

Fully Memristive Spiking Neural Network with Forward–Forward Learning

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We propose a fully memristive spiking neural network (MSNN) trained with the Forward–Forward (FF) algorithm for energy-efficient and hardware-compatible neuromorphic computing. In the proposed framework, both synapses and neurons are realized by analog memristive devices, where memristive integrate-and-fire (MIF) neurons exploit intrinsic device dynamics for temporal processing. Unlike conventional memristive spiking neural networks trained with backpropagation or surrogate gradients, the proposed method adopts a strictly layer-wise, forward-only learning rule based on local goodness optimization. This removes backward error transport, large computational graphs, and centralized control, making the architecture more suitable for analog compute-in-memory hardware. The MIF neuron is implemented using a physically grounded memristor model, enabling continuous analog membrane dynamics and spike generation through voltage-dependent switching and reset behaviour. Presynaptic activity is represented by alpha-shaped current responses, and learning is driven by contrastive positive and negative forward passes. Figure 1 shows the training flow: labelled inputs are converted into temporal alpha pulses and propagated through the MIF layers over multiple time steps, while only the last active layer is locally updated and earlier layers remain frozen.

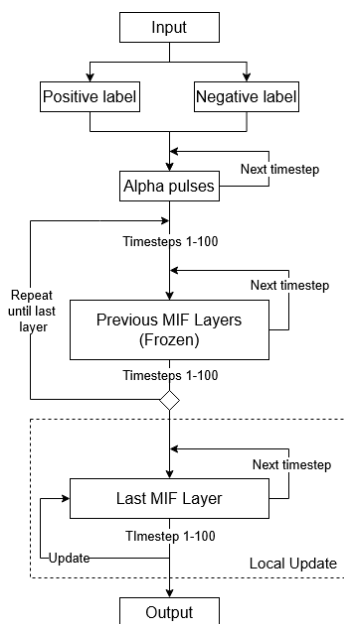


Figure 1: Training pass of the proposed FF-trained MSNN.

Experiments on MNIST, Fashion-MNIST, and KMNIST demonstrate competitive classification performance. These results show that FF learning is an effective alternative to backpropagation for fully analog memristive spiking systems, while avoiding ADC/DAC overhead and supporting compact, low-power implementations. The proposed framework provides a promising route toward scalable neuromorphic hardware for edge AI applications.

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