Dendritic computation

Presented by Hal Rockwell 9/5/20

Overview

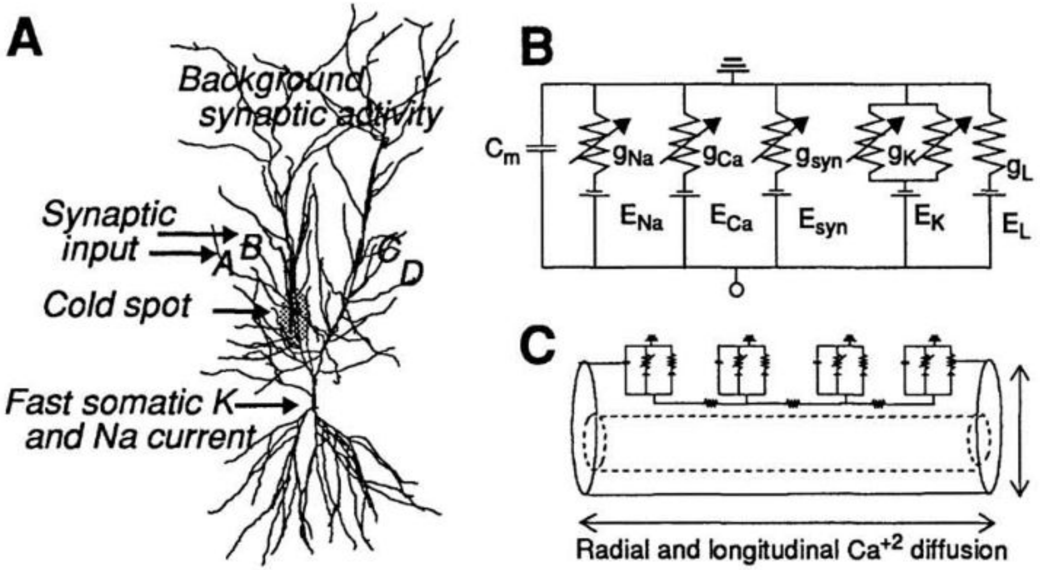
- Briefly cover two old papers on specific logical operations potentially computed by dendrites

- Then the main paper that cites them, tries to integrate a ton of information on dendritic computation into a simple model

Nonlinear Pattern Separation in Single Hippocampal Neurons with Active Dendritic Membrane

(Anthony M. Zador, Brenda J Claiborne, Thomas H. Brown)

- XOR gates

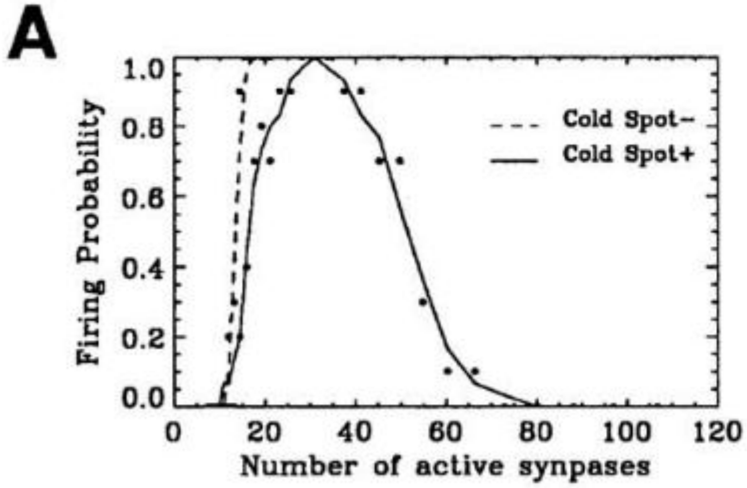


Methods and Results

- Simulate a “cold spot” at the intersection of two dendrites, a patch of low-density Ca channels and high-density Ca-responsive K channels

- Too much depolarization activates the Ca channels enough to vastly hyperpolarize through the K channels

- Leading to a closed range of stimulus intensity for a spike



Notes

- At the time, “cold spots” had not been experimentally observed, just hypothesized
    - Unfortunately, couldn’t easily find if we know now

