Synaptic integration
Nonisopotential cell (cylinder)

The definitions for the cylinder-dependent parameters are as follows:
r_i – axial resistance (Ω/cm)
r_m – membrane resistance (Ωcm)
c_m – membrane capacitance (F/cm)

\[ \tau_m = r_m c_m \]

membrane time constant – the time it takes for a neuron membrane voltage to decrease in value to 1/e or 37% after it receives an input

\[ \lambda = \sqrt{\frac{r_m}{r_i}} \]

space or length constant - the distance over which the neuron membrane voltage decays to 1/e or 37 % of its value at the origin
Summary: temporal and spatial summation of synaptic inputs
Cable and compartmental models of dendritic trees

Dendrites are modeled either as a set of cylindrical membrane cables (B) or as a set of discrete isopotential RC compartments (C).

B. In the cable representation, the voltage can be computed at any point in the tree by using the continuous cable equation and the appropriate boundary conditions imposed by the tree. An analytical solution can be obtained for any current input in passive trees of arbitrary complexity with known dimensions and known specific membrane resistance and capacitance ($R_{M}$, $C_{M}$) and specific cytoplasm (axial) resistance ($R_{A}$).

C. In the compartmental representation, the tree is discretized into set of interconnected RC compartments. Each is a lumped representation of the membrane properties of a sufficiently small dendritic segment. Compartments are connected via axial cytoplasmic resistances. In this approach, the voltage can be computed at each compartment for any (nonlinear) input and for voltage and time-dependent membrane properties (not only passive membranes).
Dendritic computations - summary

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<th>Computation</th>
<th>Implementation (Biophysical mechanism)</th>
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| Direction selectivity | 1. Dendritic delay + temporal sequence of synaptic activation  
                        2. Asymmetric mapping of inhibition and excitation  
                        3. Integration of many local direction selective detectors | Preferred ≤ Null |
|                      | [Image of dendrite]                     |         |
| Coincidence detection | 1. Backpropagating Na spike + Dendritic Ca spike  
                        2. Input segregation on dendrites + synaptic saturation  
                        3. Backpropagating Na spike + NMDA (Ca in spines)  
                        4. Local dendritic Na spike generated by precisely timed excitation  
                        5. Short local delays in thin dendrites | Ca channels (high density)  
                        Soma input alone  
                        Apical & soma input together  
                        Burst of Na spikes in soma |
|                      | [Images of dendritic structures]         |         |
| Logical operation     | 1. "On path" dendritic inhibition + distal excitation (AND-NOT)  
                        2. Local spike in dendritic spines (AND, OR) | \( \theta, \text{AND-NOT}_1, \text{AND-OR}_1, \text{AND}_2, \text{AND}_3, \text{AND}_4 \) |
|                      | [Image of dendritic structure]           |         |
| Feature extraction    | 1. Mapping synaptic inputs to distinct nonlinear dendritic subunits | [Image of visual features detectors]

From Idan Segev and Michael London
Direction selectivity

Summation of dendritic inputs in a model neuron. When four synaptic inputs (A–D) arrive at four separate locations of a neuron with brief intervals, spatial summation can be significant only when they synapses are activated in a preferred order i.e., D to A, but not A to D. From Arbib, M. A., 1989, The Metaphorical Brain 2: Neural Networks and Beyond, p. 60.

Logical operations

In birds, a special type of neuron is responsible for computing the time difference between sounds arriving to the two ears. Coincident inputs from both ears arriving to the two dendrites are summed up at the soma and cause the neuron to emit action potentials. However, when coincident spikes arrive from the same ear, they arrive at the same dendrite and thus their summation is sublinear, resulting in a subthreshold response.

In layer 5 pyramidal neurons excitatory distal synaptic input (EPSP - red) that coincides with backpropagation of the action potential (bAP) results in a large dendritic Ca2+ spike, which drives a burst of spikes in the axon. Otherwise, a single AP is generated.
Mapping of synaptic inputs onto dendritic branches may play a role in feature extraction responsible for face recognition. In neurons with active dendrites, clusters of inputs active synchronously on the same branch can evoke a local dendritic spike, which leads to significant amplification of the input. Specific configuration of inputs may trigger a spike while activation of synapses at different branches will not generate a response. The features extracted by dendrites may be fed into a soma or features extracted by multiple neurons are fed to a next cortical cell.

Exploring dendritic input-output relation using information theory. (A) Reduced model of a neuron consisting of a passive dendritic cylinder, a soma and an excitable axon. The dendritic cylinder is bombarded by spontaneous background synaptic activity (400 excitatory synapses, each activated 10 times/s; 100 inhibitory synapses, each activated 65 times/s). (B) Soma EPSPs for a proximal (red line) and a distal (blue line) synapse. (C) Two sample traces of the output spike train measured in the modeled axon. Identical background activity was used in both cases; the location of only one excitatory synapse was displaced from proximal to distal. This displacement noticeably changes the output spike train. (D) The mutual information (MI), which measures how much could be known about the input (the presynaptic spike train) by observing the axonal output, is plotted as a function of the maximal synaptic conductance. The distal synapse transmits significantly less information compared to the proximal synapse. For strong proximal synapses, the MI is saturated because, for large conductance values, each input spike generates a time-locked output spike and no additional information is gained by further potentiating this synapse. From: Idan Segev and Michael London. Untangling Dendrites with Quantitative Models. Science 290, 2000