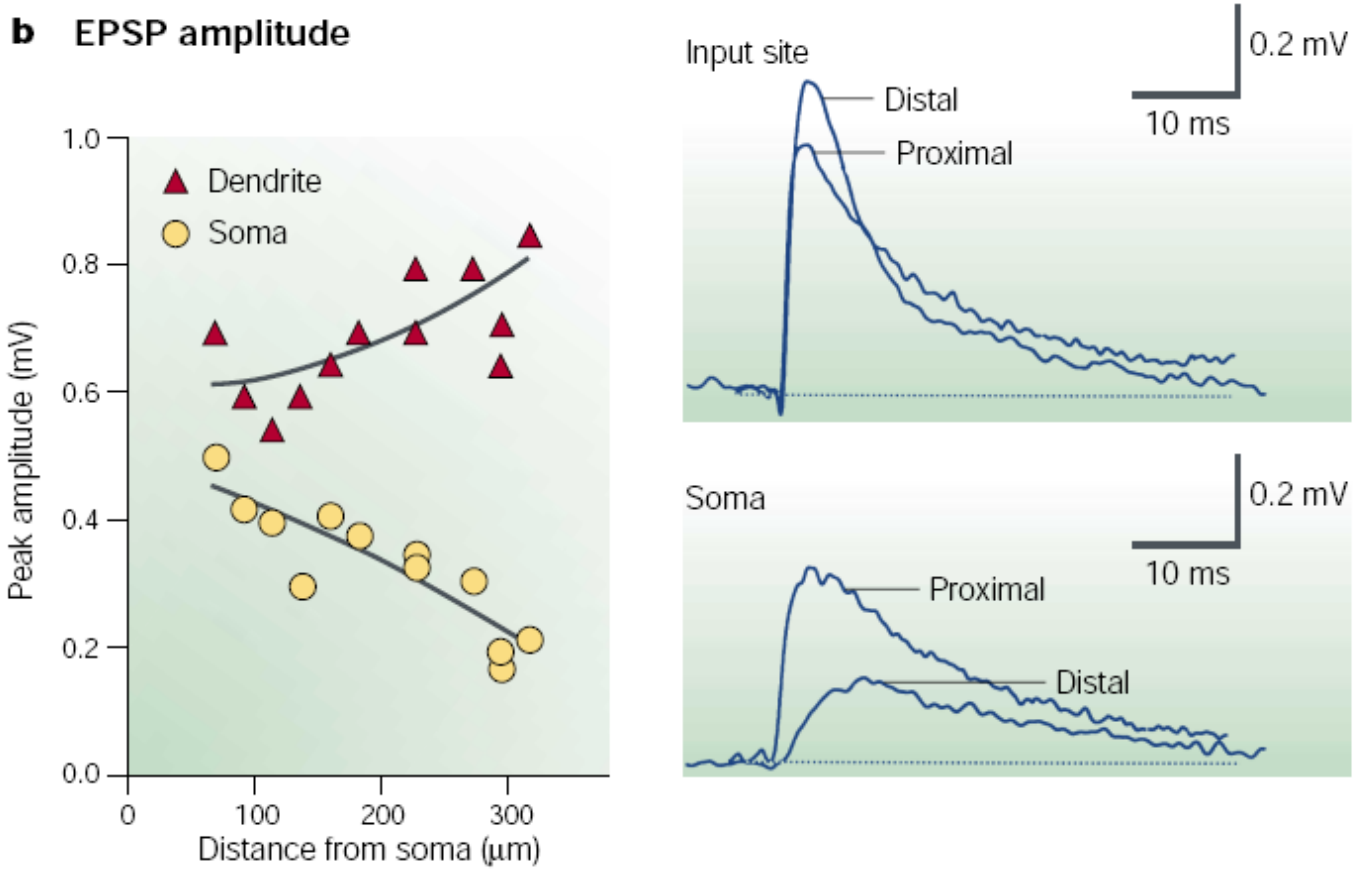




Passive properties



Passive properties



Active properties: voltage-gated channels

For short intervals (0-5ms), summation is linear or slightly supralinear

For longer intervals (5-100ms), summation is sublinear

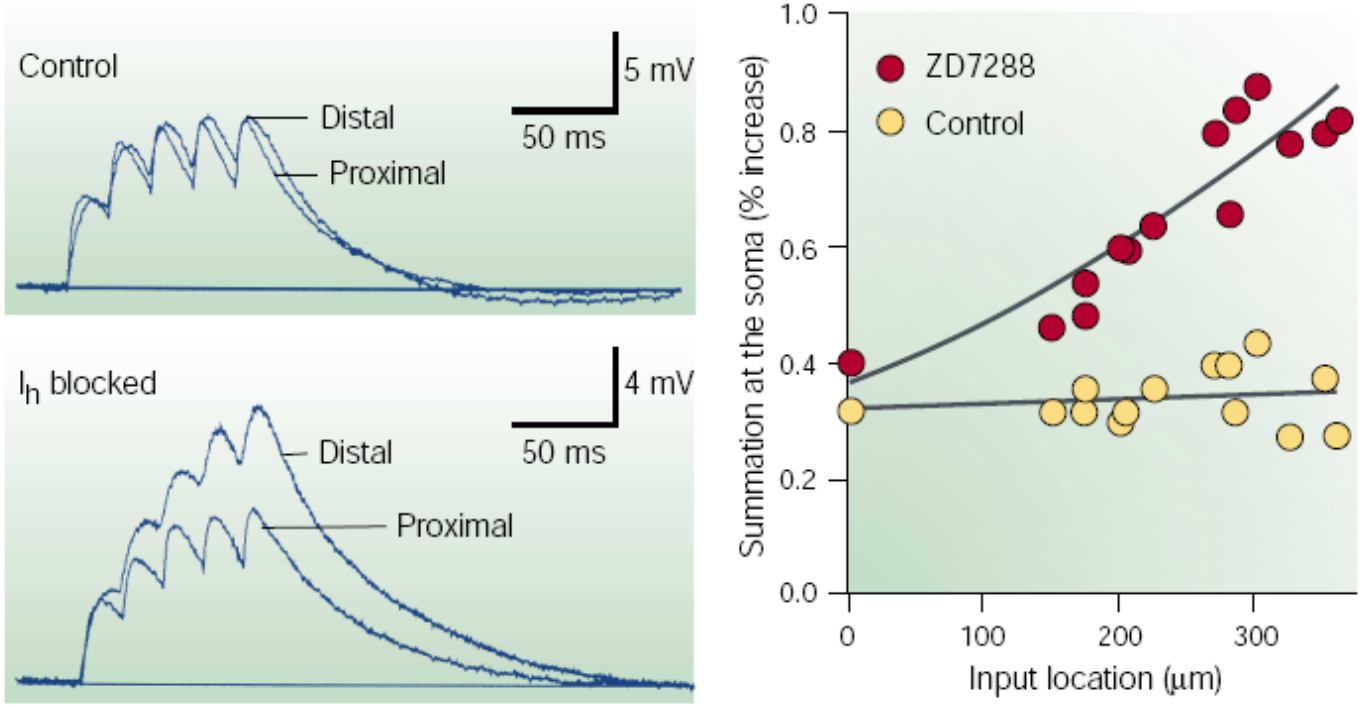
Na^+, Ca^{2+} or NDMA receptor block eliminates supralinearity

I_h and K^+ block eliminates supralinearity

Major player in synaptic scaling: hyperpolarization activated K current, I_h