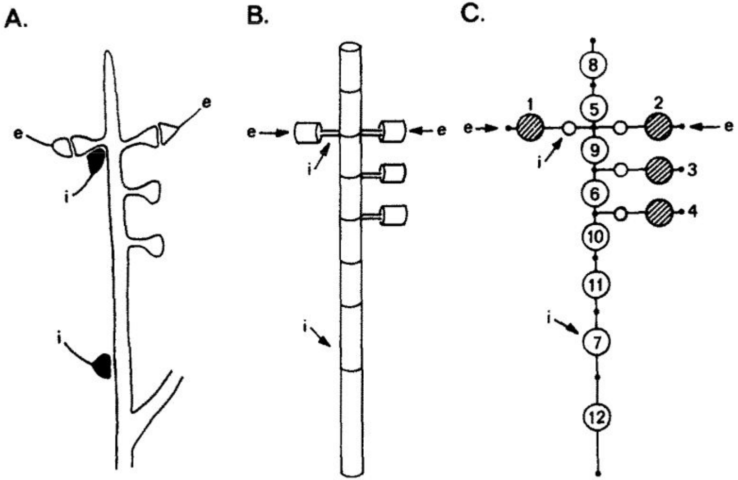
- The model was a hippocampal pyramidal cell, not cortical (but they’re similar)

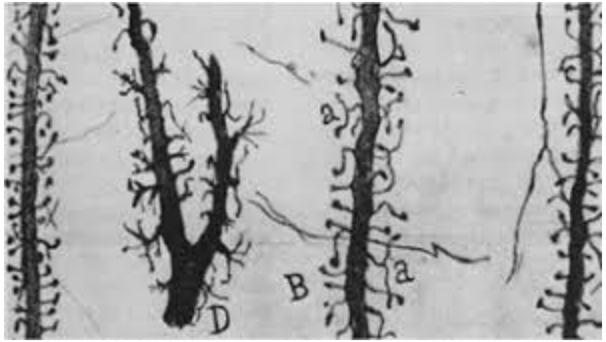
- Not explicitly stated, but I think multiple such gates could exist in a cell, potentially at any dendritic branching point

Logic Operations are Properties of Computer-Simulated Interactions Between Excitable Dendritic Spines

(Gordon M. Shepherd, Robert K. Brayton)

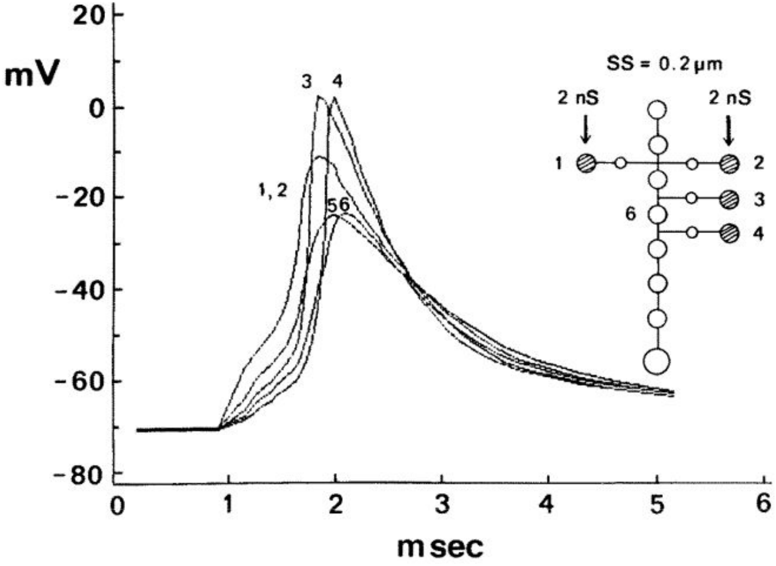
- AND, OR, AND-NOT gates
- Focused on spines



