Dendritic Integration 2

Foundations of Cellular Neuroscience

FAES

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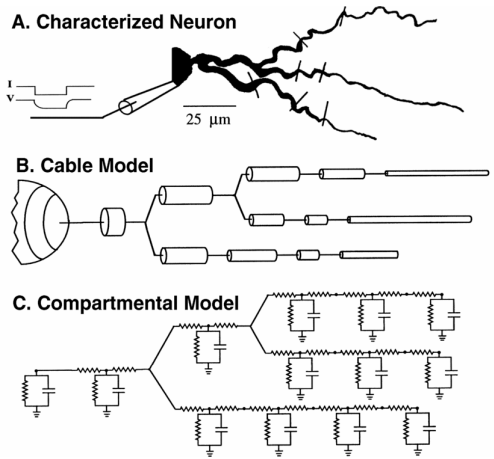
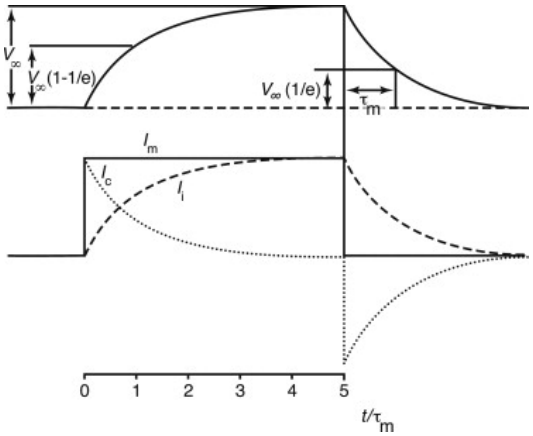
Key concepts

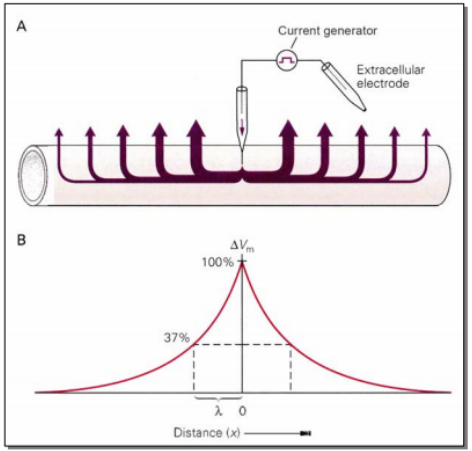
Input Resistance



Time constant $\tau = RC$

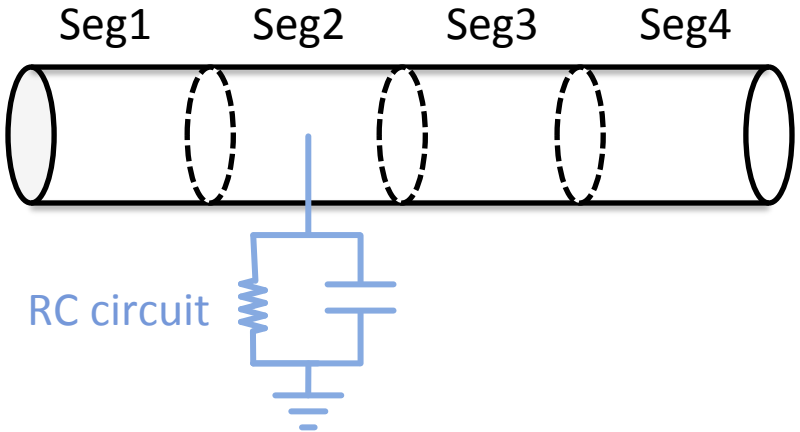


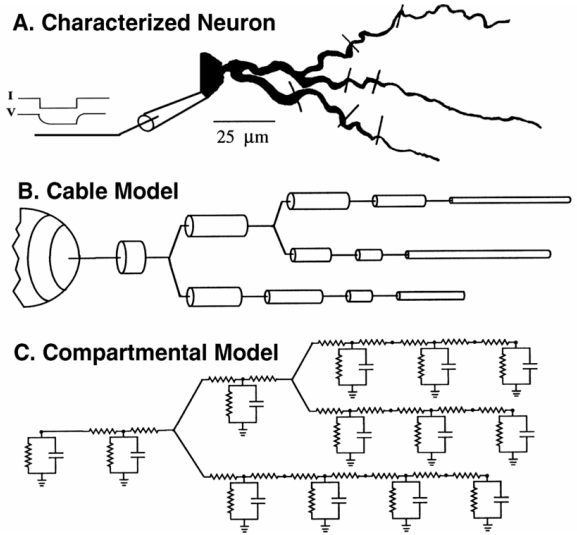
Space constant $\lambda = \sqrt{R\downarrow m} / R\downarrow i \cdot d/4$



Cable theory

Complex morphologies can be broken into simple segments





Outline

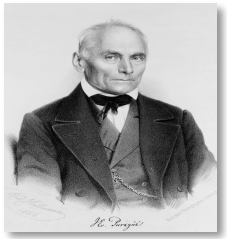
Synaptic integration

- Cable theory
- Time and space constant
- Distance dependence
- Spine

Today

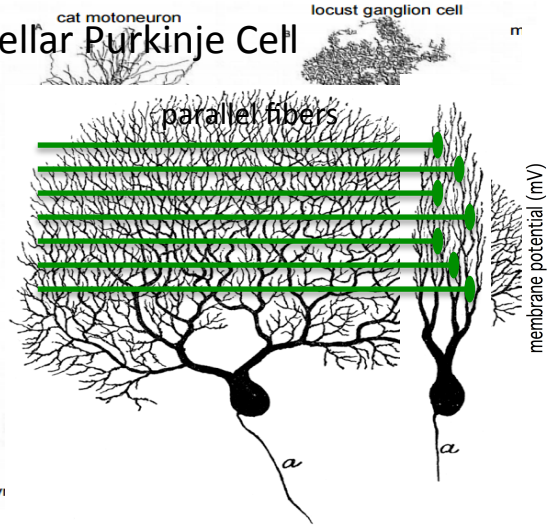
- Spatial/temporal summation
- Integrating excitation/inhibition
- EPSP attenuation
- Back-propagating action potentials
- Dendritic spikes

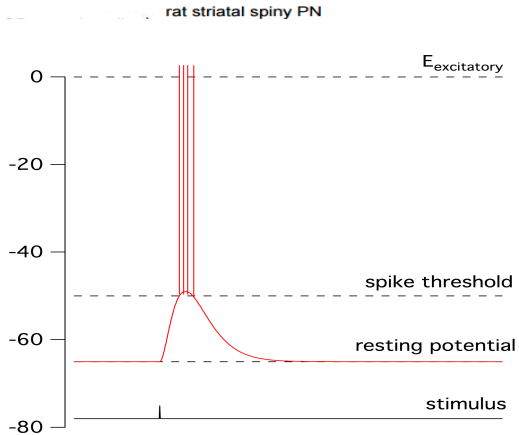
Different neurons integrate differently



Jan Purkinje

Cerebellar Purkinje Cell

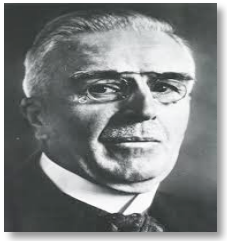




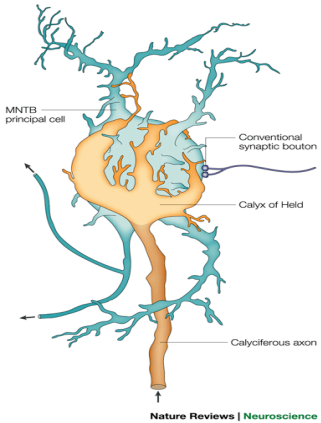
"*spatial* summation"