Increases in density down the dendrite
Effectively outward current due to deactivation during EPSP hyperpolarizes, shortens EPSP duration, reduces local summation

Active properties: voltage-gated channels



Major player in synaptic scaling: hyperpolarization activated K current, I_h

Increases in density down the dendrite

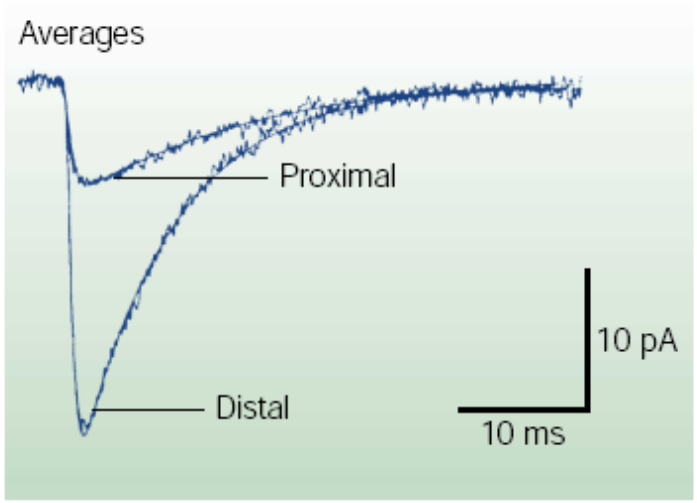
Effectively outward current due to deactivation during EPSP hyperpolarizes, shortens EPSP duration, reduces local summation

