Bridging Spiking Neural Networks and Deep State-Space Models: To Reset or Not Reset

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Spiking neural networks (SNNs) are biologically inspired, event-driven models well suited for processing temporal data, offering low-latency and energy-efficient computation, especially on neuromorphic hardware. Like SNNs, state-space models (SSMs) are also built on the principles of state and recurrence. More recently, deep SSMs have emerged as a powerful class of models, achieving competitive performance across a variety of tasks involving long temporal sequences. In this talk, we highlight the bridge between SNNs and deep SSMs, introduce spiking and a generalized state reset into deep SSMs, and demonstrate the potential performance gains provided by these neuroscience inspired non-linearities. In particular, we propose a multi-output, stateful neuron model that incorporates nonlinear feedback via a state reset mechanism, see Fig. 1. Unlike traditional SNN neuron models, the proposed neuron model supports a more flexible structure through a general state transition matrix, multiple neuron outputs, and a reset mechanism with learnable parameters [1]. Compared to standard SSM-based neural network models, the proposed neuron enables low-bit spike-based representations, includes nonlinear feedback, and permits instability in the state transition matrix.

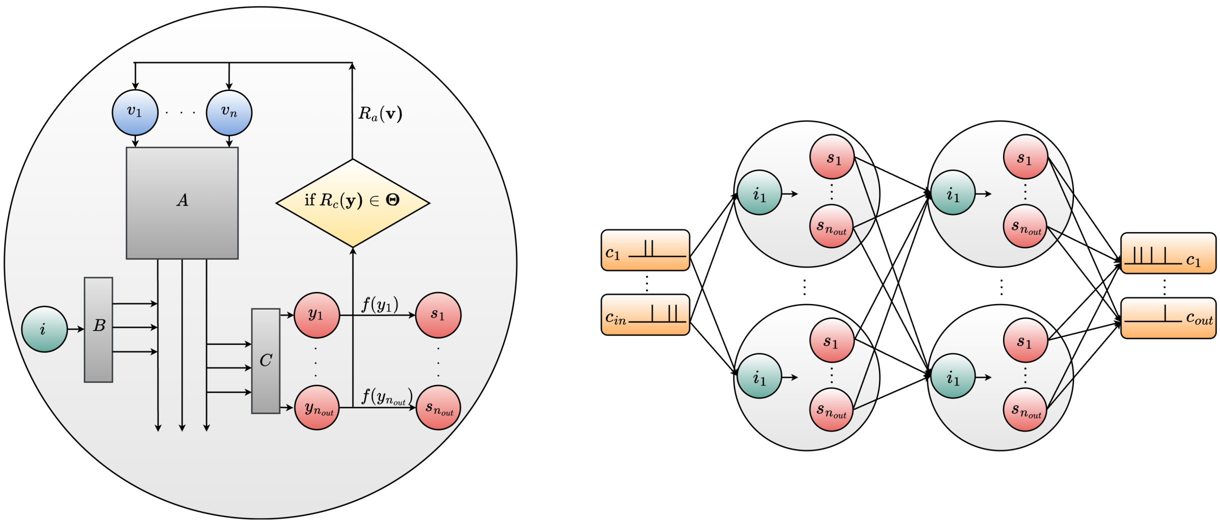

Figure 1: Left: Illustration of dynamics of a neuron with multiple outputs and a general reset mechanism. Right: An illustration of a network with two hidden layers and multiple-output spiking neurons.

Our approach generalizes the reset mechanism used in SNNs, which is typically derived from neuroscience models and tied to specific state variables. Our proposed model clearly conceptualizes the three different mechanisms: the spiking function, the reset condition, and the reset action. Overall, our results on various tasks, including an audio keyword spotting task, an event-based vision task and a sequential pattern recognition task, demonstrate that promising performance gains for temporal modeling emerge from careful integration of concepts from SNN and SSM frameworks. These findings show that strong performance does not require stable linear SSM dynamics, opening the door to a broader class of SSM-based neural network models.

[1] S.Karilanova et. al., IEEE Journal of Selected Topics in Signal Proc., 19 (6), 1172-1186, 2025.