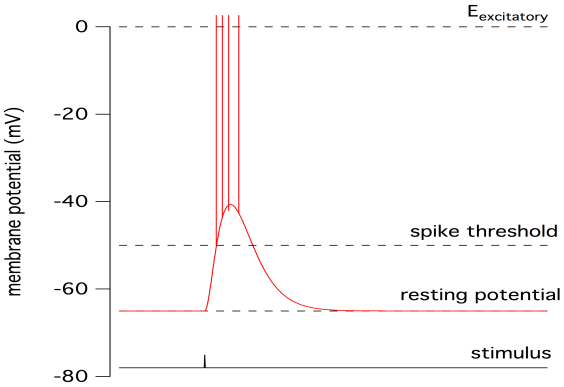
Different neurons integrate differently

MNTB neuron (Calyx of Held)

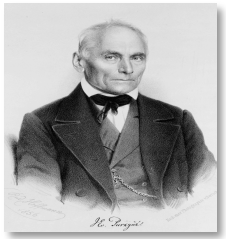


Hans Held





Different neurons integrate differently



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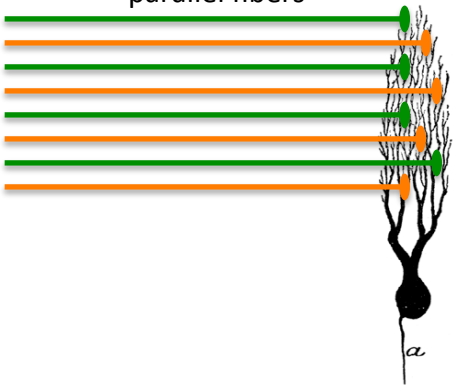
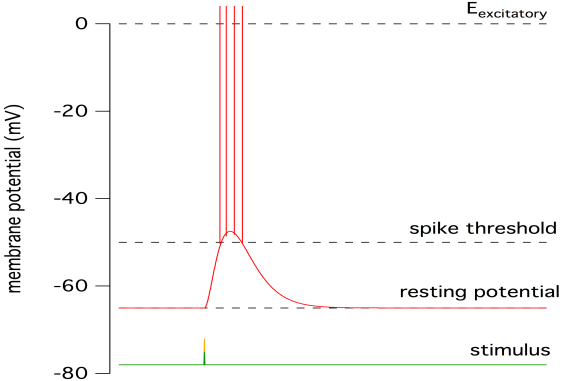
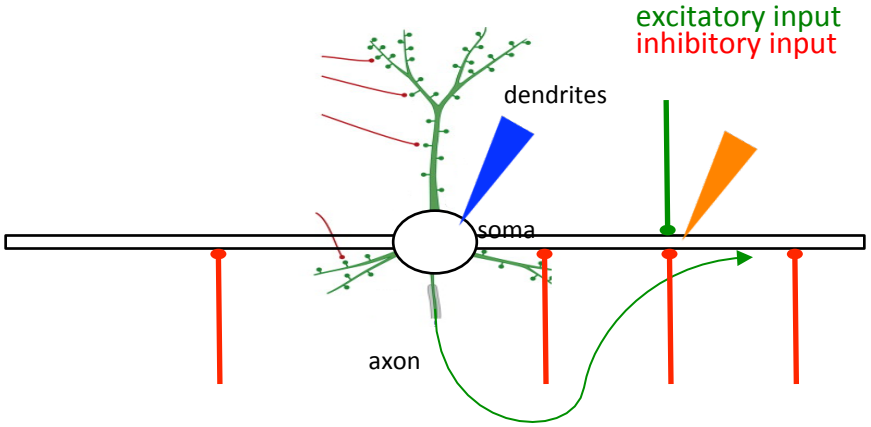




"*temporal* summation"

Integrating excitation and inhibition



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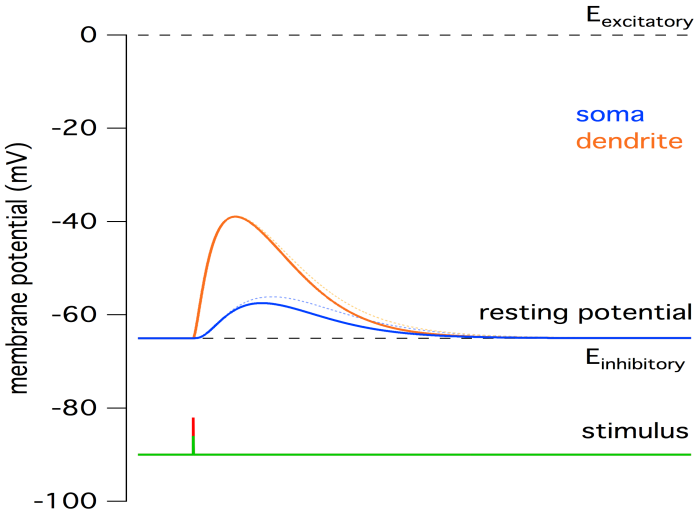
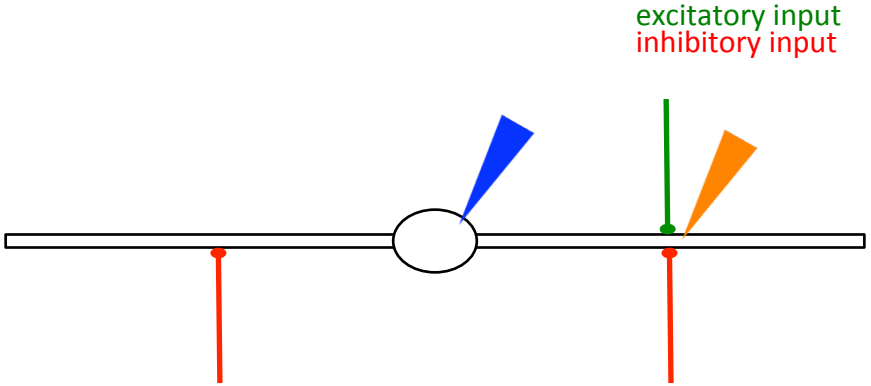
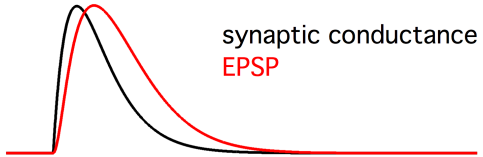
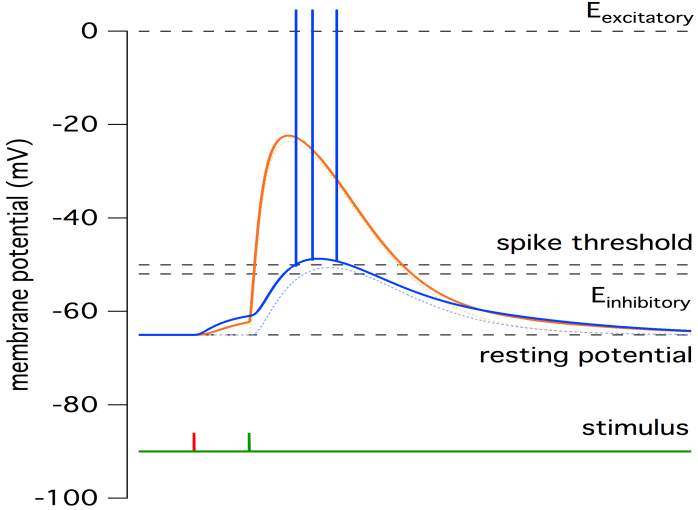


Can inhibition actually be excitatory?





