



Exceptional service in the national interest

A NEUROSCIENCE PERSPECTIVE ON DENDRITES FOR NEUROMORPHIC COMPUTING

Frances S. Chance

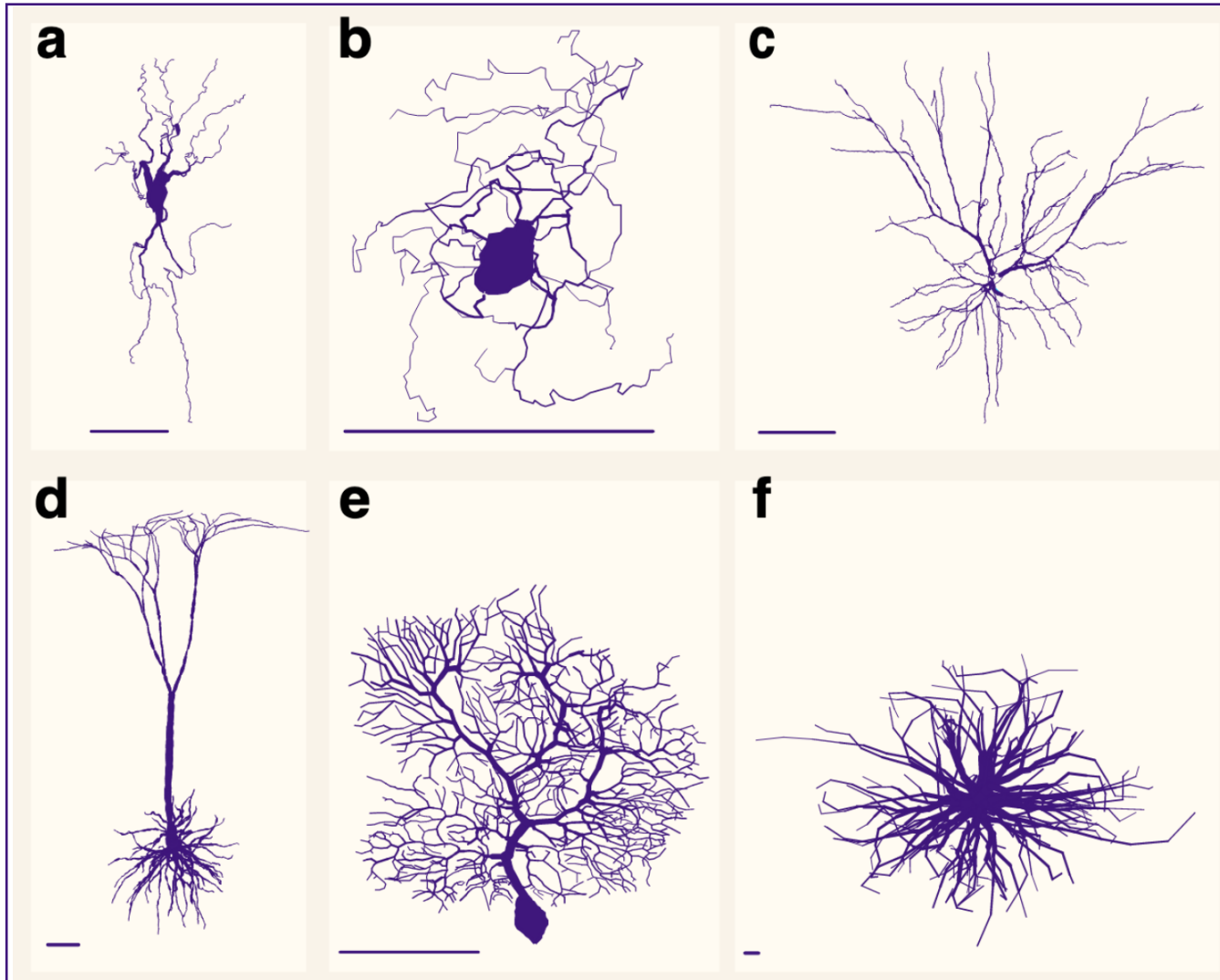
Sandia National Laboratories

NICE 2025, March 27, 2025



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BIOLOGICAL NEURONS (AND THEIR DENDRITES) ARE COMPLEX



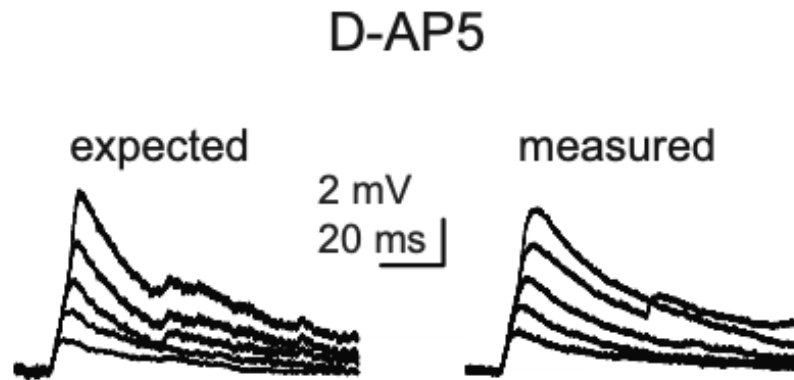
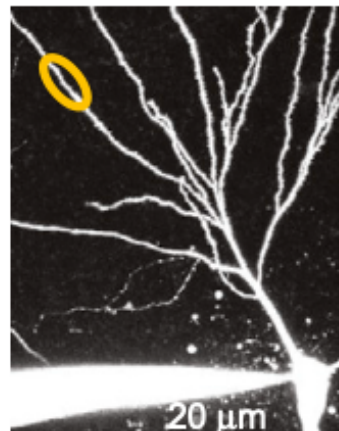
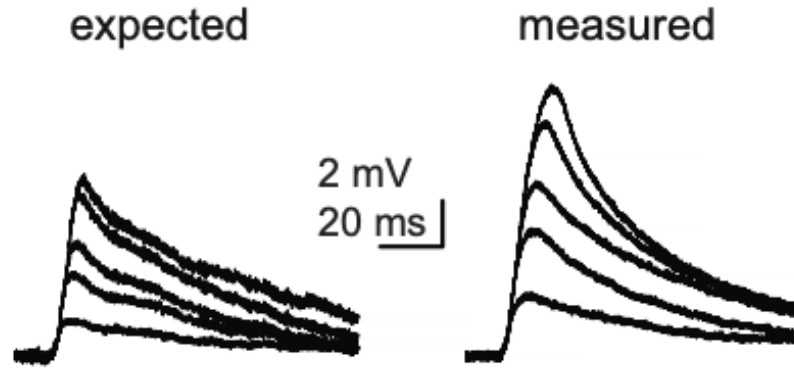
Conventional view: dendrites receive and route synaptic inputs

Biological view: dendrites offer a “computational toolkit”. [London et al 2005]

What inspiration (or tools) should we draw from biology for neuromorphic/ artificial systems?

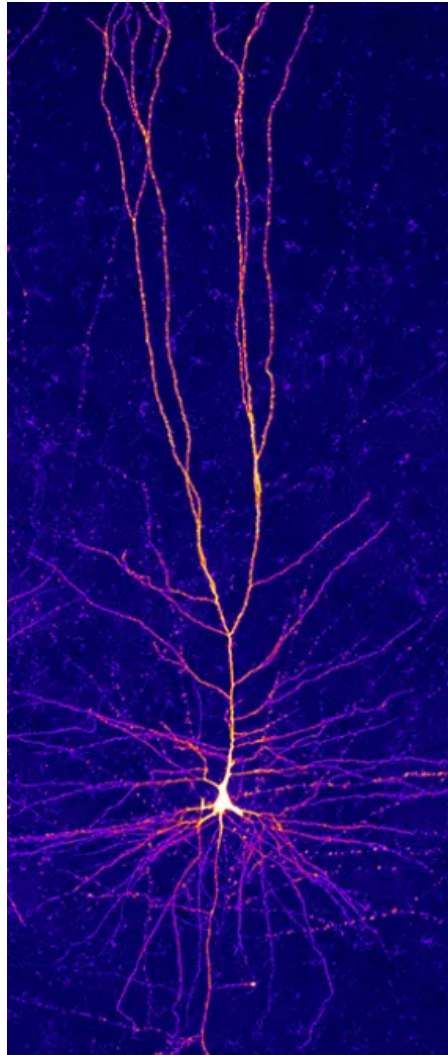
from Koch & Segev (2000) Nature 3: 1171

DENDRITES ARE NONLINEAR

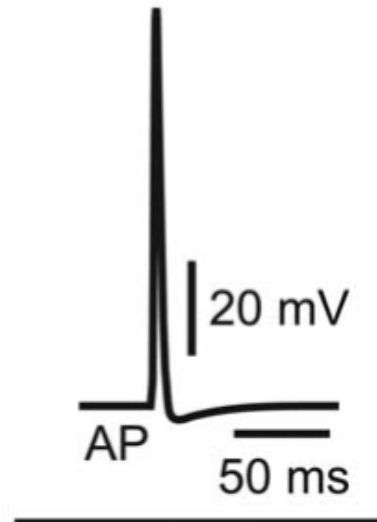


from Makara & Magee 2013

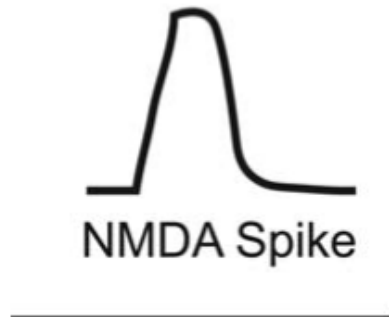
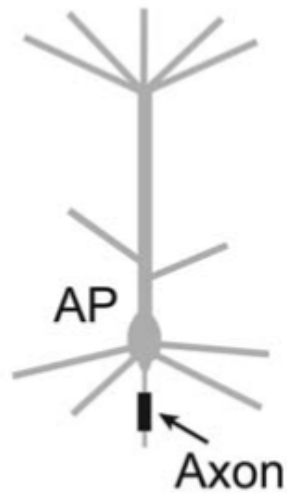
DENDRITIC SPI



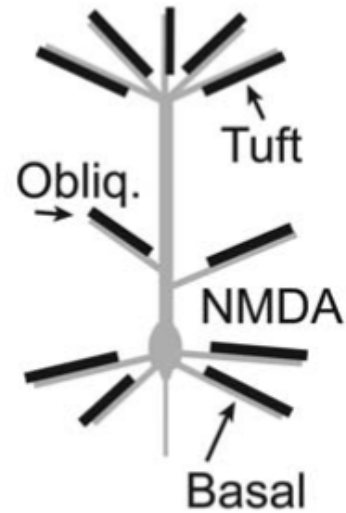
from
<https://thesublimeblog.org/2020/02/18/beautiful-science-dendrites/>



Initiation Site



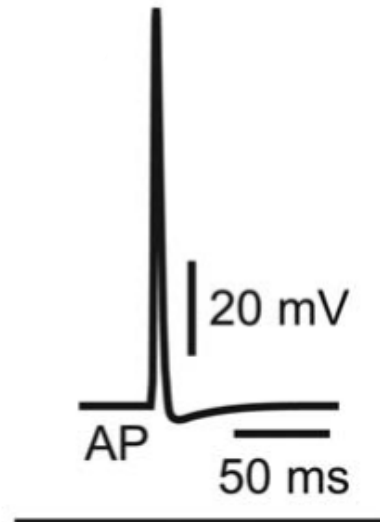
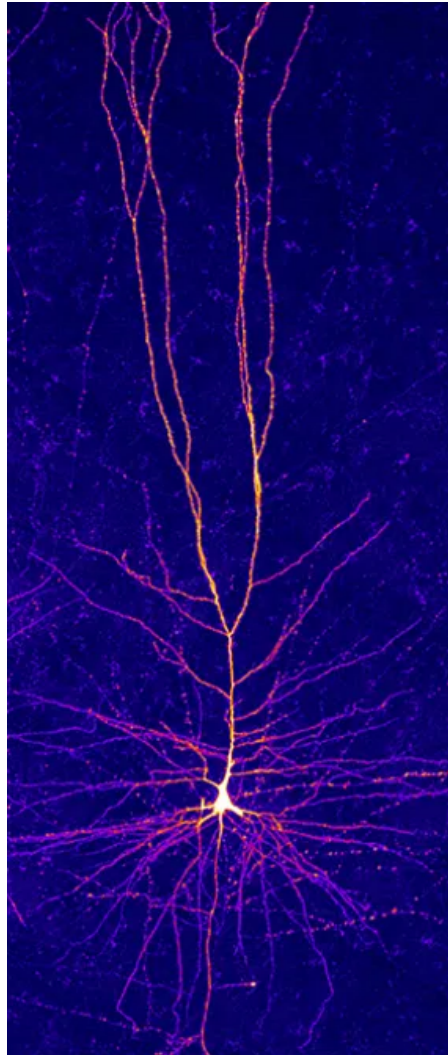
Initiation Sites



