Physical AI

Maintaining Sparse Activity: Dendritic Integration Enhances Temporal Prediction in Spiking Neural Networks

Pro²Future

Michael Siegl[1], Michael Haslgrübler[1], Alois Ferscha[2]

Pro2Future GmbH[1], JKU-IPC[2]

[1] Pro2Future GmbH, Science Park 4, Altenberger Strasse 69, 4040 Linz, AT

[2] Johannes Kepler University, Altenberger Strasse 69, 4040 Linz, AT

MOTIVATION & GOALS

Spiking Neural Networks (SNNs) offer extreme energy efficiency for AI solutions, a necessity for battery-operated **Physical AI** systems. Yet traditional single-compartment models struggle with complex temporal tasks. This work introduces **multi-compartment (MC)** SNN architectures featuring **active dendritic processing**. This enables local non-linearities and branch-specific coincidence detection to overcome the expressivity limitation of standard point-neurons.

We propose **active multi-compartment LIF** (MC-LIF) and **adaptive LIF** (MC-adLIF) neurons for deep, surrogate-gradient-trained SNNs. We combine these building blocks into a flexible **recurrent spiking neural network** (RSNN) architecture.

Project FactBox

Project Name FedPhAI
Project ID StratP II P.S
Duration 12 Months

Area 1
Perception

Project Lead
Dr. Michael Haslgrübler

APPROACH

The neuron models were emulated and trained on GPUs as 2-layer **recurrent spiking neural networks (RSNNs)** using **BPTT** with sigmoidal **surrogate** gradient functions under a **fixed parameter** regimen with **trainable time-constants**.

Three **time-series classification** with **different modalities** were evaluated: Spiking Heidelberg Digits (SHD) and Spiking Speech Commands (SHC) and QTDB from PhysioNet (ECG) with 0.45M, 1.6M and 4.6k with respective parameter counts.

CONTRIBUTION

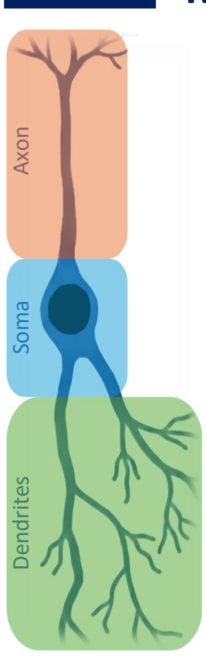
Scientific contribution

- discrete-time formulation of active dendritic compartments with learnable plateau dynamics
- active dendrites significantly improve the plain LIF baseline without increasing the mean firing rate
- Scalable RSNN Architecture

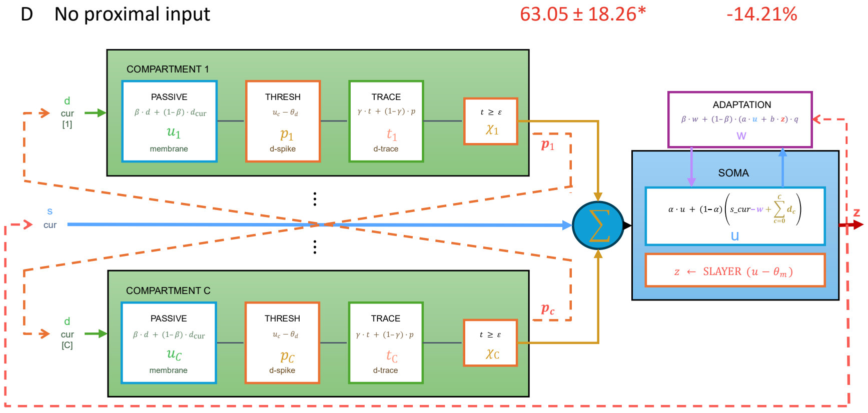
Economic contribution

- Lower Latency in Processing Signal
- Extends Runtime for Battery-Powered Physical AI
- Decreases Edge Hardware Unit Costs

MC ARCHITECTURE and BENCHMARK RESULTS



	Description	Test Accuracy (%)	Δ Baseline
B	**Hybrid + Recurrent Dendrites**	**77.26 ± 0.65**	---
T	Learnable thresholds for dAPs (θ_c)	77.02 ± 0.46	-0.24%
R	Compartments only connect to soma	76.79 ± 0.39	-0.47%
P	Passive summation only ($d_c = u_c$)	76.38 ± 0.34	-0.88%
A	Active plateaus only ($d_c = \chi_c \varphi_c$)	75.14 ± 1.49*	-2.12%
D	No proximal input	63.05 ± 18.26*	-14.21%



Model	Metric	0-Comp	1-Comp (MC)	2-Comp (MC)	3-Comp (MC)
SHD (LIF)	Accuracy	88.64 ± 1.09 [a]	90.32 ± 0.93 [b]	**90.46 ± 0.60 [b]**	89.99 ± 1.02 [b]
	Sparsity	3.57 ± 1.66	3.70 ± 1.74	3.45 ± 1.28	3.21 ± 0.88
SHD (adLIF)	Accuracy	93.85 ± 0.56 [a]	**94.43 ± 0.58 [a]**	94.34 ± 0.59 [a]	94.01 ± 0.78 [a]
	Sparsity	5.41 ± 3.15	7.09 ± 4.23	7.87 ± 4.42	8.44 ± 4.03
SSC (LIF)	Accuracy	76.04 ± 0.34 [a]	76.92 ± 0.44 [b]	**77.26 ± 0.65 [b]**	76.71 ± 0.64 [ab]
	Sparsity	4.28 ± 0.33	4.38 ± 1.07	4.43 ± 0.87	5.09 ± 1.20
SSC (adLIF)	Accuracy	80.24 ± 0.41 [ab]	**80.61 ± 0.20 [b]**	80.57 ± 0.23 [b]	79.98 ± 0.55 [a]
	Sparsity	10.45 ± 1.80	11.80 ± 2.02	12.42 ± 2.73	13.20 ± 3.77
ECG (LIF)	Accuracy	68.66 ± 6.41 [a]	**85.75 ± 0.61 [b]**	84.99 ± 1.46 [b]	84.71 ± 1.02 [b]
	Sparsity	34.70 ± 15.86	32.89 ± 6.91	35.35 ± 7.41	33.43 ± 8.53
ECG (adLIF)	Accuracy	87.50 ± 0.42 [a]	**87.67 ± 0.71 [a]**	87.36 ± 2.51 [a]	85.86 ± 2.10 [a]
	Sparsity	25.47 ± 7.14	23.92 ± 6.79	25.11 ± 8.03	23.66 ± 8.19

Contact: Dr. Michael Haslgrübler, Pro2Future GmbH, michael.haslgruebler@pro2future.at, +43 732 2468 - 9475

Acknowledgement: This work was supported by Pro²Future II (FFG, 911655) and JKU, Institute of Pervasive Computing.

JKU Institut für Pervasive Computing

JKU Johannes Kepler Universität Linz · TU Graz · AVL · Fronius · UAR Upper Austrian Research GmbH · Bundesministerium Innovation, Mobilität und Infrastruktur · Bundesministerium Wirtschaft, Energie und Tourismus · FFG Forschung wirkt. · oberösterreich · Das Land Steiermark · SFG