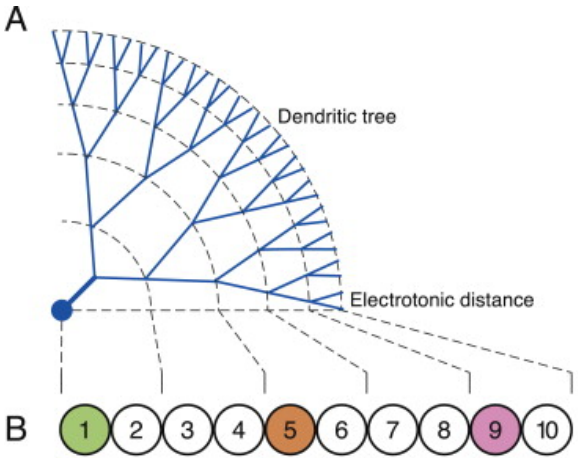


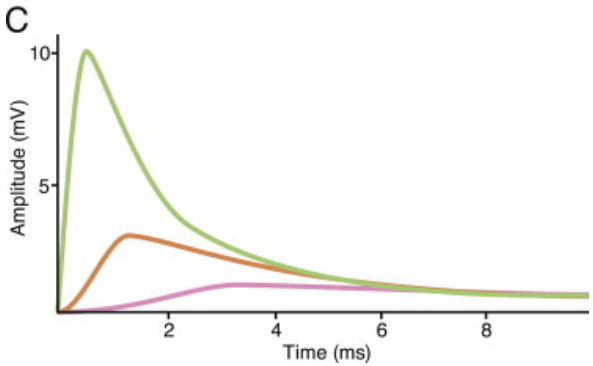
(see Gulledge and Stuart (2003) *Neuron*)

EPSP attenuation

Excitatory Post-Synaptic Potential (EPSP)

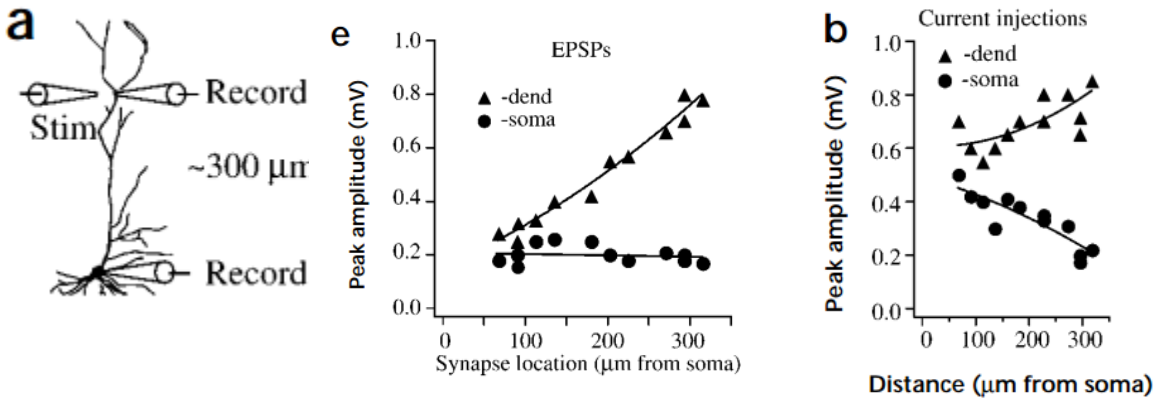
Wilfrid Rall





EPSP attenuation

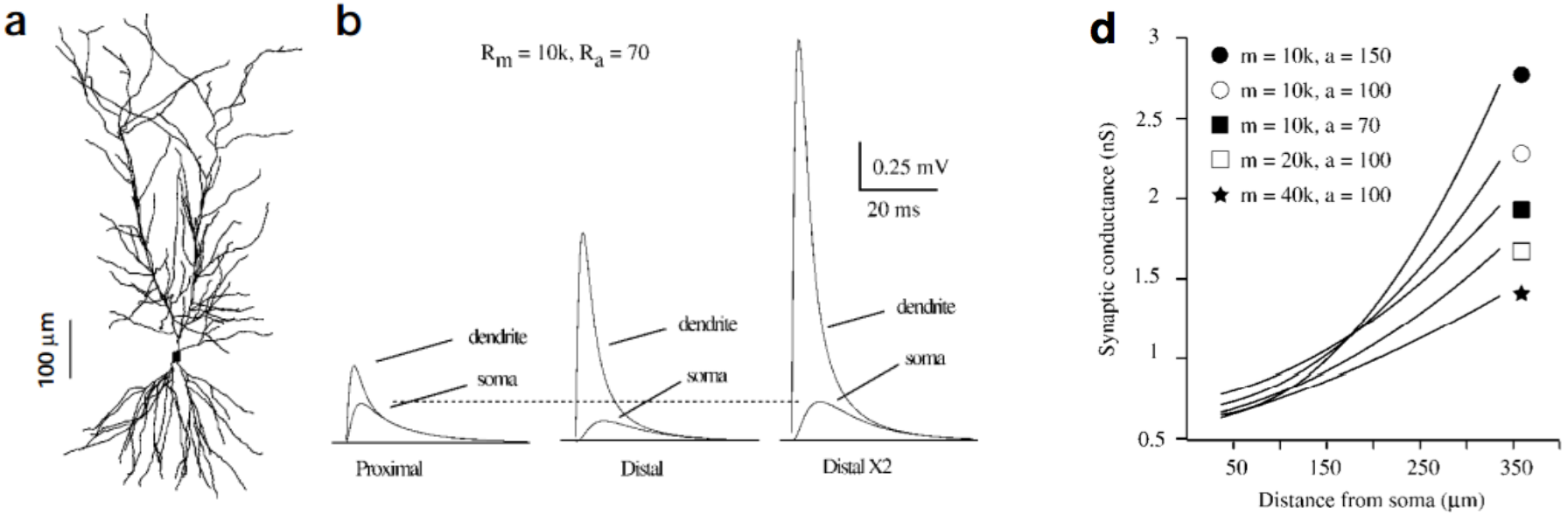
Excitatory Post-Synaptic Potential (EPSP)