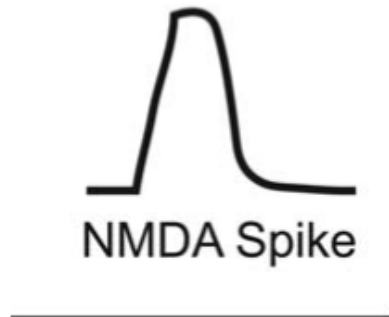
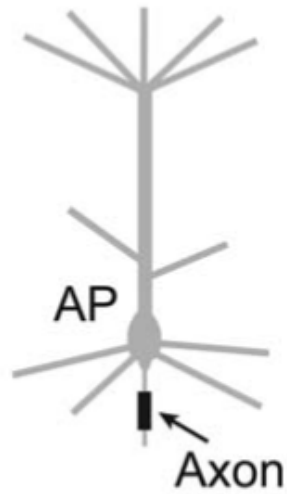
from Antic et al 2010



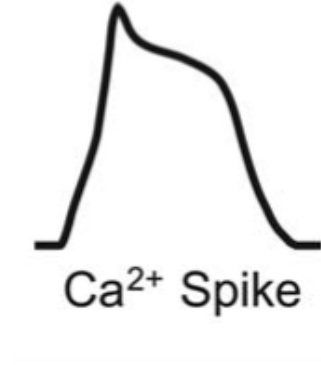
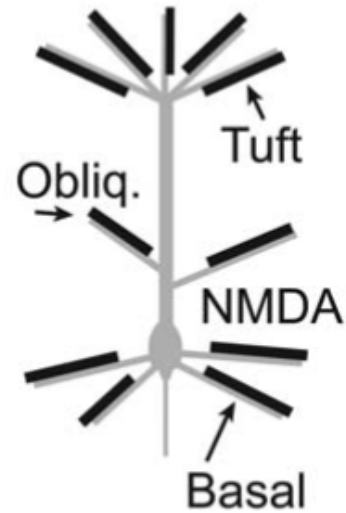
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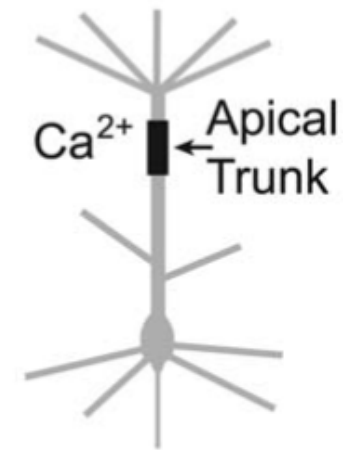
Initiation Site



Initiation Sites



Initiation Site



from
<https://thesublimeblog.org/2020/02/18/beautiful-science-dendrites/>

from Antic et al 2010

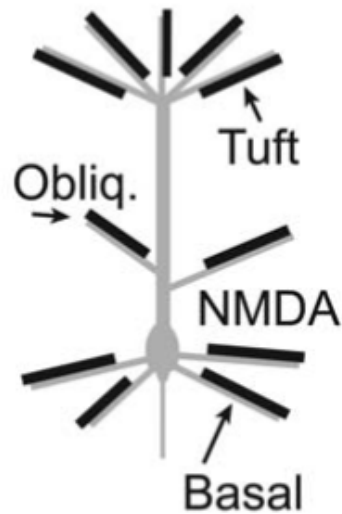


DENDRITIC SPIKES

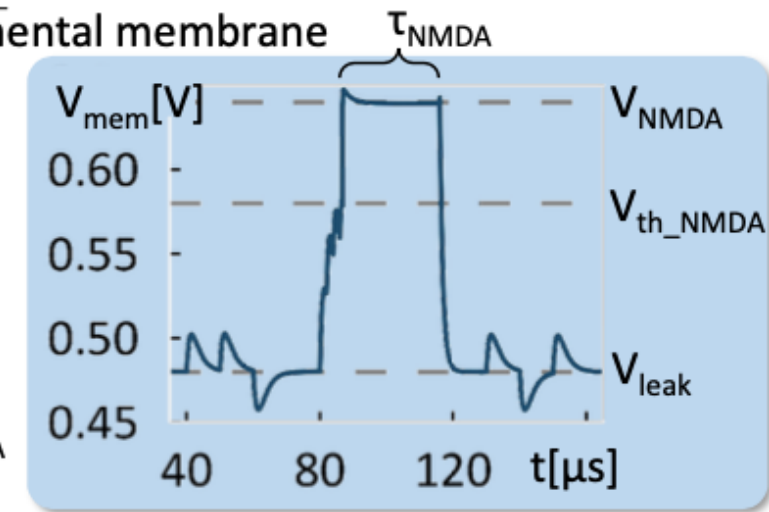
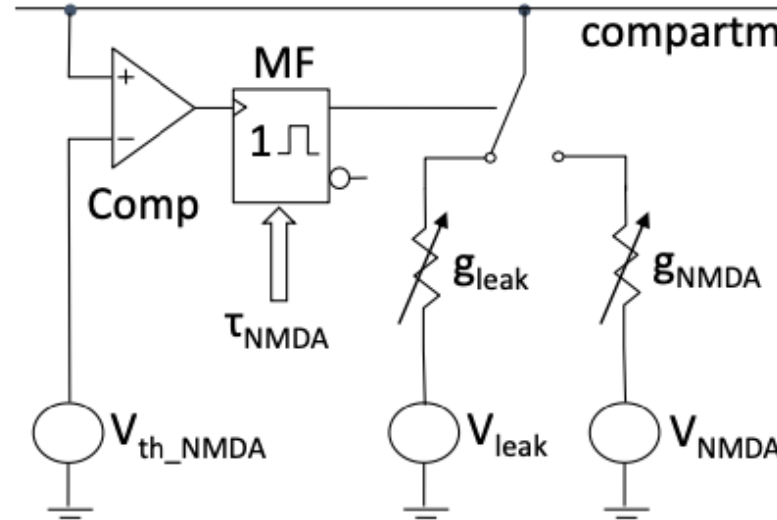


NMDA Spike

Initiation Sites



from Antic et al 2010

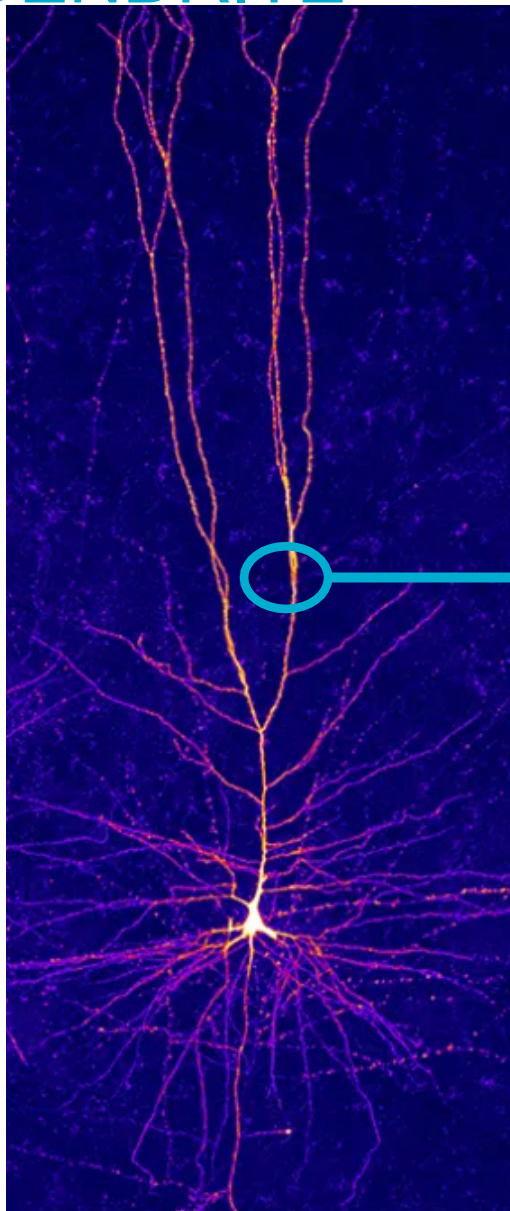


from Schemmel et al 2017

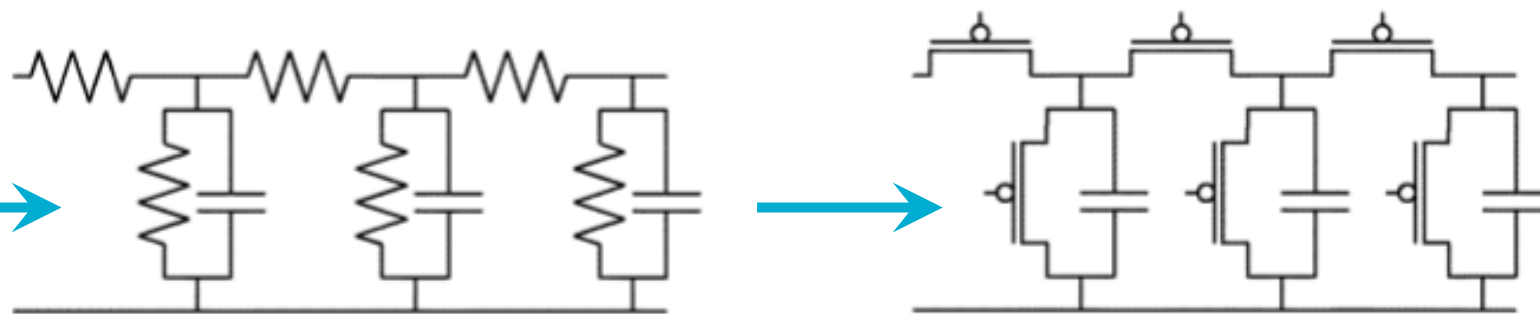


Synaptic inputs to a neuron change both membrane conductance and input current

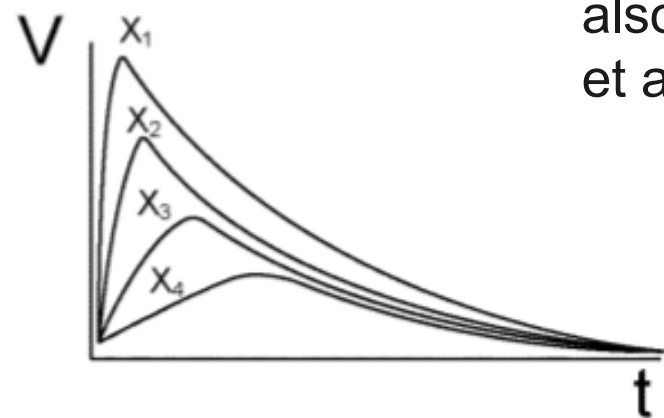
MEMBRANE CONDUCTANCE IN A NEUROMORPHIC DENDRITE



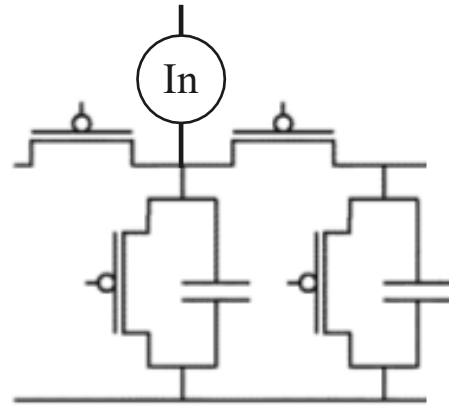
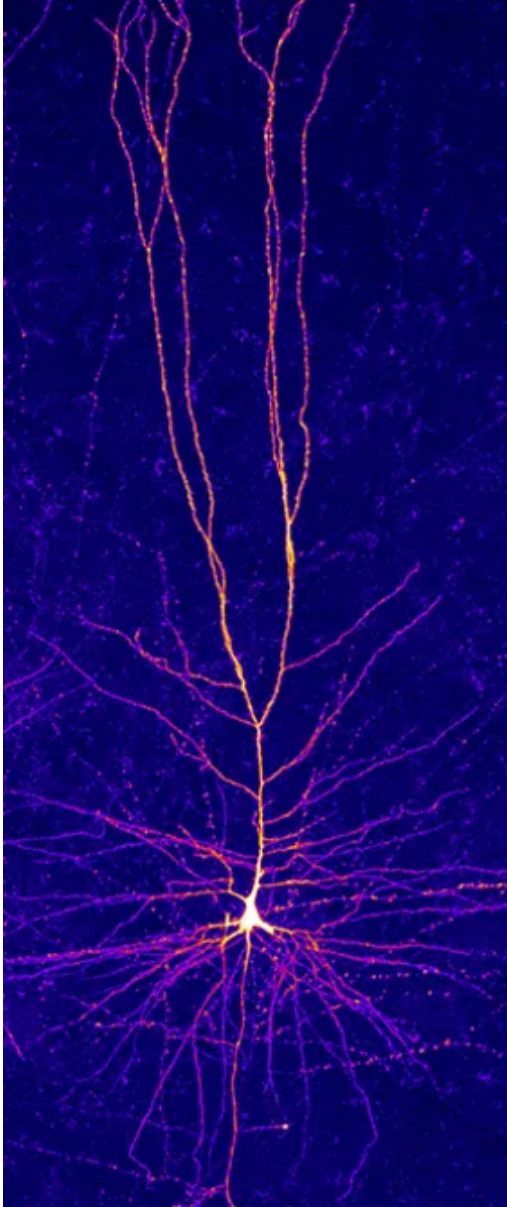
Passive membrane properties were demonstrated by Nease et al in an analog neuromorphic dendrite [IEEE TBioCAS 6: 76, 2012]