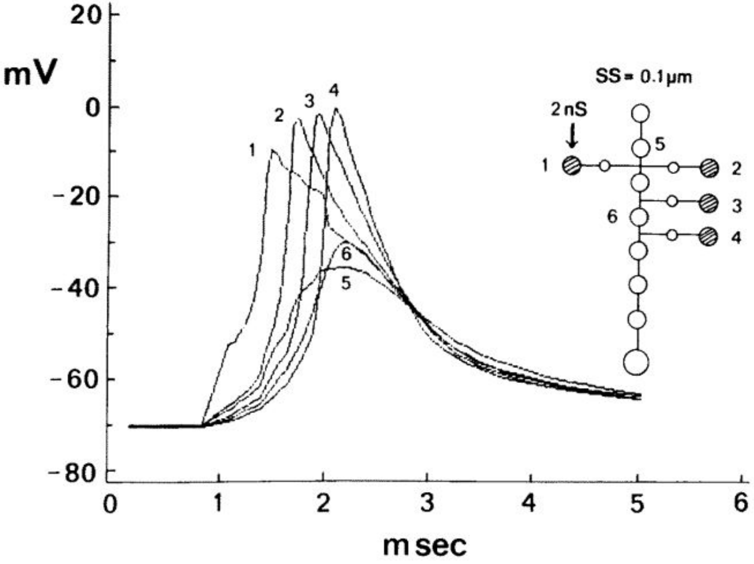


Methods and Results: AND and OR

AND



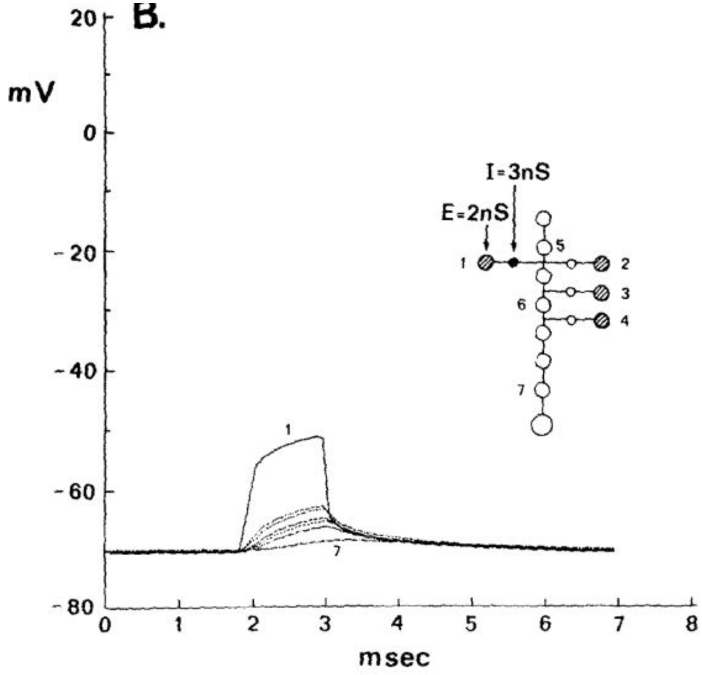
OR



Methods and Results: AND-NOT

- Includes inhibition, which makes it easy

- Paper's focus is generally on the specifics of the synaptic setup, not the logic operations



An Augmented Two-Layer Model Captures Nonlinear Analog Spatial Integration Effects in Pyramidal Neuron Dendrites

(Monika P. Jadi, Bardia F. Behabadi, Alon Poleg-Polsky, Jackie Schiller, Bartlett W. Mel)

- Reviews a huge body of work showing complex, varied, nonlinear processing in dendrites

- Then, proposes a simple linear-nonlinear cascade model that ignores most of the work reviewed, elaborates it to include some of that