Magee and Cook 2000

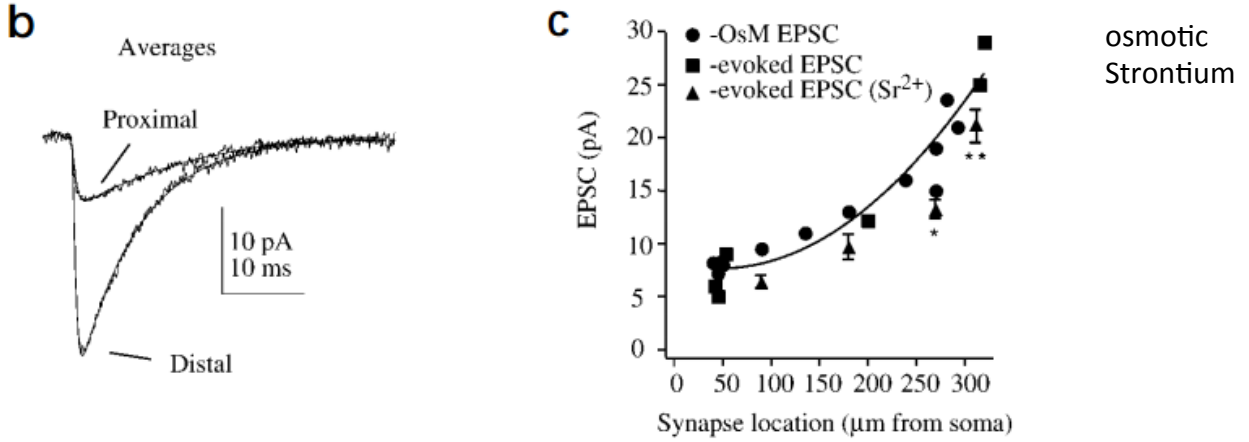
EPSP attenuation

Simulation



Magee and Cook 2000

EPSP attenuation



osmotic
Strontium

Magee and Cook 2000

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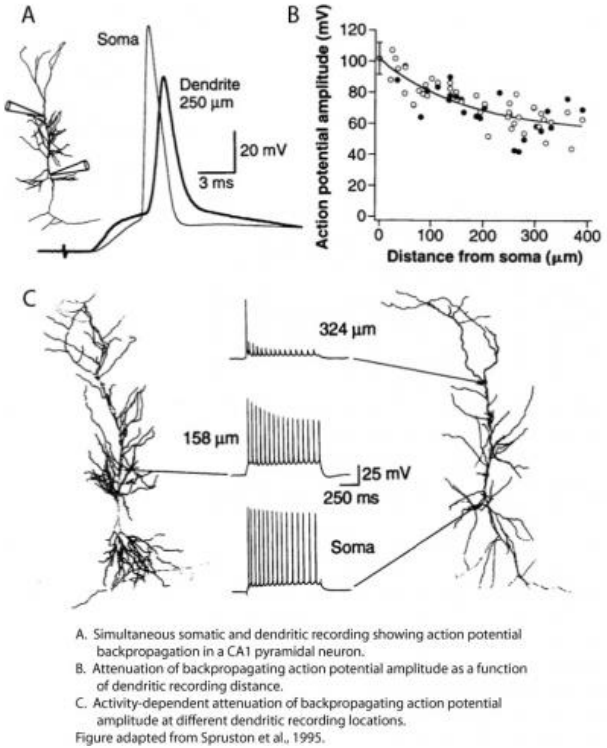
- Dendritic spikes

Active dendritic properties

Na^+ channels
Backpropagating Action Potentials

Some dendrites have enough Na^+ channels to support AP back-propagation

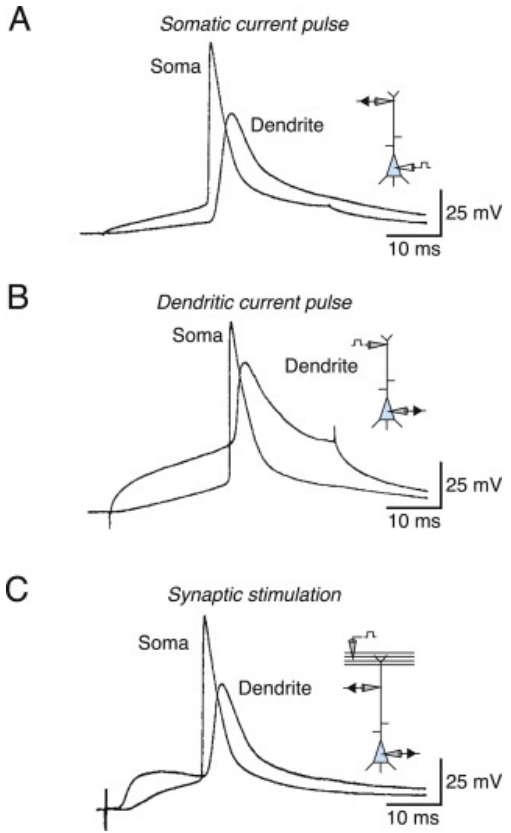


A. Simultaneous somatic and dendritic recording showing action potential backpropagation in a CA1 pyramidal neuron.
B. Attenuation of backpropagating action potential amplitude as a function of dendritic recording distance.
C. Activity-dependent attenuation of backpropagating action potential amplitude at different dendritic recording locations.
Figure adapted from Spruston et al., 1995.

Active dendritic properties

Na^+ channels
Backpropagating Action Potentials

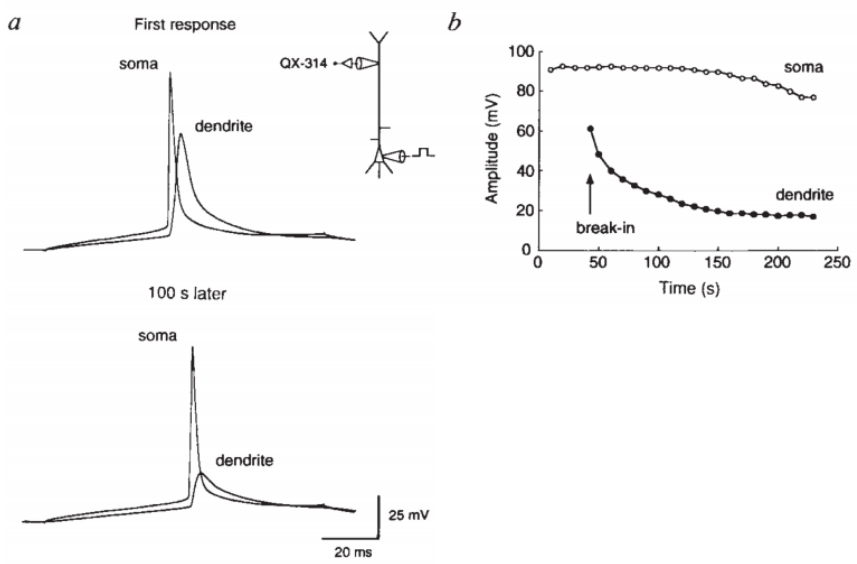
Some dendrites have enough Na^+ channels to support AP back-propagation, but:



Stuart and Sakmann 1994

Active dendritic properties

How to prove that Na^+ channels are required for bAP?