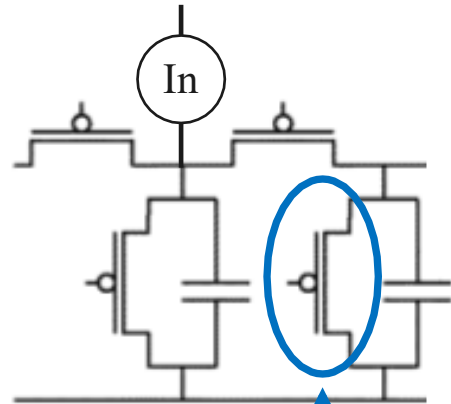
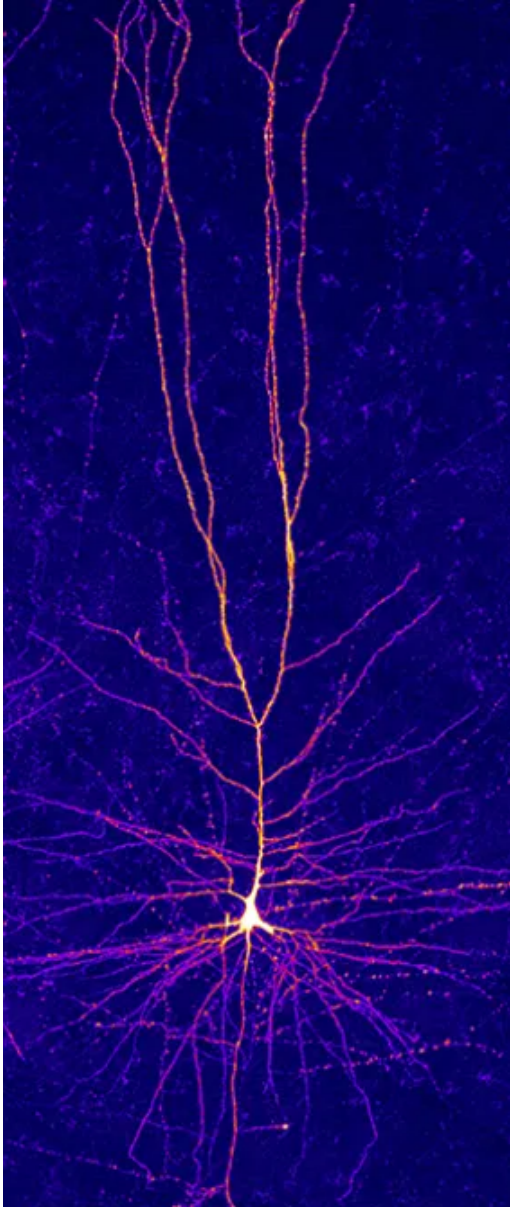
also see George-Cardwell et al 2013



SHUNTING IN A NEUROMORPHIC DENDRITE

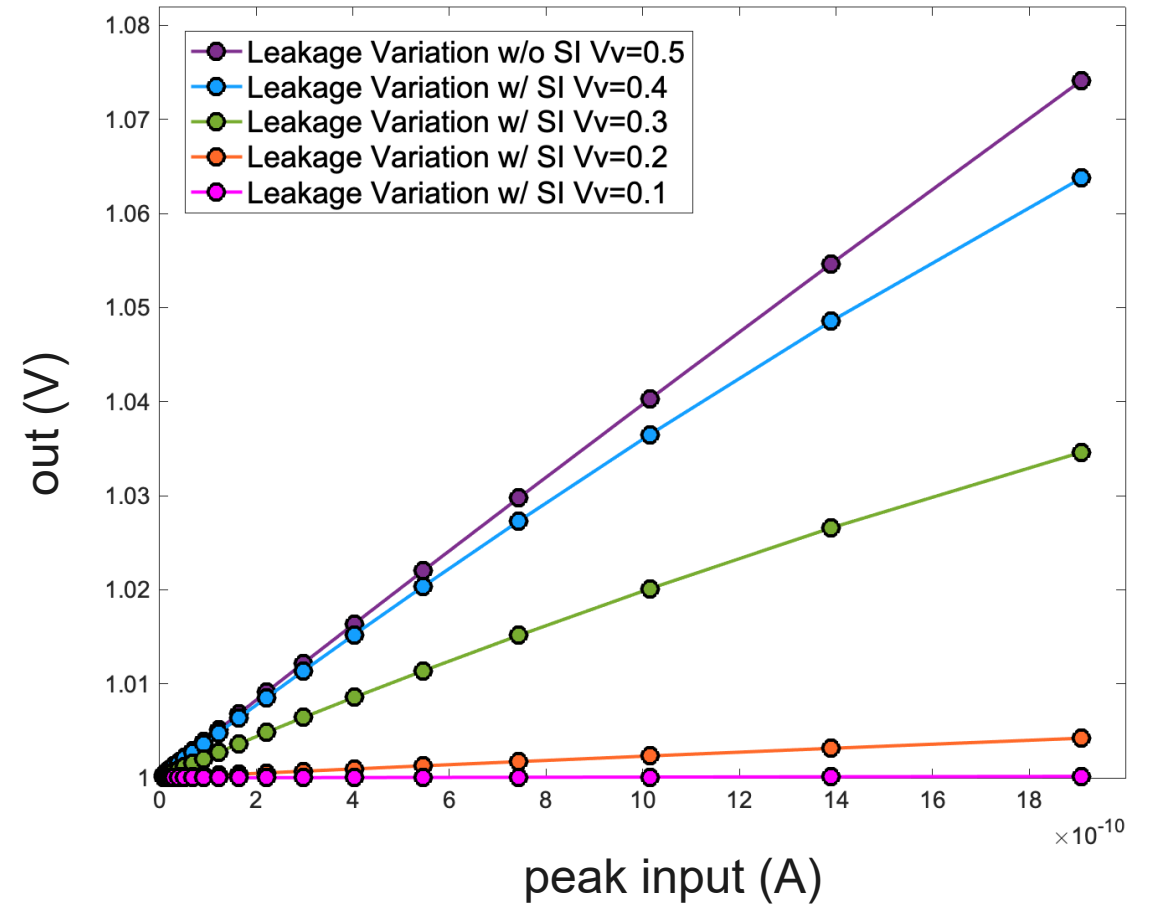
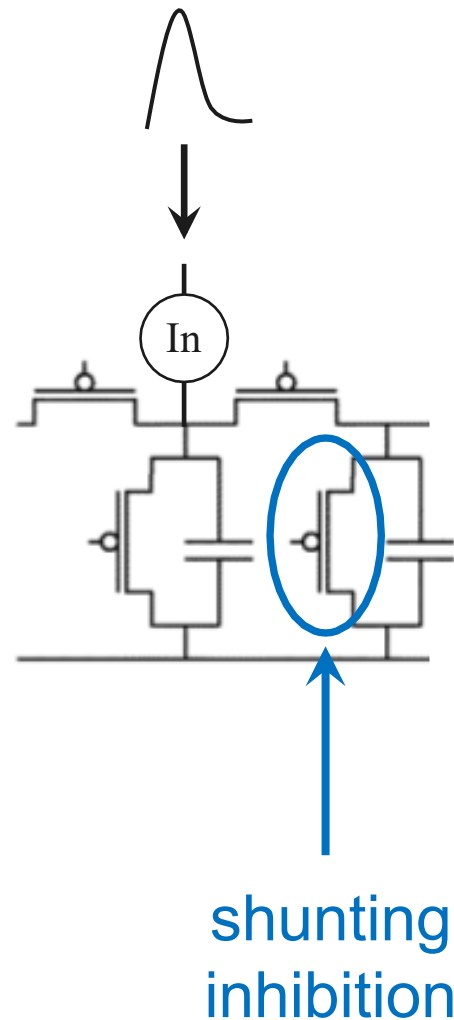
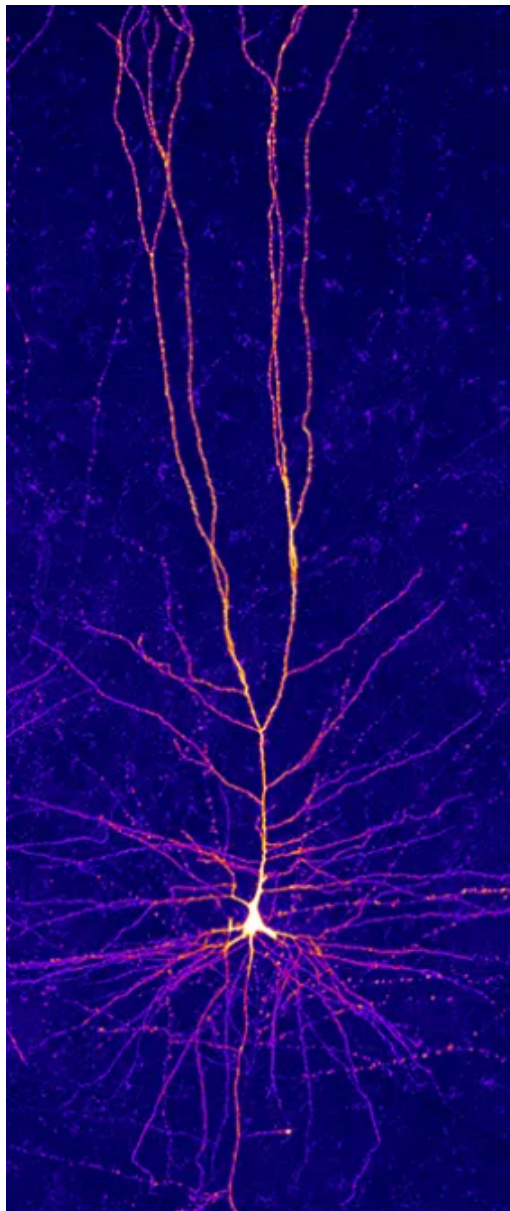