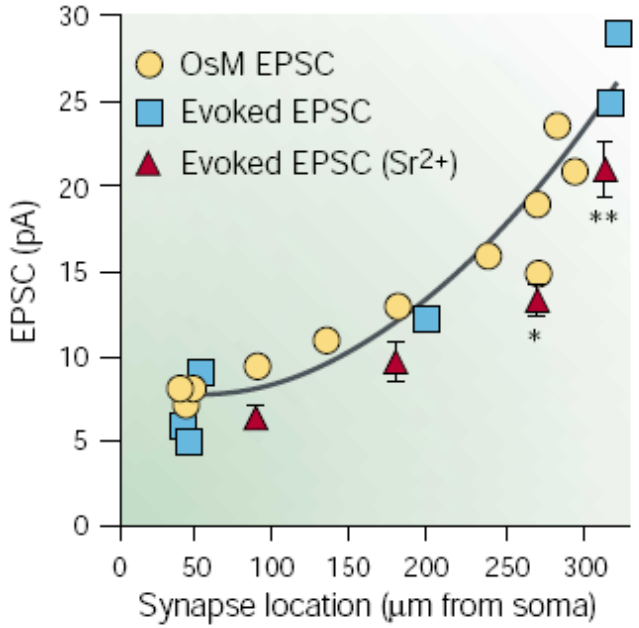
Synaptic properties

While active properties contribute to summation, don't explain normalized amplitude

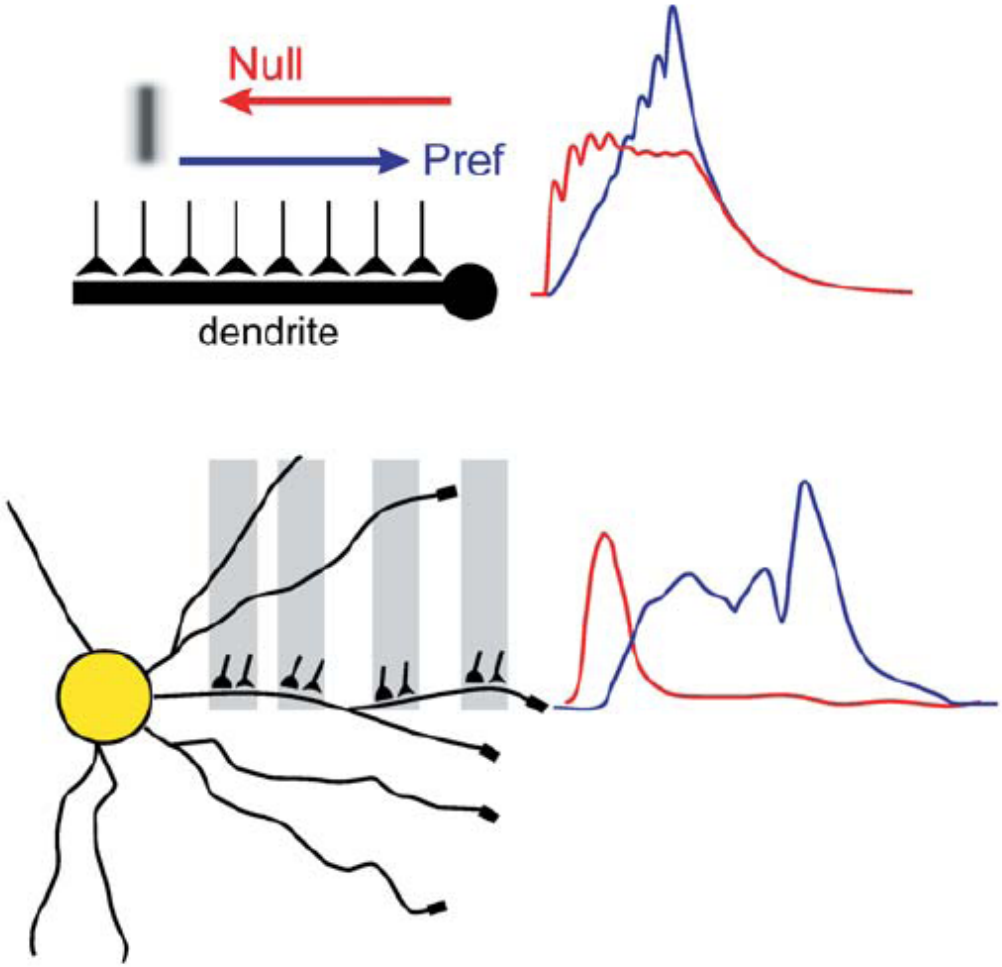
Shape of EPSC determines how it is filtered .. Adjust ratio of AMPA/NMDA receptors

Eliminate role of I_h





Direction selectivity



Rall; fig London and Hausser