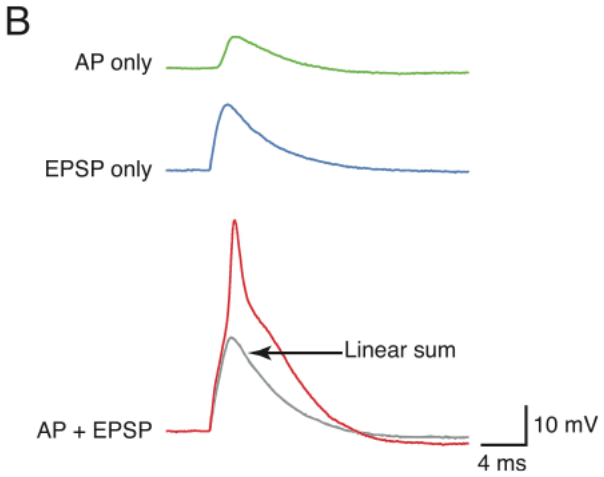


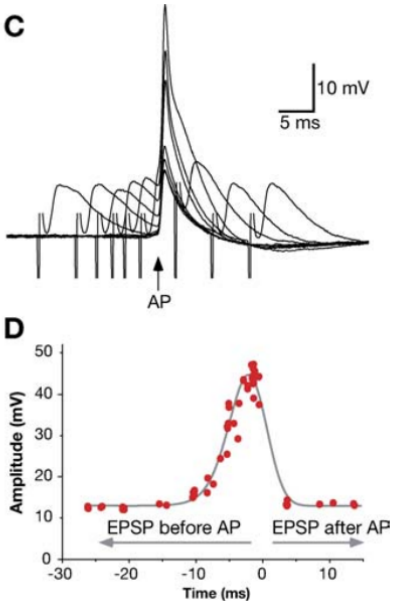
Stuart and Sakmann 1994

Active dendritic properties

Na^+ channels

Backpropagating Action Potentials can allow non-linear integration

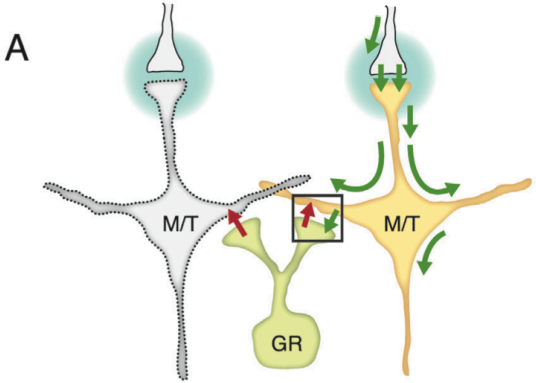


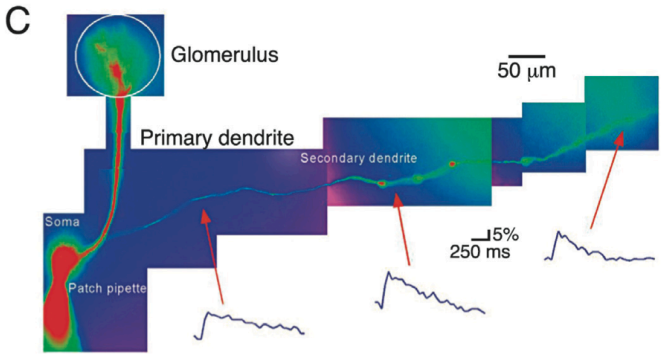


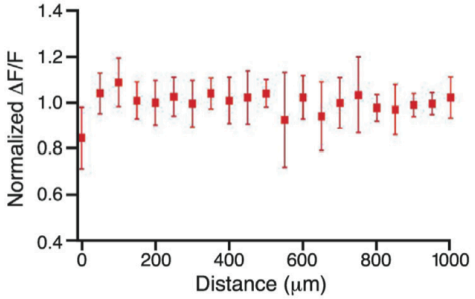
Stuart and Hausser 2001

Are bAPs functional?

GR: granule cell
M/T: mitral cell







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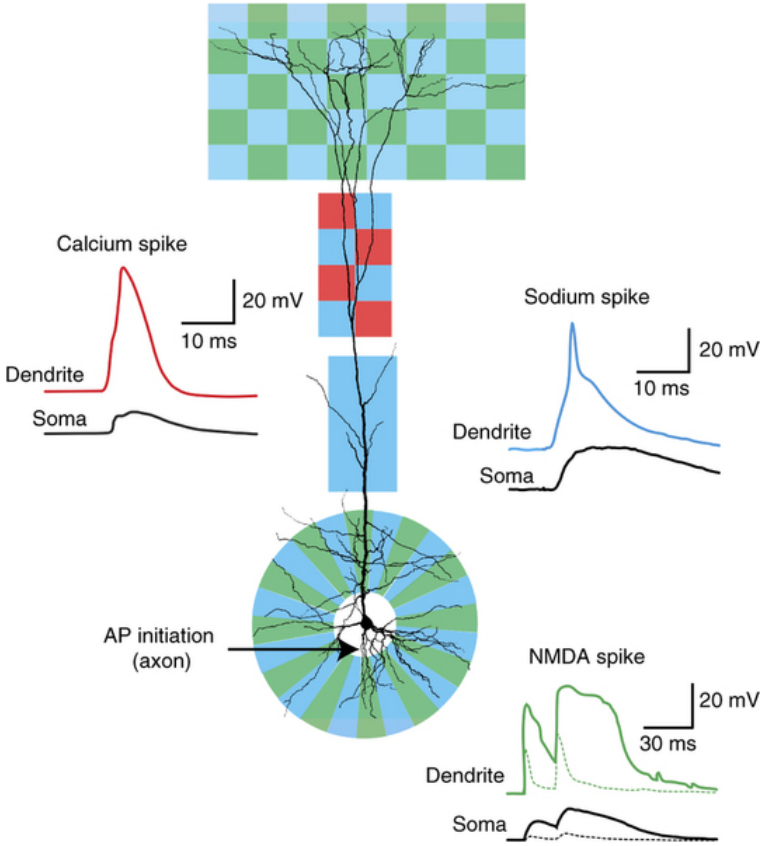
Dendritic spikes