SHUNTING IN A NEUROMORPHIC DENDRITE



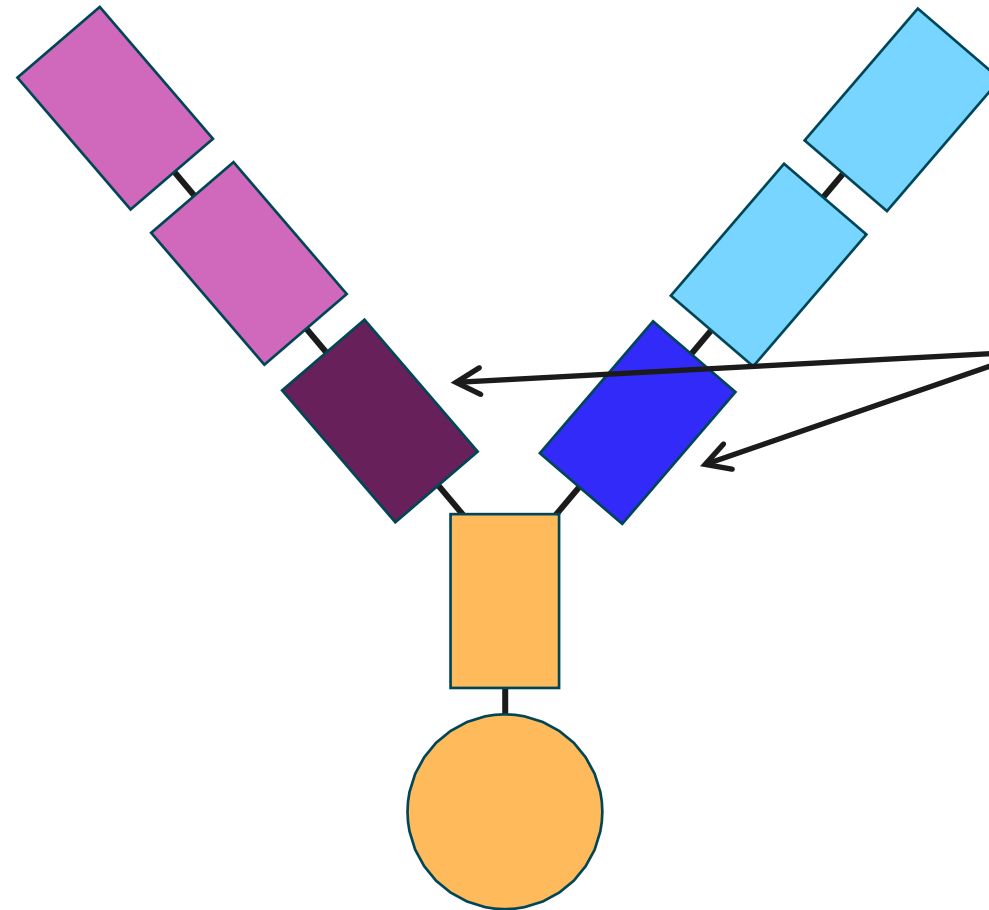
shunting
inhibition

SHUNTING IN A NEUROMORPHIC DENDRITE



Chance & Cardwell, NICE 2023

SHUNTING ON THE PROXIMAL DENDRITE AS A GATE

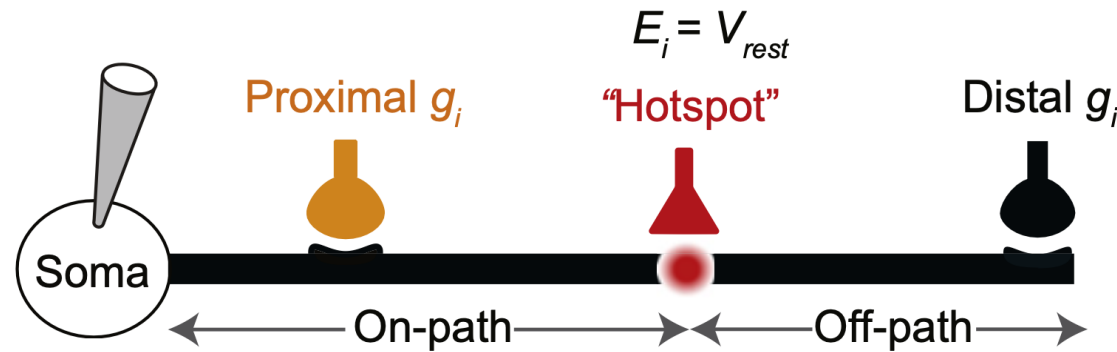


Shunting as attention-like mechanism

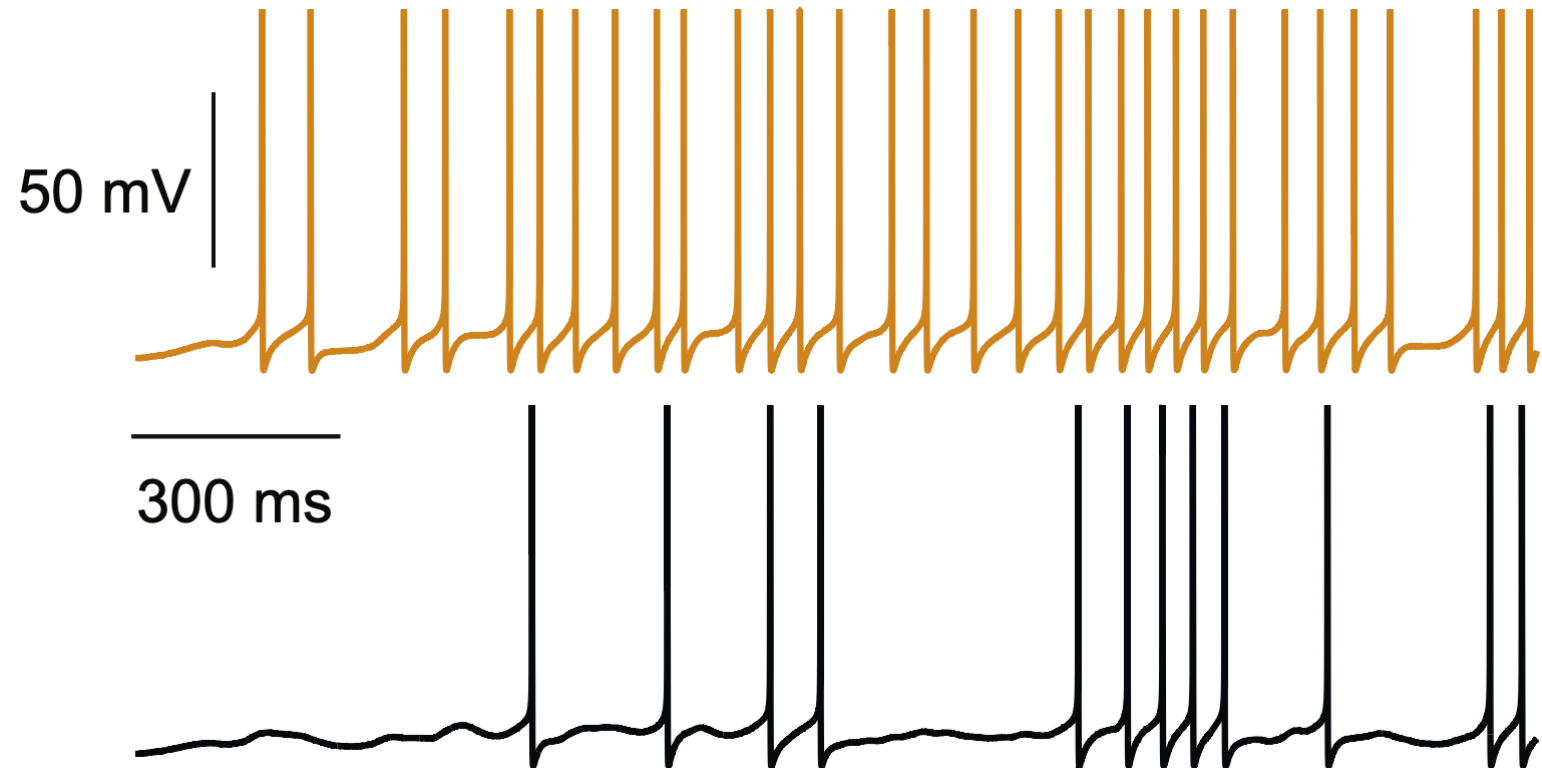
INHIBITION ON THE DISTAL DENDRITE AS A GATE



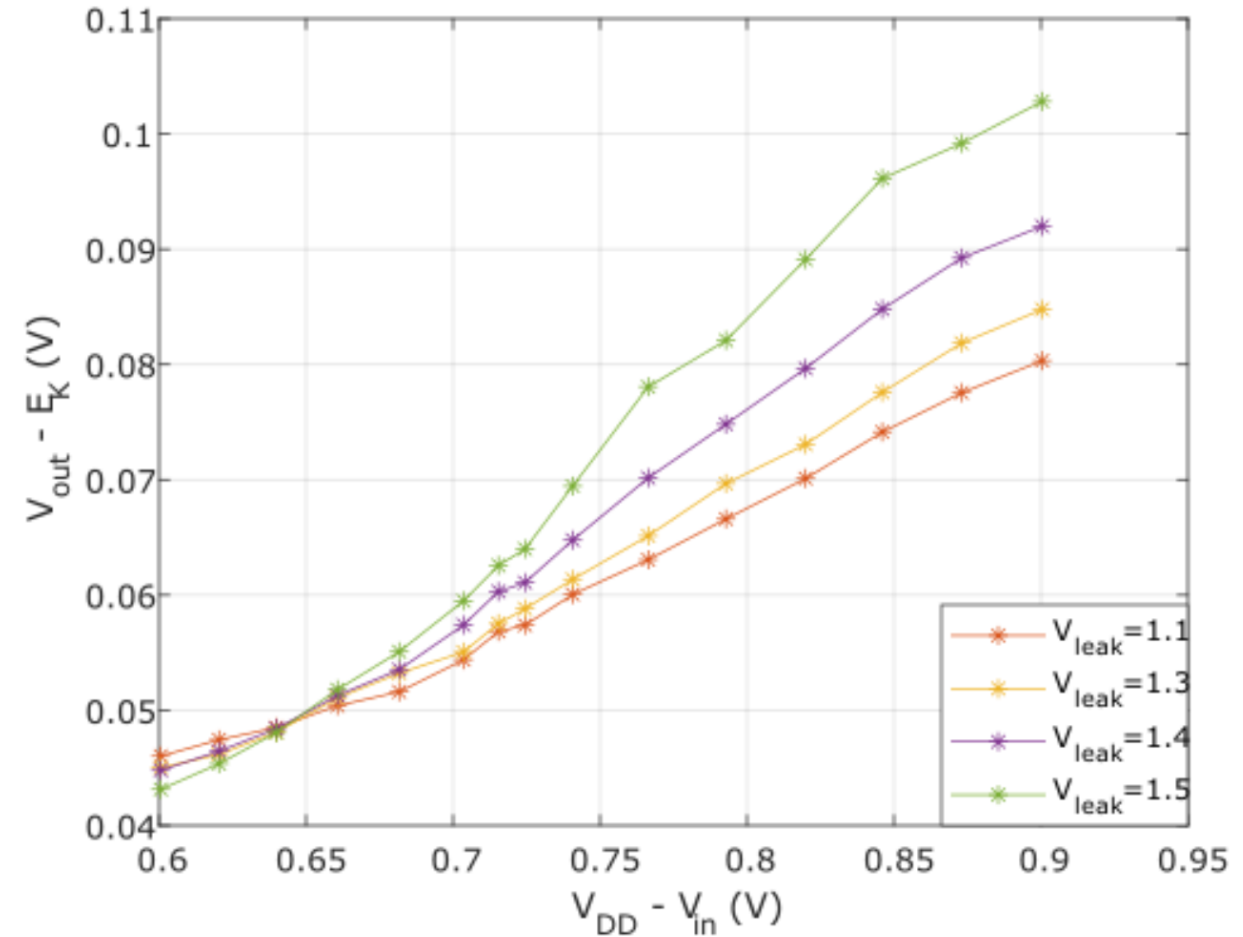
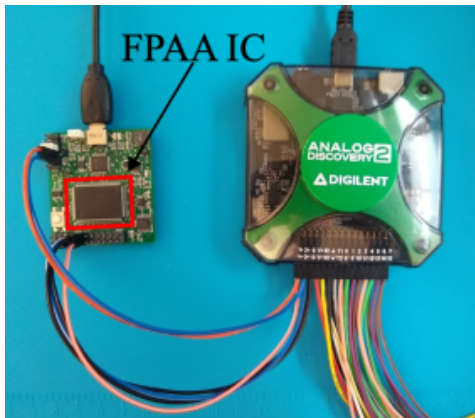
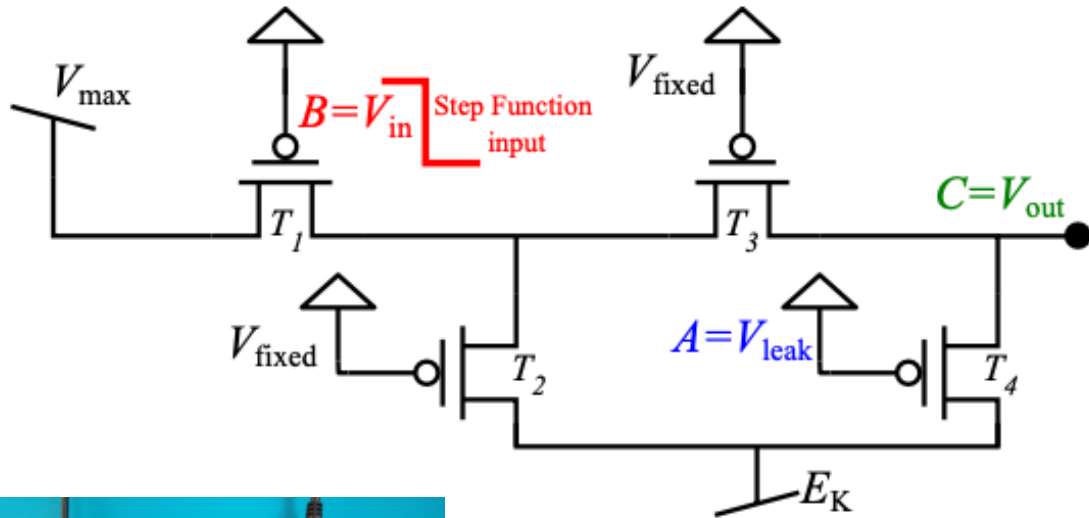
from Gidon & Segev 2012
Neuron 75: 330



