Nonlinear Dendritic Coincidence Detection for Supervised Learning

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1 Introduction

In recent years, a growing body of research has addressed the functional implications of the distinct physiology and anatomy of cortical pyramidal neurons. In particular, on the theoretical side, we saw a paradigm shift from treating neurons as point-like electrical structures towards embracing the entire dendritic structure. This was mostly due to the fact that experimental work uncovered dynamical properties of these cells that simply could not be accounted for by point models.

An important finding was that the apical dendritic tree of cortical pyramidal neurons can act as a separate nonlinear synaptic integration zone. Under certain conditions, a dendritic Ca^{2+} spike can be elicited that propagates towards the soma, causing rapid, bursting spiking activity. One of the cases in which dendritic spiking can occur was termed 'backpropagation-activated Ca^{2+} spike firing' ('BAC firing'): A single somatic spike can backpropagate towards the apical spike initiation zone, in turn significantly facilitating the initiation of a dendritic spike. This reciprocal coupling is believed to act as a form of coincidence detection: If apical and basal synaptic input co-occurs, the neuron can respond with a rapid burst of spiking activity. The firing rate of these temporal bursts exceeds the firing rate that is maximally achievable under basal synaptic input alone, thus representing a form of temporal coincidence detection between apical and basal input.

Naturally, these mechanisms also affect plasticity and thus learning within the cortex. While the interplay between basal and apical stimulation and its effect on synaptic efficacies is subject to ongoing research, there is some evidence that BAC-firing tends to shift plasticity towards long-term potentiation (LTP). Thus, coincidence between basal and apical input appears to also gate synaptic plasticity.

In our work, we combined a phenomenological model predicting the output firing rate as a function of two streams of synaptic input (subsuming basal and apical input) with a BCM-like plasticity rule.