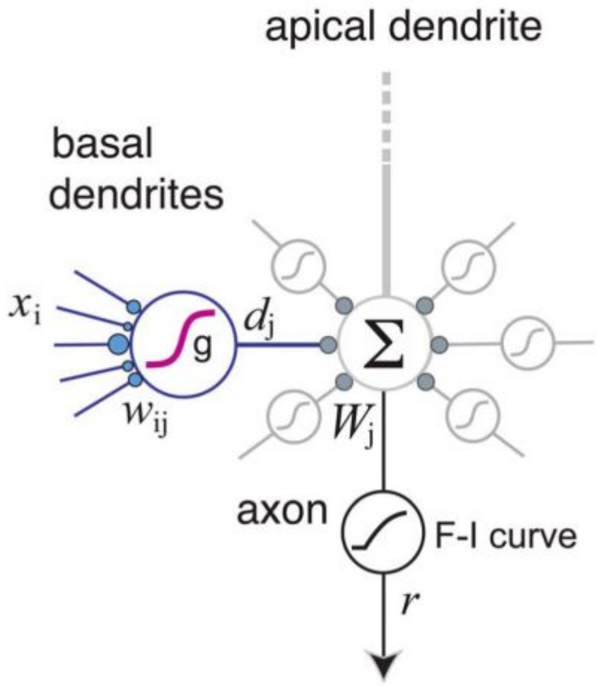
The Standard Two-Layer Model

- Explains 67% of biophysical model's firing rate variance in response to synaptic variation, opposed to 11% for a point neuron

- Assumption is that same-branch inputs sum sigmoidally, branches sum linearly at the soma, some experimental confirmation in brain slices

$$d_j = g\left(\sum_i w_{ij} x_i\right) \quad (1)$$

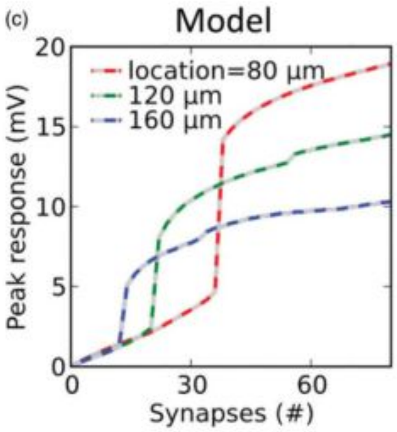
$$r = \mathrm{F-I}\left(\sum_j W_j d_j\right). \quad (2)$$

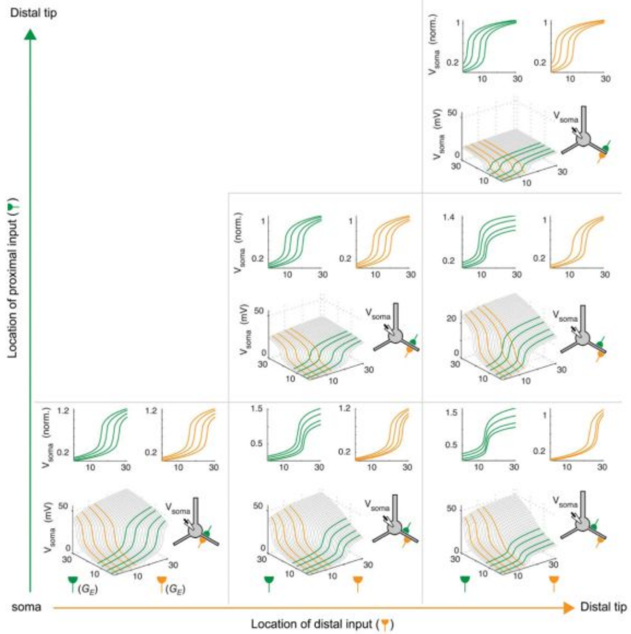


Problems

- Spatial integration within dendrites is more complex
  - Essentially have multiple different sigmoidal functions to choose between

