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Towards deep learning applications with biological dendrites

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Abstract

Deep learning (DL) algorithms have successfully solved challenging tasks, including image recognition, autonomous driving, and natural language processing. Artificial neural networks (ANNs), the backbone of most DL architectures, are inspired by biological networks. Yet, in contrast to real brain networks, state-of-the-art DL models require a lot of energy to be trained. Typical ANNs, consisting of numerous, densely connected nodes that mimic neuronal somata, ignore the nonlinear operations performed by biological dendrites: an excitatory biological neuron typically receives thousands of synaptic connections on its dendritic tree, which can interact nonlinearly and drive localized regenerative events, the so-called dendritic spikes. These spikes allow the dendrites to perform an array of complex computational tasks and mediate various forms of localized synaptic and intrinsic plasticity. The lack of these critical functions in ANNs comprises their performance in terms of flexibility and energy efficiency. This study explores the potential advantages that biological dendrites and their specific inputs may provide to ANNs. To incorporate dendrites in ANNs, we designed and implemented a novel architecture whereby each node consists of a soma with its own (connected) dendrites. Dendritic nodes are furnished with nonlinear activation functions, the exact form of which could vary across layers. The dendritic ANN is trained against various benchmark datasets via the backpropagation of the error algorithm, and its performance is compared to that of a traditional ANN consisting of dense (all-to-all) layers and having the same number of trainable parameters. We find that the dendritic ANN outperforms the conventional ANN on all tested classification tasks, using only a small number of trainable parameters. Consistent with experimental evidence, our work shows that biological dendrites empower ANNs by enhancing their information processing power and storage capacity.