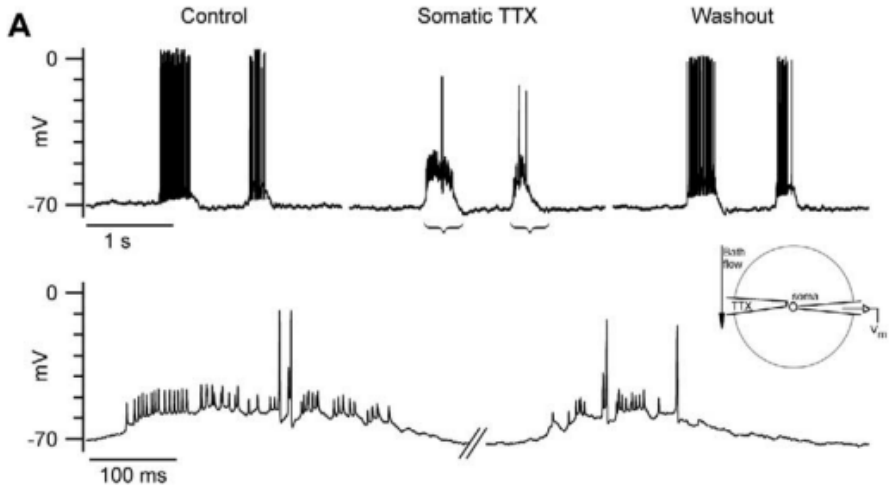


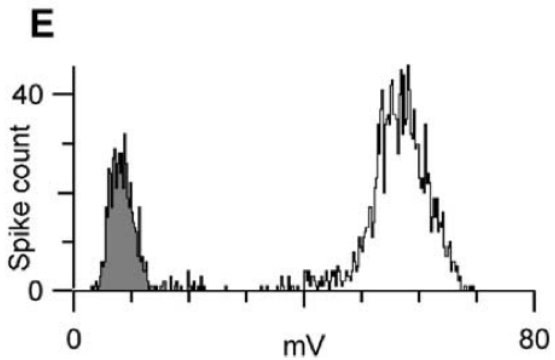
Stuart and Spruston 2015

Sodium spike

Na^+ channels
Dendritic spikes

Some dendrites have enough Na^+ channels to support dendritic AP generation



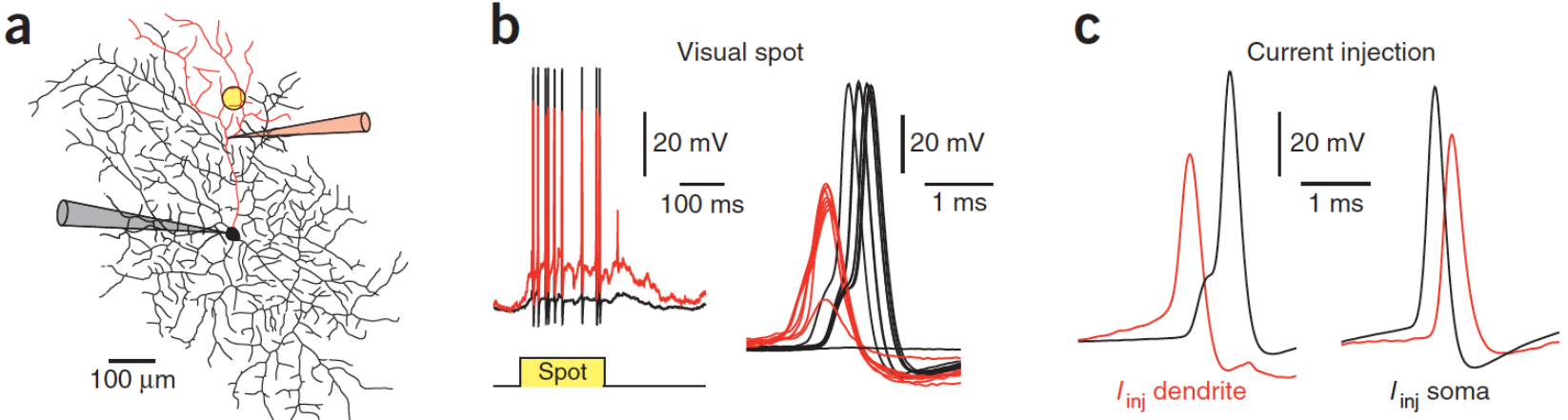


somatic recordings from rabbit retinal ganglion cell

Oesch et al 2005

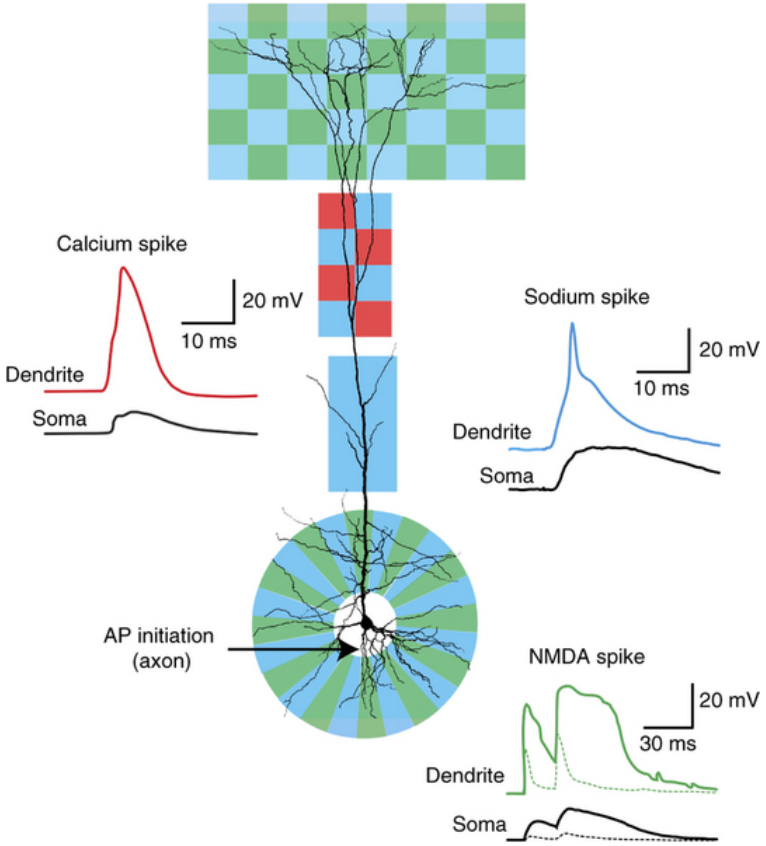
Sodium spike

somatic and dendritic recordings from rabbit retinal ganglion cell



Sivyer and Williams (2013*) Nat. Neurosci.*