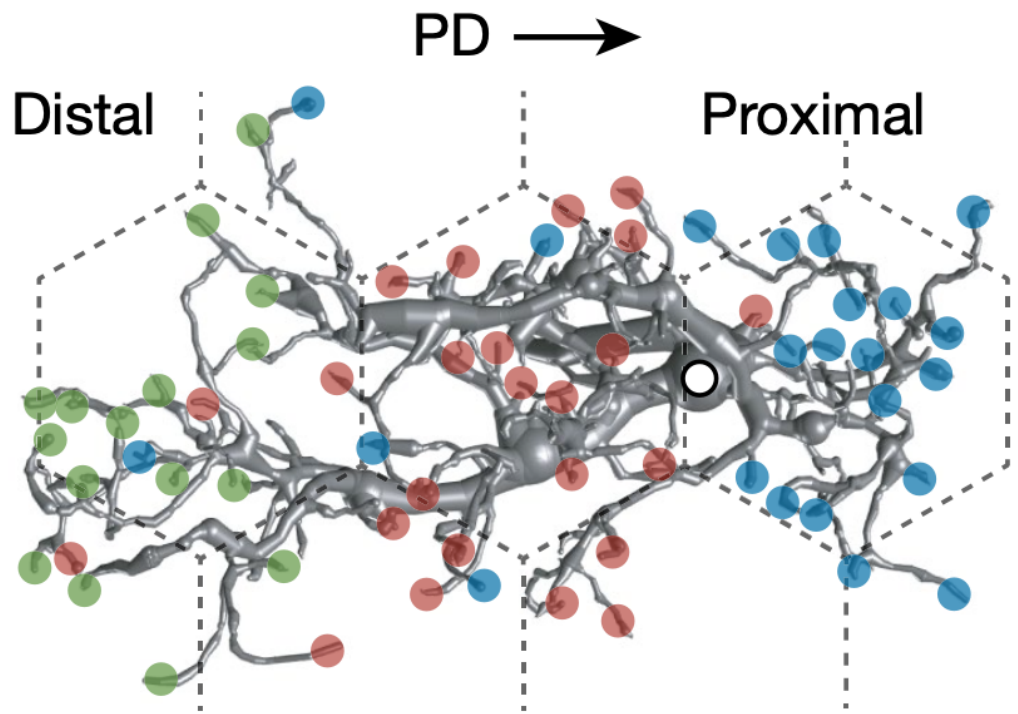
multi-compartment
simulation



SHUNTING IN A NEUROMORPHIC DENDRITE

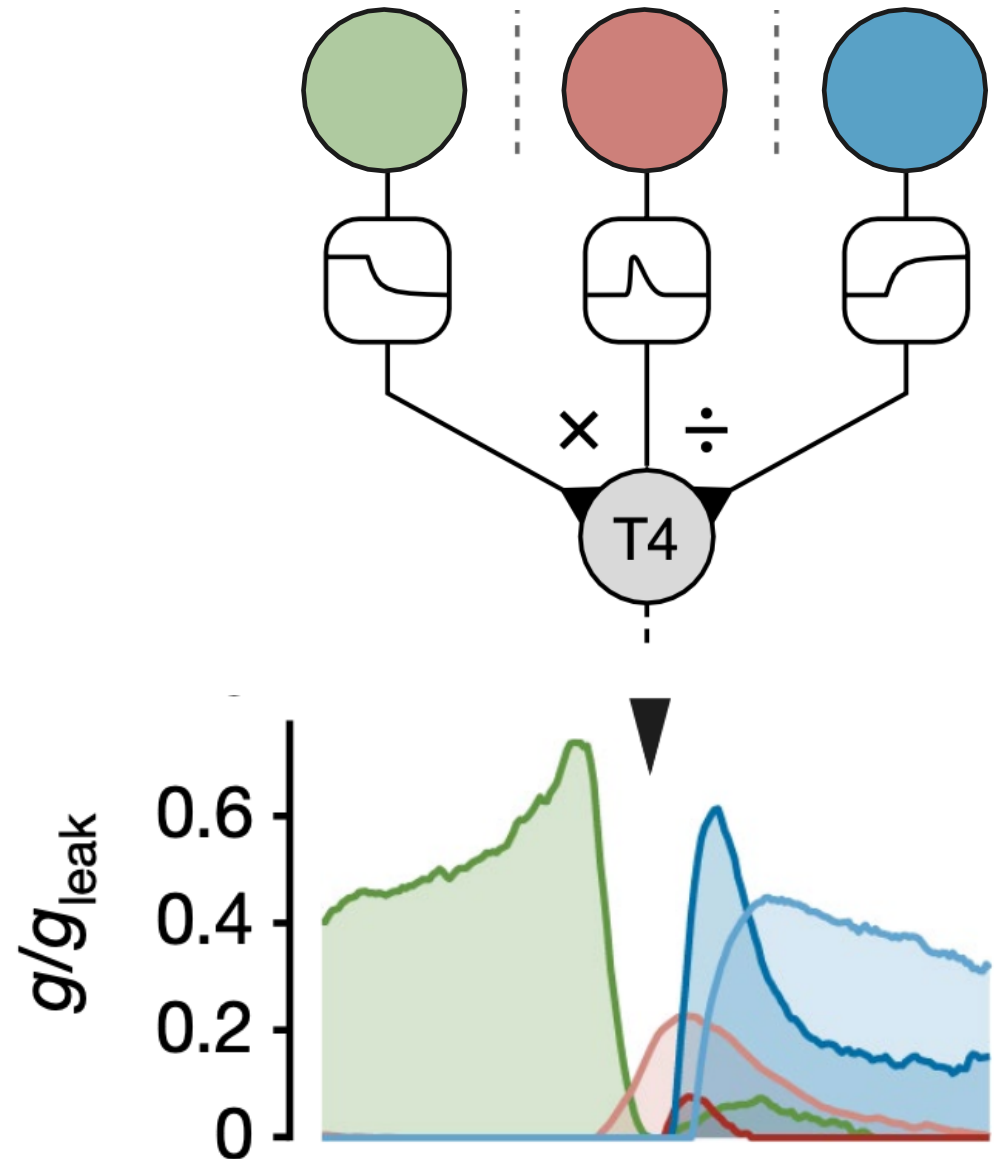


DIRECTION SELECTIVITY FROM SHUNTING IN A BIOLOGICAL DENDRITE

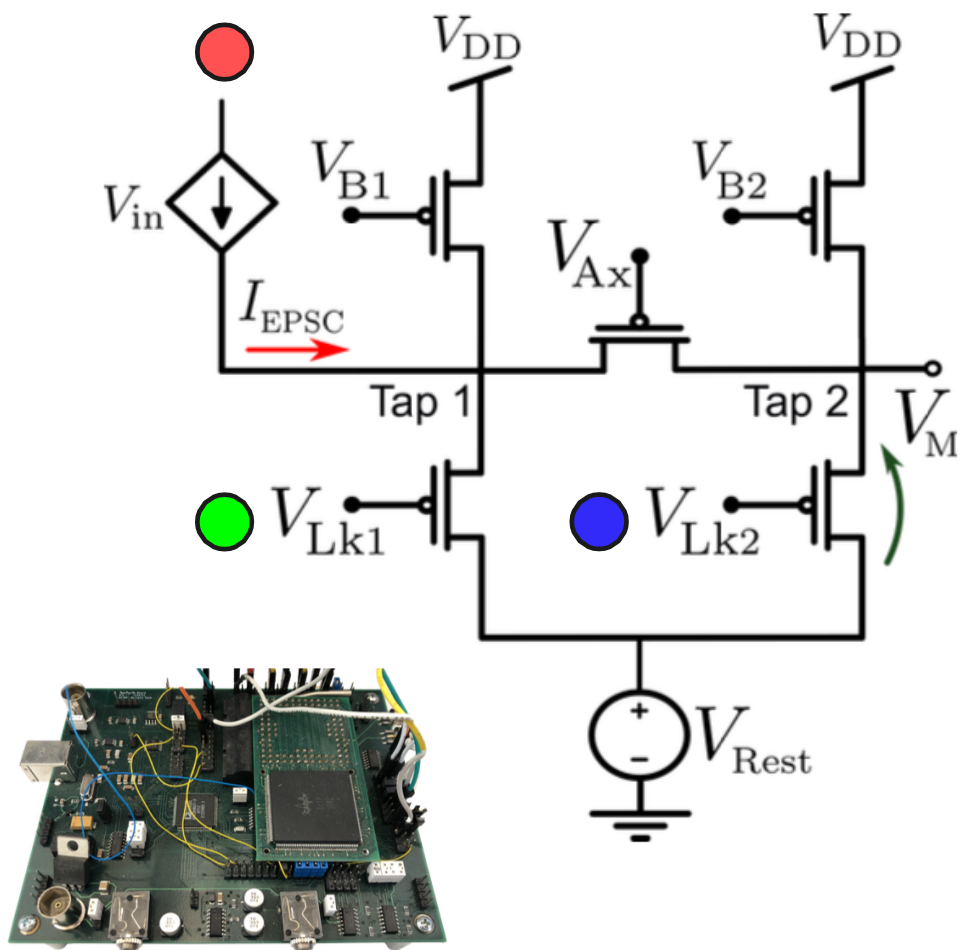


- Column border
- T4 dendrite
- Axon root
- Glutamate
- Acetylcholine
- GABA

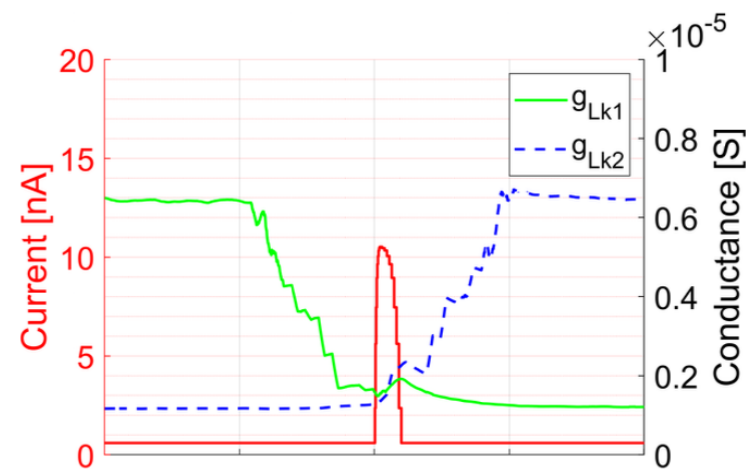
adapted from Groschner et al, 2022 Nature 603: 119



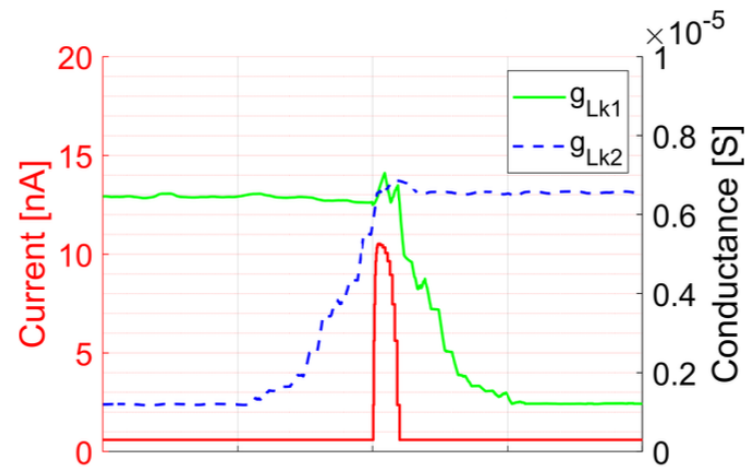
DIRECTION SELECTIVITY FROM SHUNTING IN A NEUROMORPHIC DENDRITE



Stimulus Moves in Preferred Direction

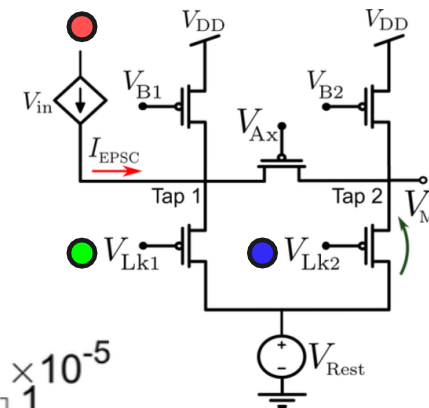


Stimulus Moves in Non-Preferred Direction

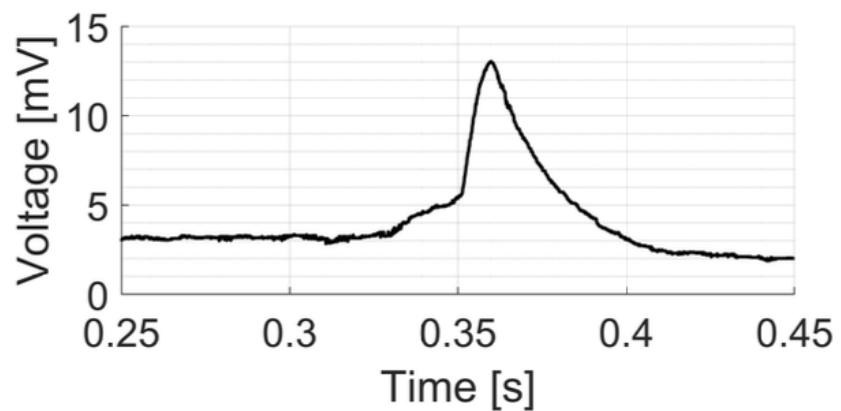
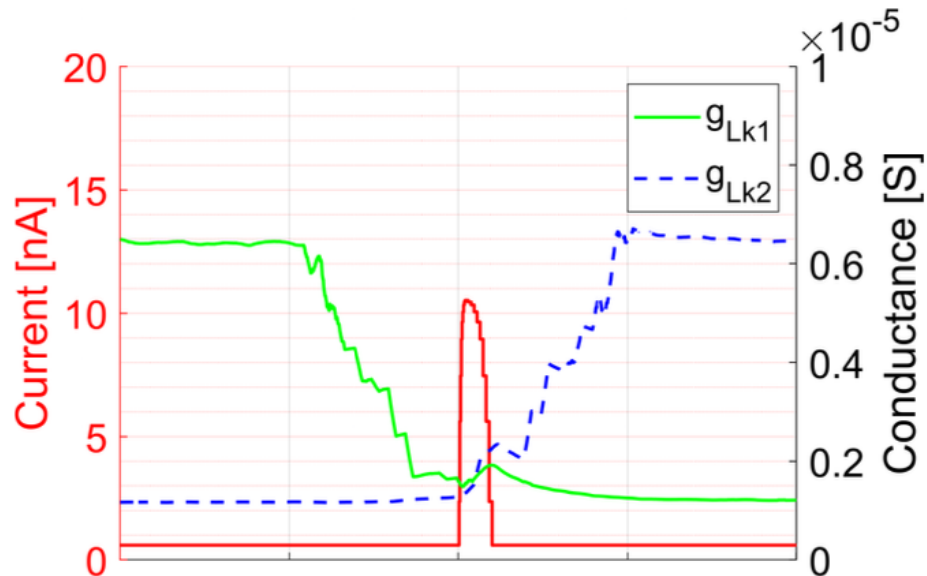


