Reconfigurable logic inspired by dendritic computation for neural network (NN) acceleration

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Abstract: Reconfigurable logic, epitomized by FPGAs, plays a pivotal role in modern electronics and computing due to its unique blend of flexibility, performance, and efficiency. Within this framework, biological neurons that learn complex non-linear input output mappings can serve as a template for designing reconfigurable low-power and area-efficient circuitry. Typically, the soma activation applies a monotonically increasing activation such as the sigmoid function whereas dendritic activation's characteristics are non-monotonic in nature. A single neuron with sigmoid activation can be reconfigured to perform most logical functions but fails to perform those that are not linearly separable (such as XOR). In contrast, dendritic activation can execute all Boolean logic due to its non-monotonicity and characteristic thresholding. This behaviour is essential for creating a compact and adaptable circuit capable of executing binary logic operations. The circuitry design for dendritic computation involves two distinct modules, namely, the weight storage network and the activation unit. The experimental setup for dendritic activation is demonstrated using programmable CMOS transistors with MoS_2 and WSe_2 as the channel material for n and p-type transport, respectively. Finally, the output of this function is fed to a comparator to produce the desired logic.

Similar characteristics can be exploited when non-monotonic activation is applied in deep artificial neural networks. We investigated the utilization of a dendritic activation function in models that approach MNIST digit classification with a two-layer fully connected network, CIFAR-10 image classification with a convolutional network, and CORA node classification with a graph convolutional network. For a holistic comparison, networks of identical architecture were trained on the same hyperparameters with the sole difference being interlayer activation. In comparison to ReLU and sigmoid activation functions, we found that a dendritic activation function reaches 99% accuracy in fewer training epochs on the MNIST dataset, achieves higher final accuracy at several depths on a two-class subset of the CIFAR-10 dataset, and retains accuracy at larger depths on the CORA dataset. These results establish the potential benefits of utilizing a hardware-based dendritic activation function for the acceleration of both reconfigurable logic and fundamental neural network operations.