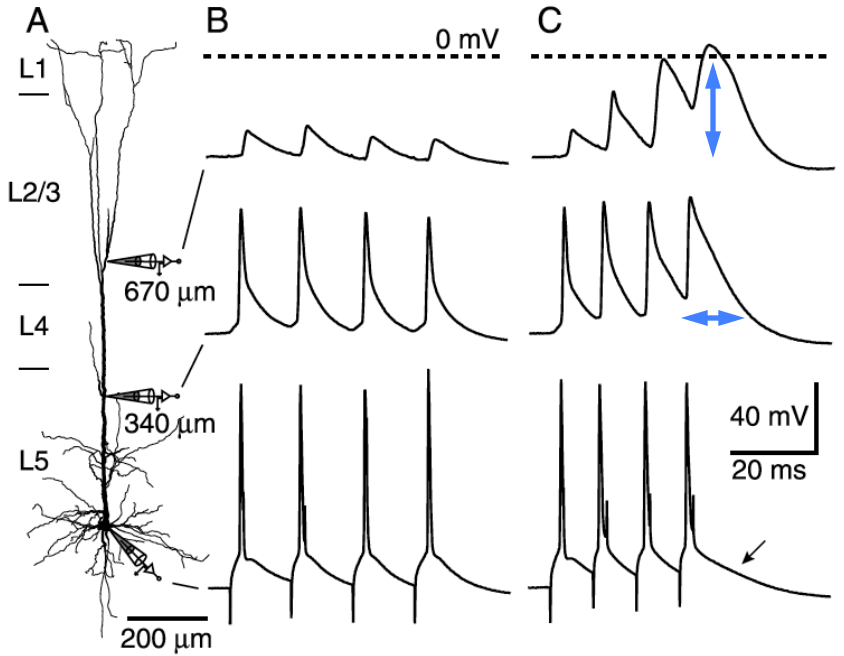
Dendritic spikes



Stuart and Spruston 2015

Dendritic calcium spike

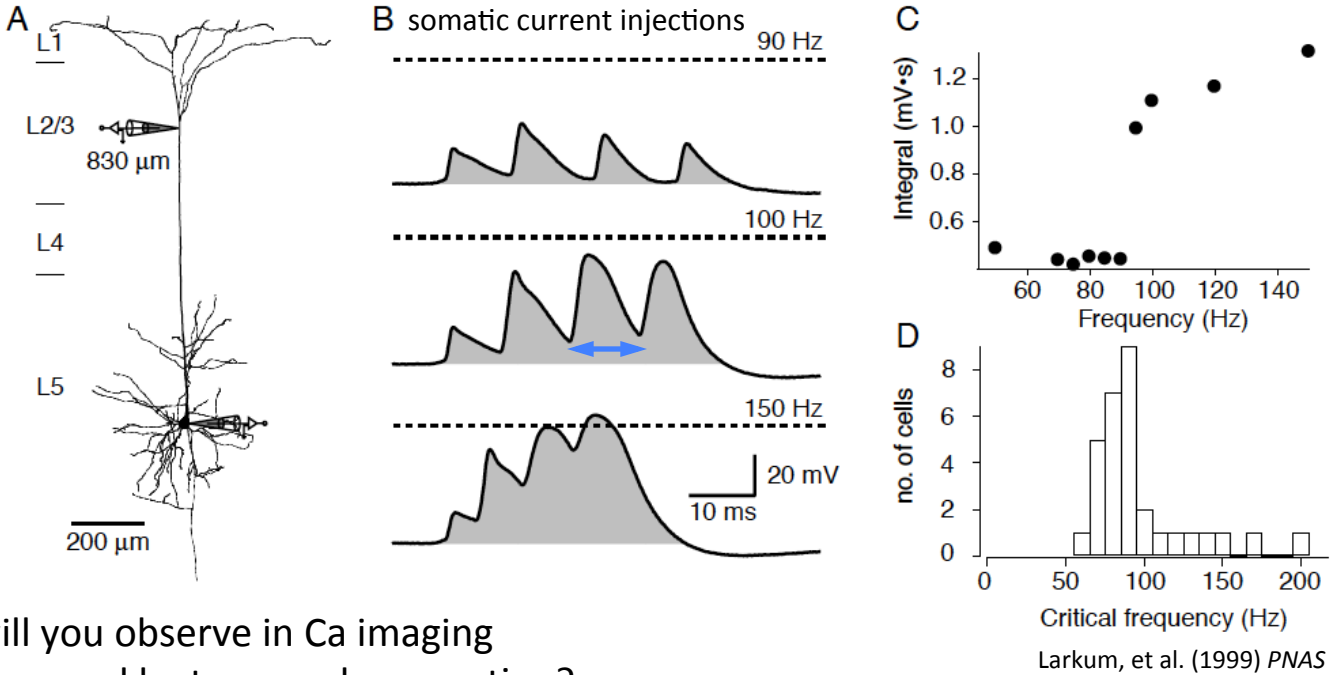
somatic and dendritic recordings from rat layer 5 pyramidal cell



Larkum, et al. (1999) *PNAS*

Dendritic calcium spike

somatic and dendritic recordings from rat layer 5 pyramidal cell

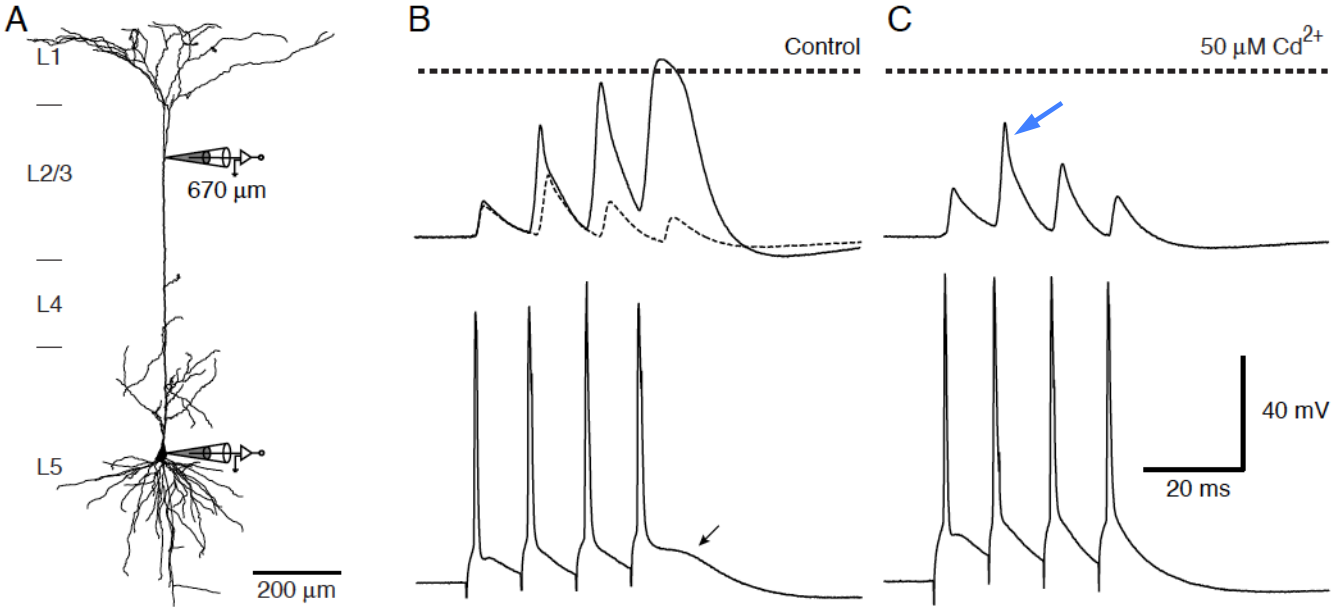


Larkum, et al. (1999) *PNAS*

What will you observe in Ca imaging
if this is caused by temporal summation?