from Parker et al ICONS 2024

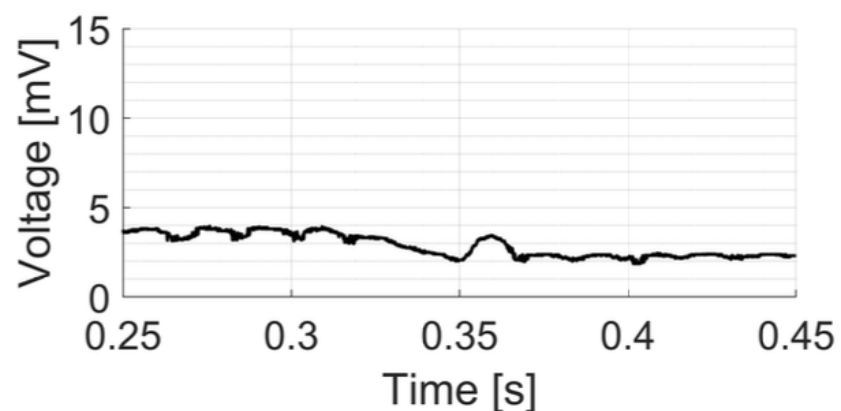
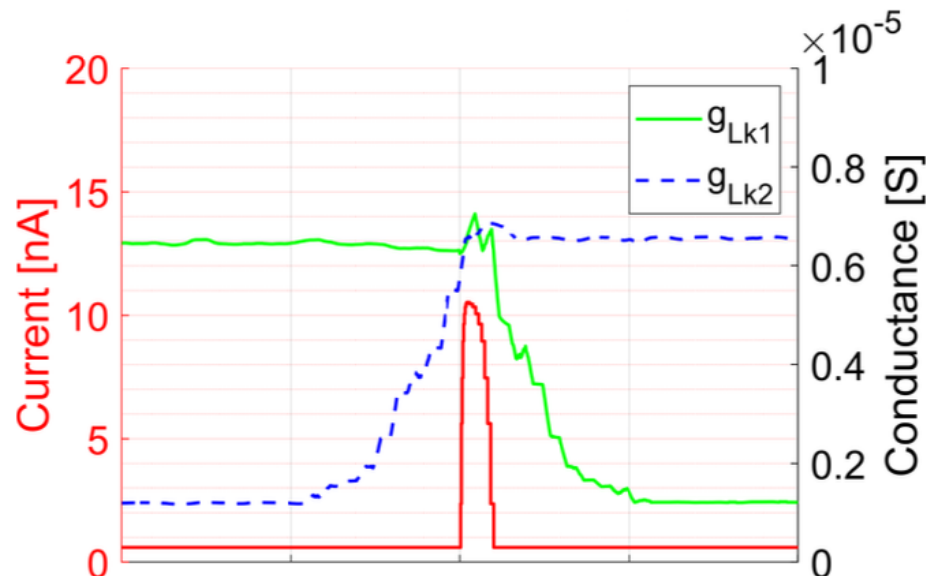
DIRECTION SELECTIVITY FROM SHUNTING IN A NEUROMORPHIC DENDRITE



