Analog Implementation of Sound Source Localization with Continuous-Time Neurons

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Real-time, dynamic signal processing applications, such as sound source localization, require the extraction of multi-time scales to capture all relevant information. Current state-of-the-art methods achieve this by modeling spiking neural networks with recurrent connections. However, these models require complex and expensive training with algorithms such as BPTT. The SpikingGamma model by [1] solves this problem by modeling the synapse as a sum of temporal kernels and implementing a neuron model based on the Linear-Non-Linear Sigma Delta model. As a result, it is possible to capture multi-timescales efficiently, without any recurrency. However, an efficient implementation has not yet been realized.

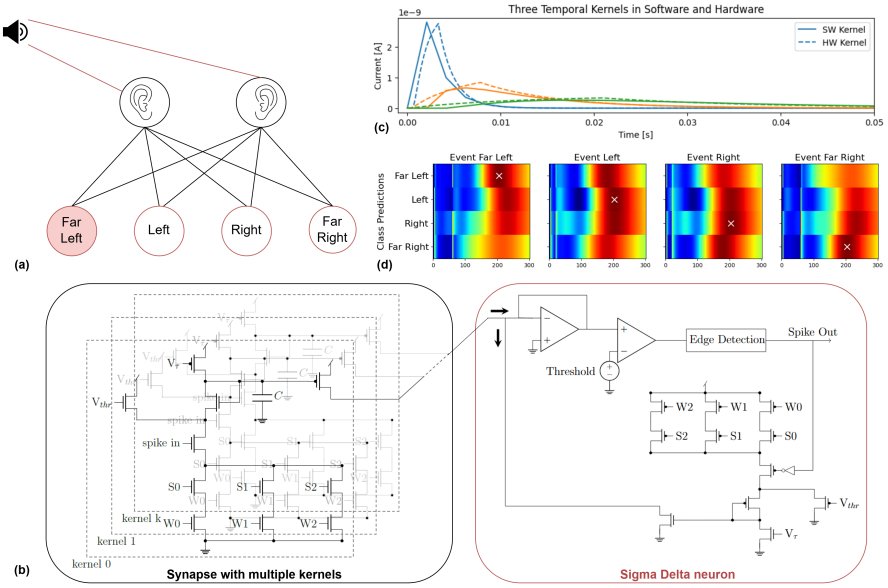

Figure 1: The sound source localization use case with four output classes/locations (a), the proposed circuits for the synapse with multiple kernels and the novel Sigma Delta neurons (b), the first three gamma kernels in both software and hardware simulation (c), and the output of the network for different locations, the white cross indicates the predicted class (d).

To enable energy-efficient, real-time processing, this work implements the SpikingGamma model in analog neuromorphic hardware. The model's synaptic kernels map effectively onto the dynamics of the DPI synapse, facilitating an efficient analog realization of its temporal filtering. Because existing analog spiking neurons lack the functionality required to realize the full SpikingGamma neuron dynamics, an analog architecture is introduced that combines the proposed Spiking Gamma synapse with a novel sigma–delta neuron. Evaluations demonstrate that this approach successfully replicates the synaptic buckets and closely matches the target SpikingGamma behavior. Consequently, the proposed circuit achieves continuous-time, efficient computation for sound source localization tasks.

[1] R. Koopman et al., arXiv, 2026.