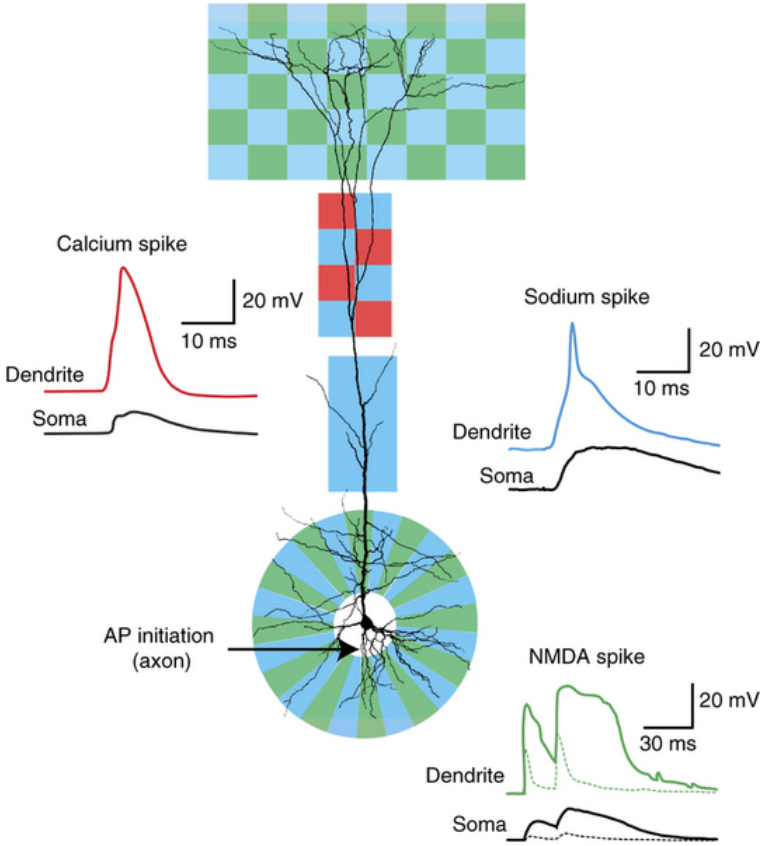
Dendritic calcium spike

somatic and dendritic recordings from rat layer 5 pyramidal cell



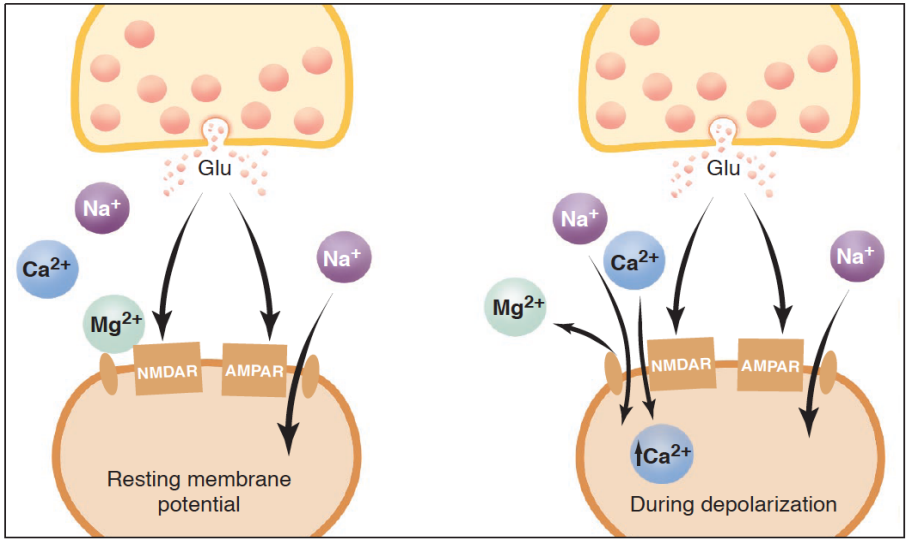
Larkum, et al. (1999) *PNAS*

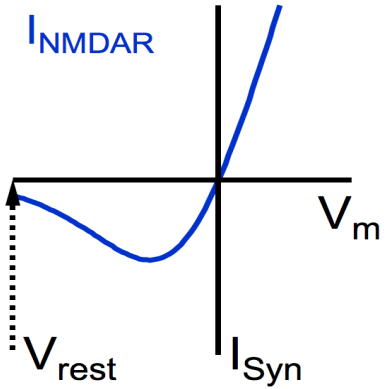
Dendritic spikes



Stuart and Spruston 2015

NMDA receptors amplify synaptic responses



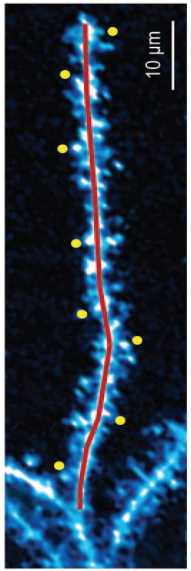


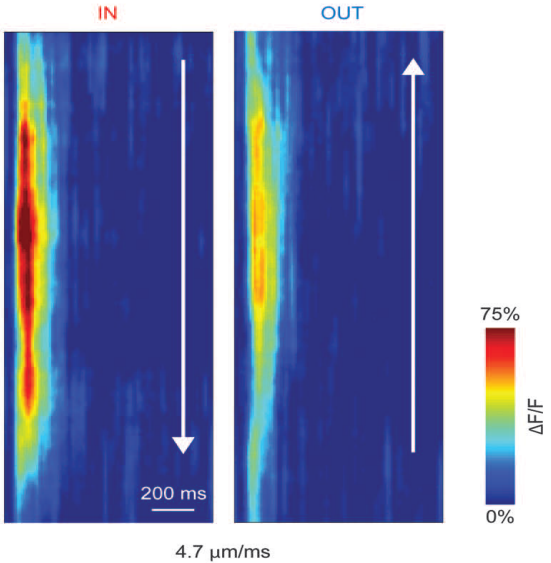
Malenka and Nicoll (1999) *Science*

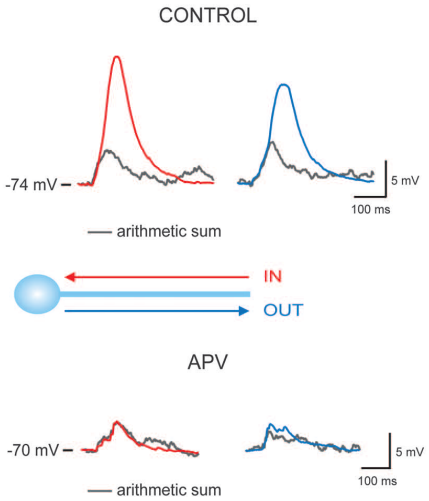
NMDA receptors amplify synaptic responses

Cortical pyramidal neurons

z resolution

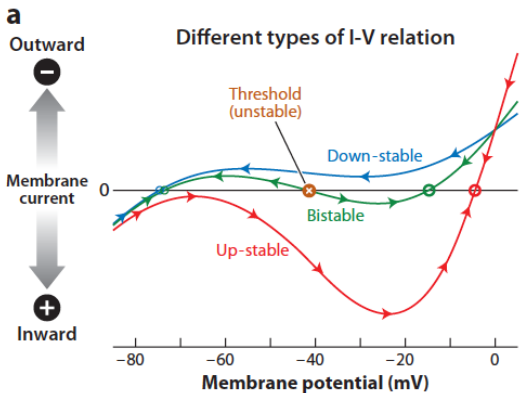






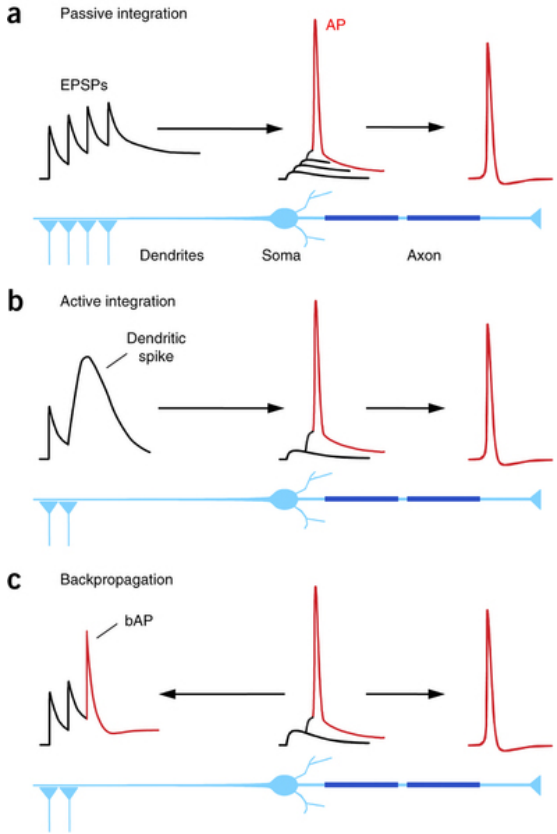
Branco, et al. (2010*) Science*

NMDA spike



Major, et al. (2013) *Annu. Rev. Neurosci.*)

Dendritic computations



Stuart and Spruston 2015