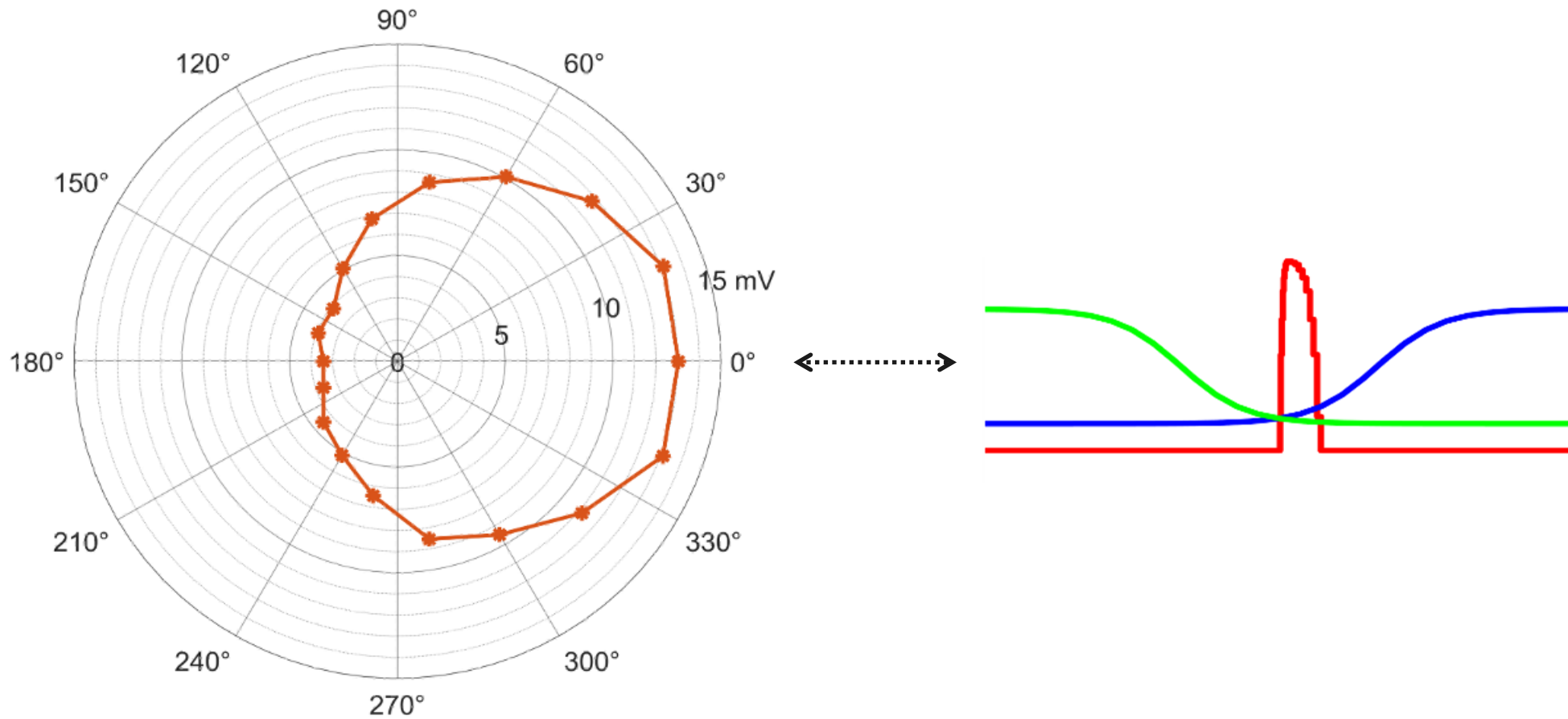
Preferred Direction



Non-Preferred Direction



DIRECTION SELECTIVITY FROM SHUNTING IN A NEUROMORPHIC DENDRITE



from Parker et al ICONS 2024

DIRECTION SELECTIVITY FROM SHUNTING IN A NEUROMORPHIC DENDRITE

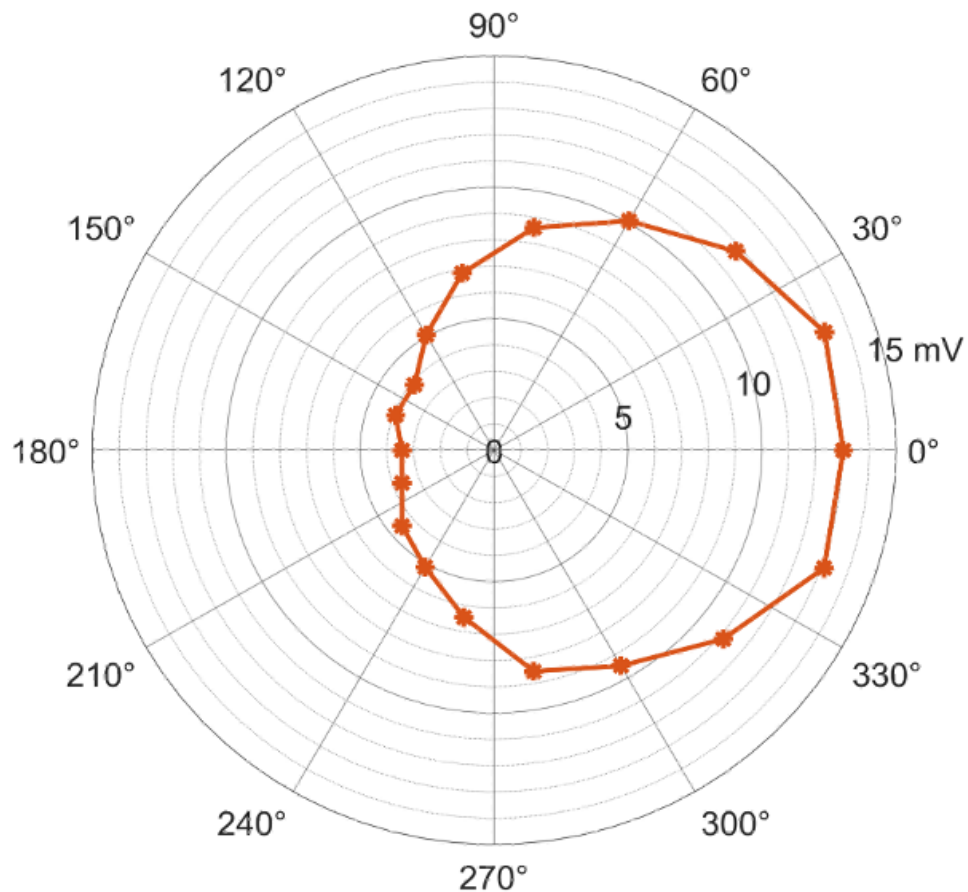


U.S. DEPARTMENT OF
ENERGY

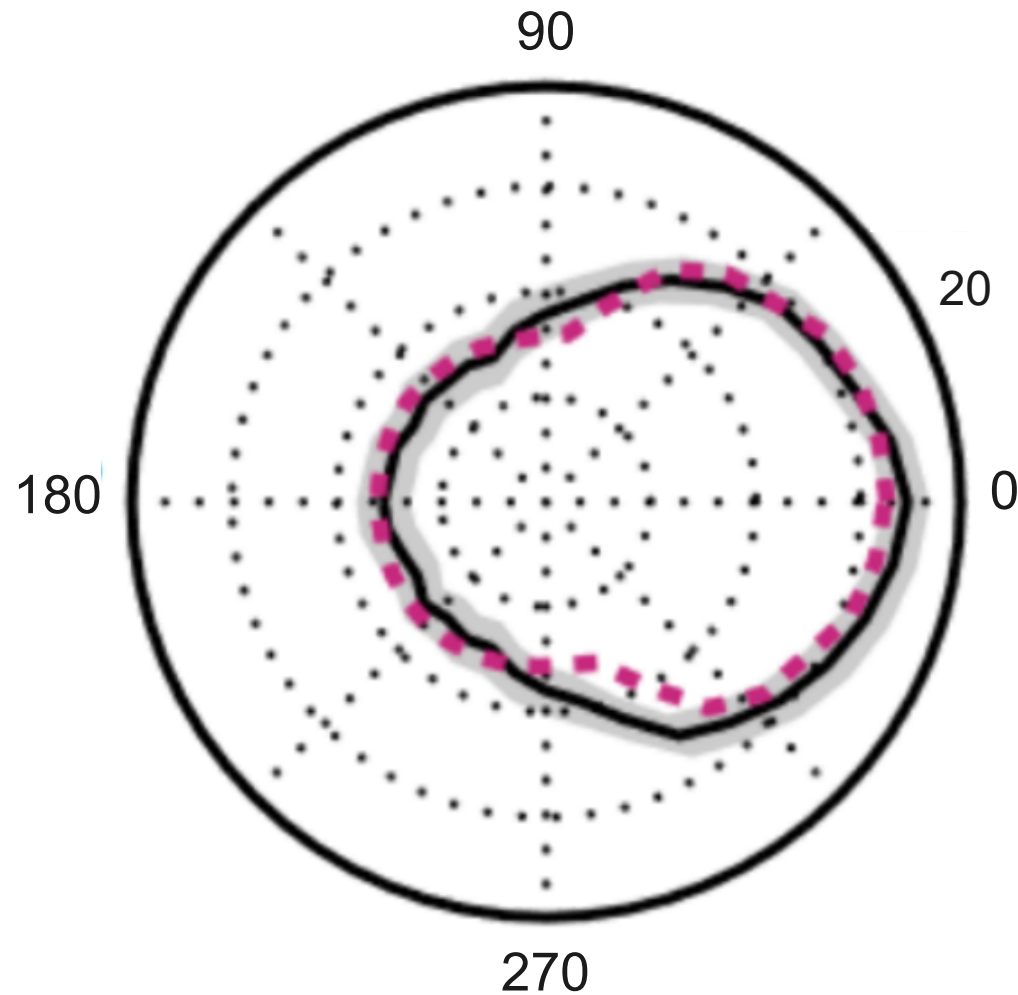
Office of
Science



Neuromorphic



Biological Data

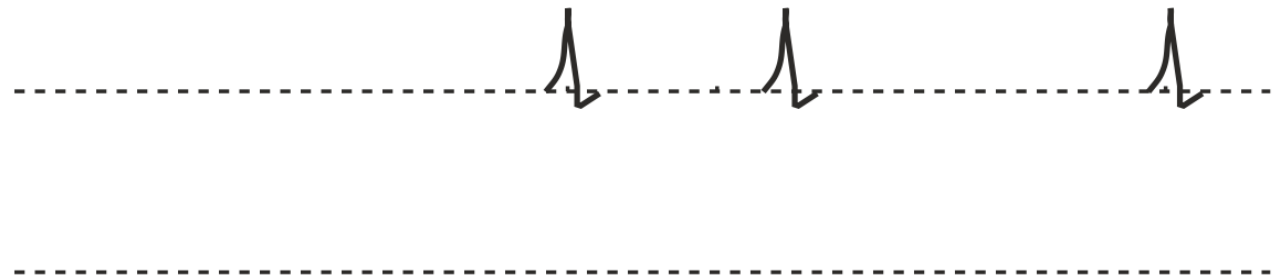
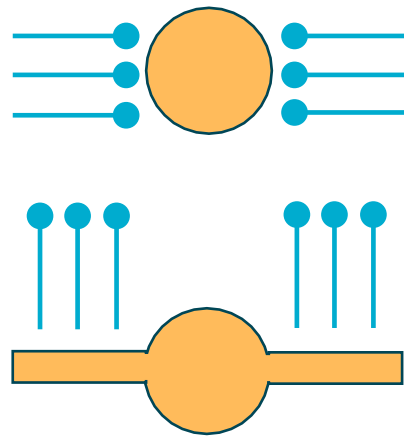
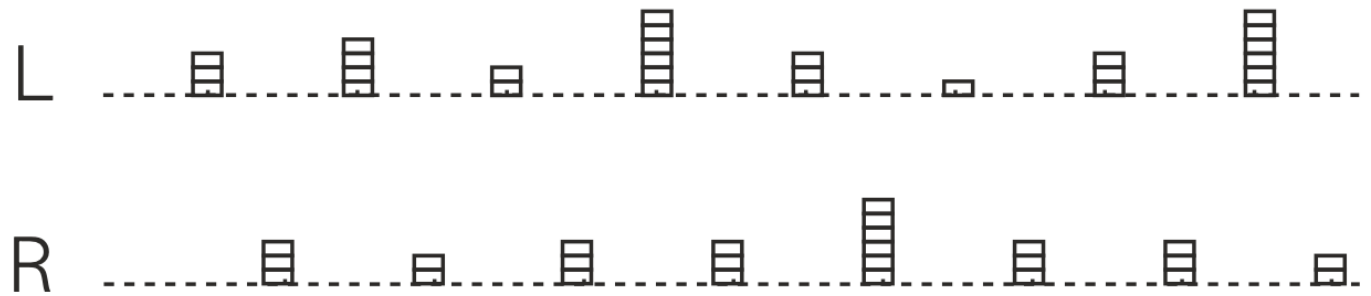


from Parker et al ICONS 2024

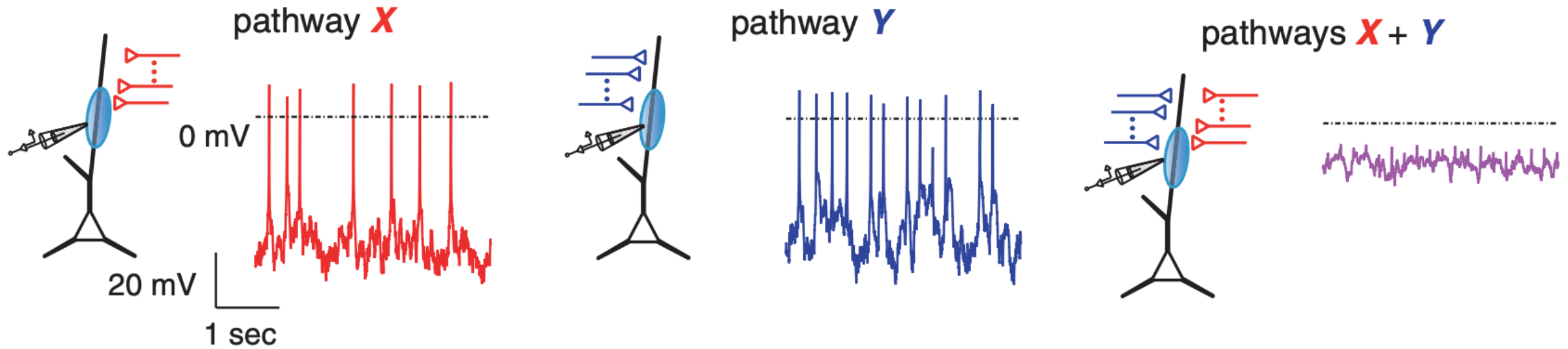
CONDUCTANCE CHANGE AS A GATE: COINCIDENCE DETECTION IN NUCLEUS LAMINARIS



Phase shift: 180°



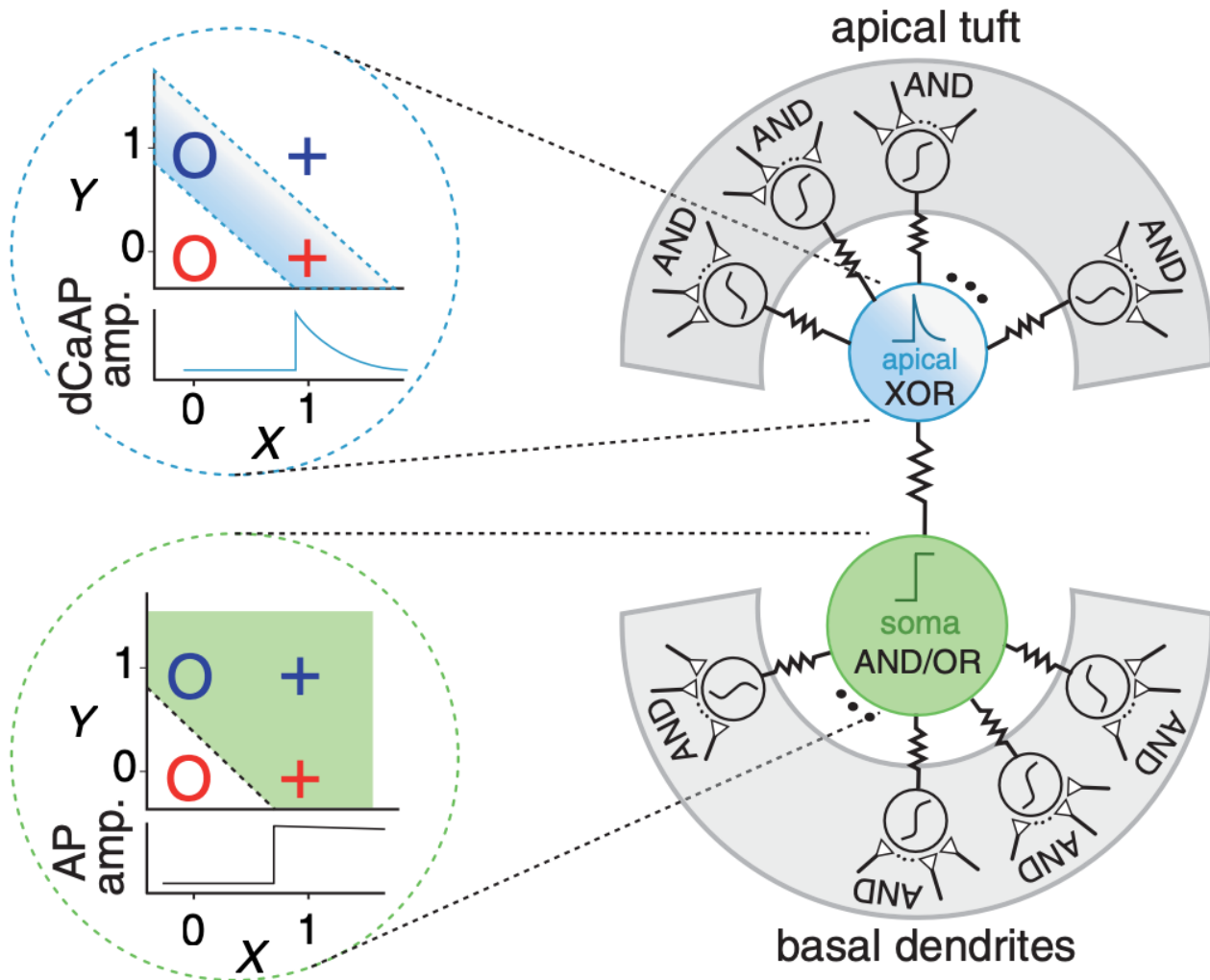
CONDUCTANCE CHANGE AS A GATE: ANTI-COINCIDENCE (XOR)



Coincident inputs (in time and space) can shunt each other, resulting in anti-coincidence

Gidon et al 2024 Science 367: 1

CONDUCTANCE CHANGE AS A GATE: ANTI-COINCIDENCE (XOR)



Coincident inputs (in time and space) can shunt each other, resulting in anti-coincidence or XOR function.



Dendrites do much more than route synaptic inputs to soma

Example Dendritic Nonlinearities

Supralinear summation

Sublinear summation

(also linear summation)