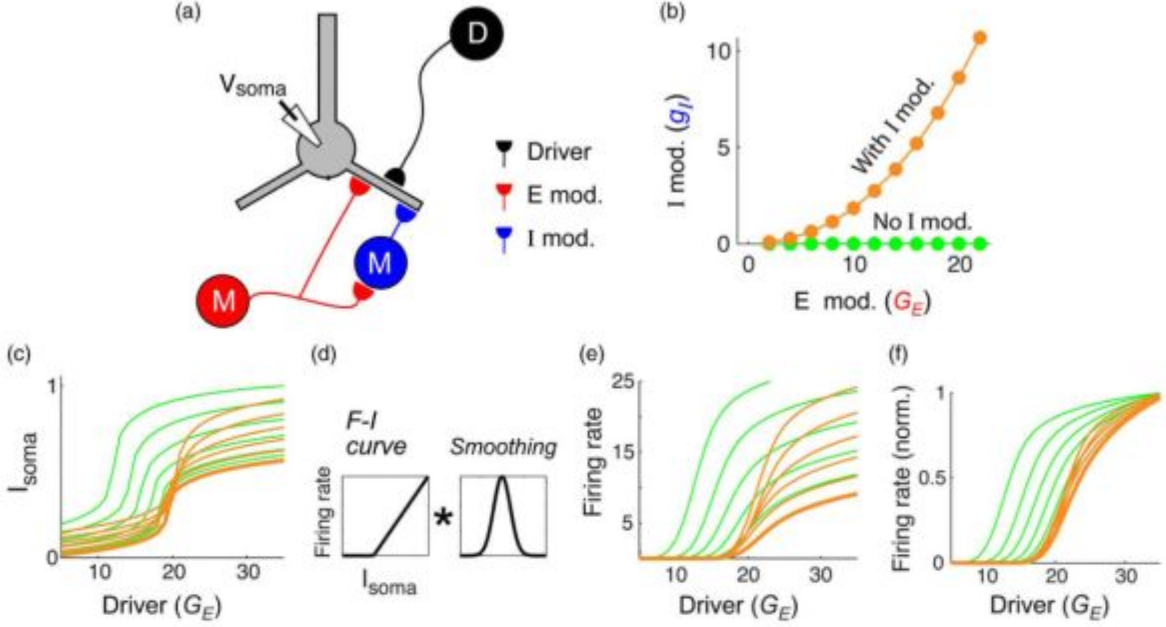
- Can model with multidimensional sigmoids





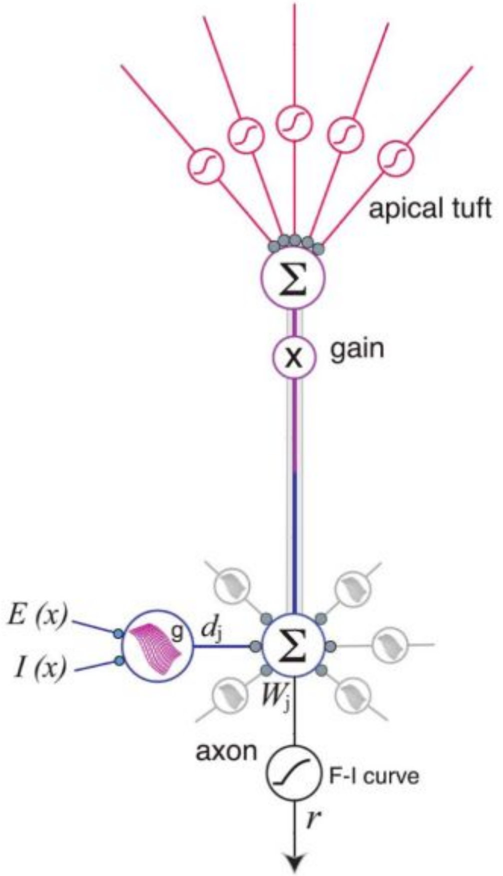
Separate inhibitory modulation

- Main point is multiplicative scaling of the excitatory input



Extended Two-Layer Model

- Multidimensional sigmoids for dendrites
- Different integration patterns for excitatory and inhibitory input
- Multiplicative scaling from the apical dendrite (unexplained in the paper)



Conclusions/Takeaways

- Single neurons can do a lot
  - But it’s not clear how much they do in the actual brain

- Moving more computation into a single neuron, rather than splitting it across the network, might help when credit assignment is limited
  - Or for keeping circuit models’ connectivity simple and biologically constrained