Dendritic spikes

Direction-selectivity



Dendrites do much more than route synaptic inputs to soma

Local Processing through Conductance Changes

Multiplicative gain modulation

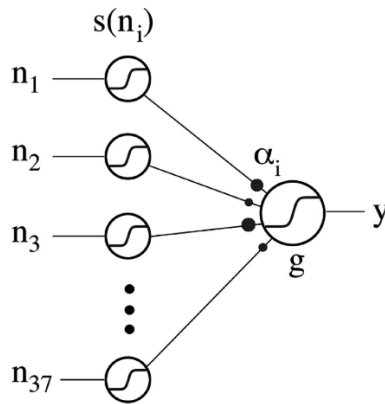
Coincidence detection

Anti-coincidence detection

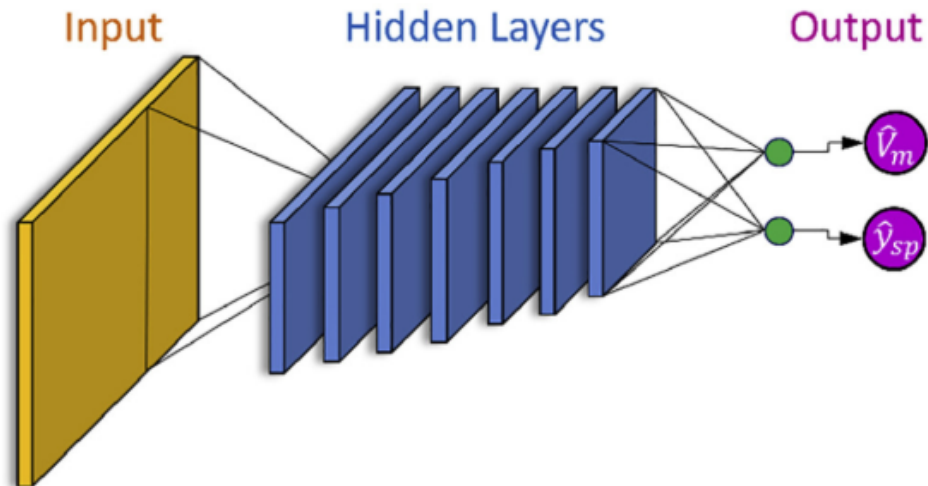
DENDRITES AS NEURAL NETWORKS



Dendrites have been compared to neural networks



from Poirazi & Mel 2003
Neuron 37: 989



from Beniaguev et al 2021
Neuron 109: 2727

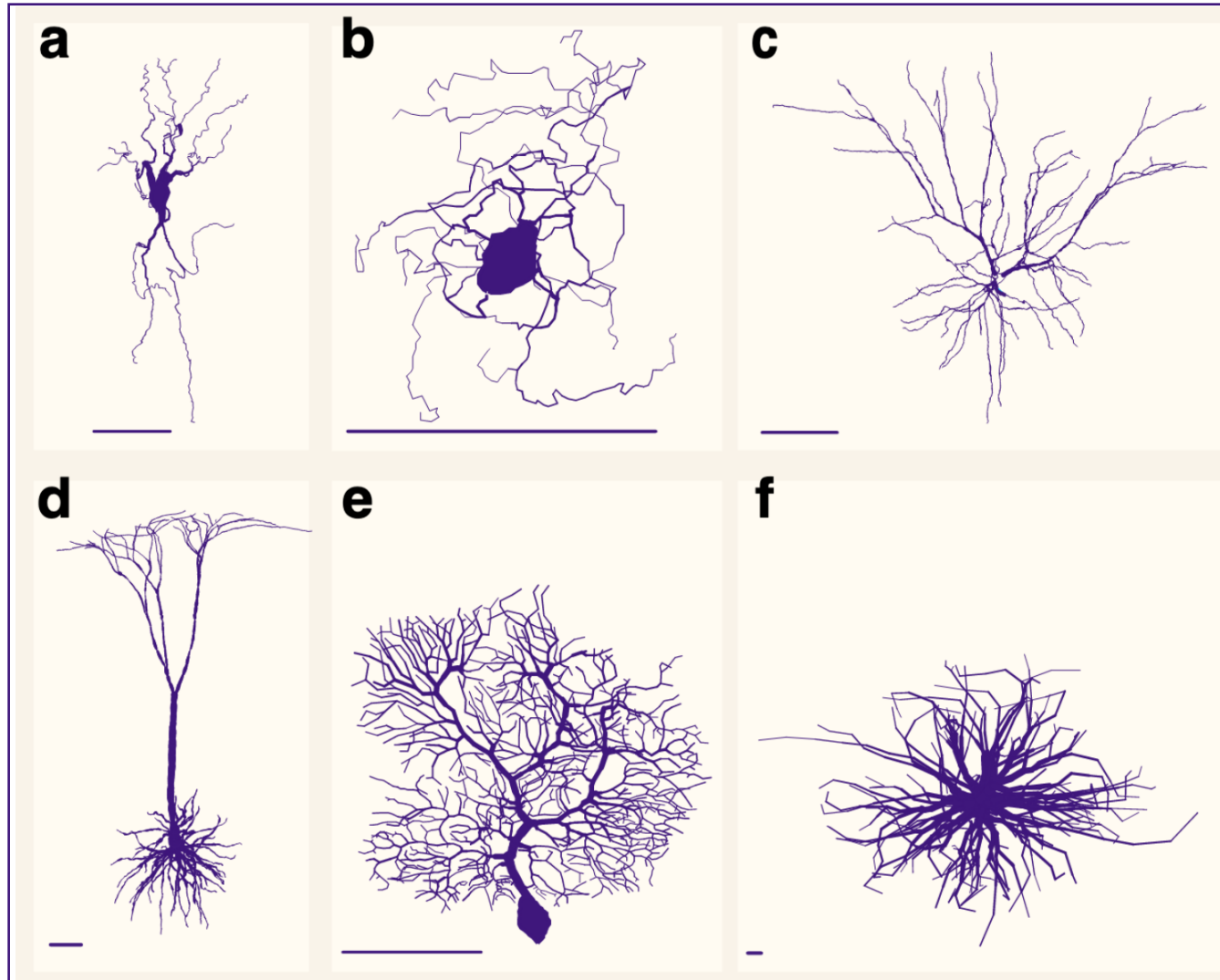
THE END



FSCCHANC@SANDIA.GOV

BACKUP SLIDES

BIOLOGICAL NEURONS (AND THEIR DENDRITES) ARE COMPLEX



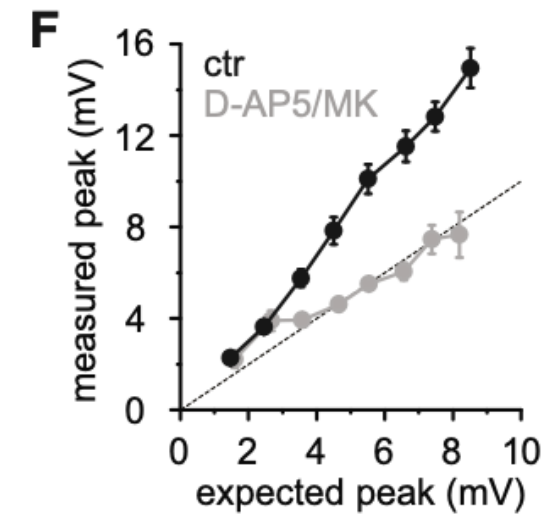
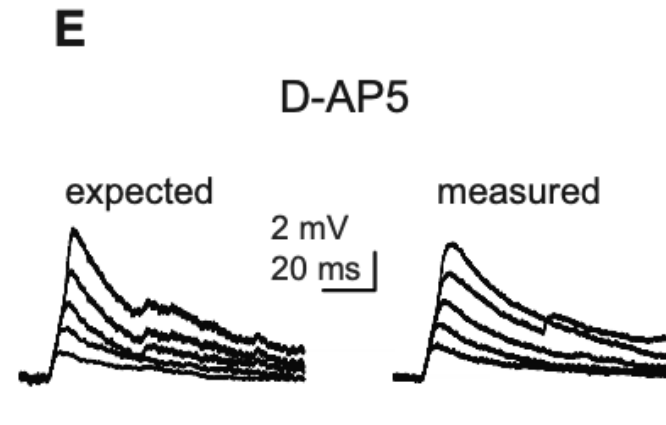
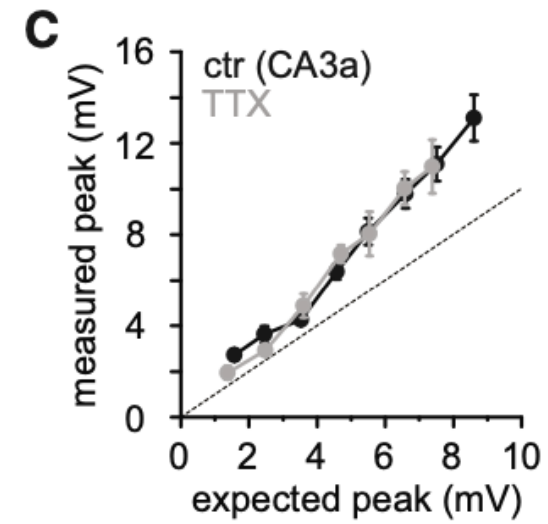
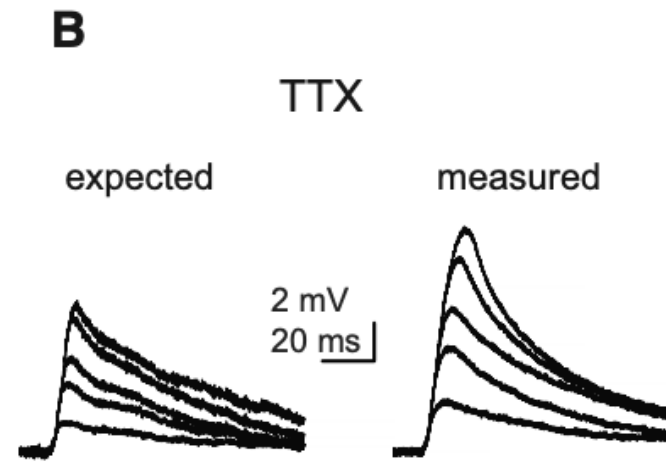
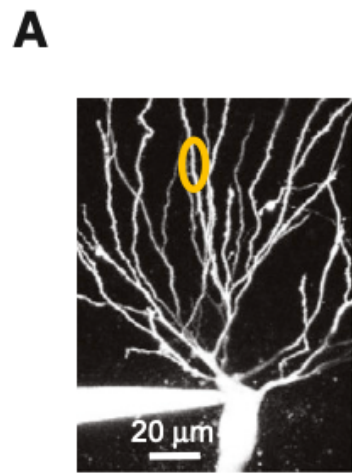
Biological view: dendrites offer a “computational toolkit”. [London et al 2005]

Neuromorphic view: Expressivity of dendrites allows single neurons to function as an ANN. [Poirazi & Mel, 2003; Beniaguev et al, 2021]

What inspiration should we draw from biology for neuromorphic/ artificial systems?

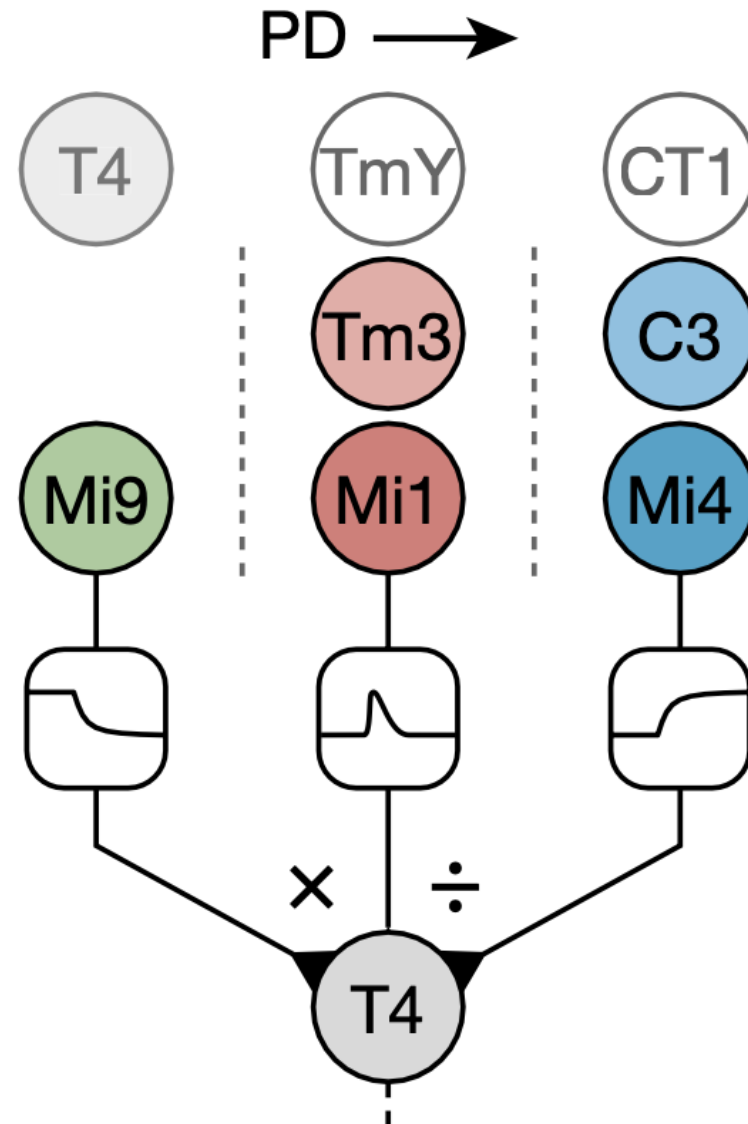
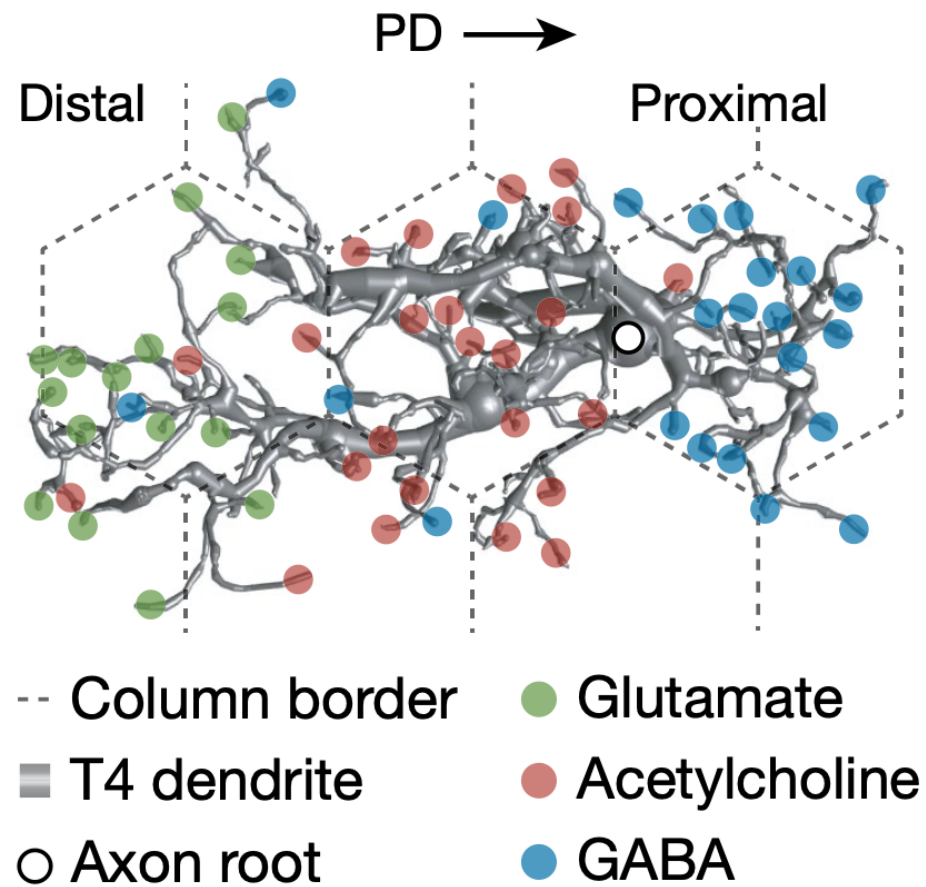
from Koch & Segev (2000) Nature 3: 1171

DENDRITES ARE NONLINEAR



from Makara & Magee 2013

DIRECTION SELECTIVITY FROM SHUNTING IN A BIOLOGICAL DENDRITE



SHUNTING AS A GATE: COINCIDENCE DETECTION IN NUCLEUS LAMINARIS



Phase shift: 180°

