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EXPRESSIVE DENDRITES IN SPIKING NETWORKS

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DENDRITIC HARDWARE & COMPUTATION

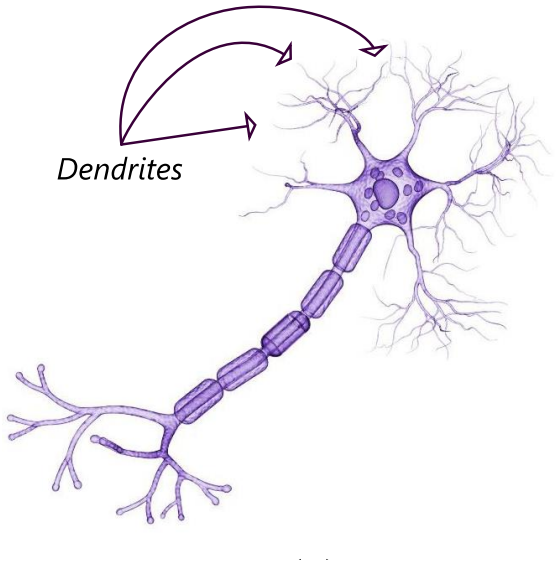
Dendrites are a nonlinear computational components

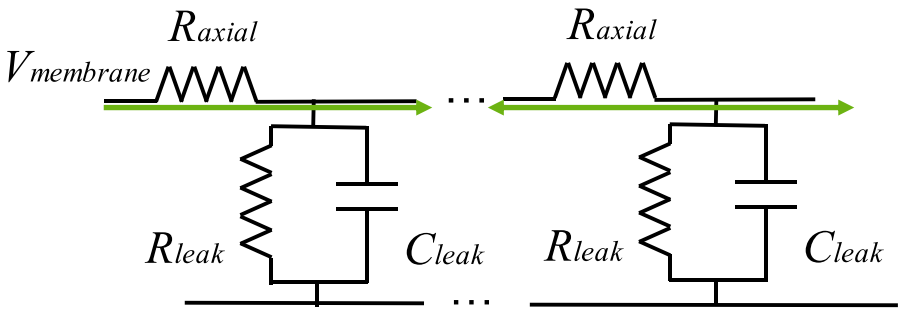
Provide a “pre-processing” computation

- Inputs travel to neighbors as well as output

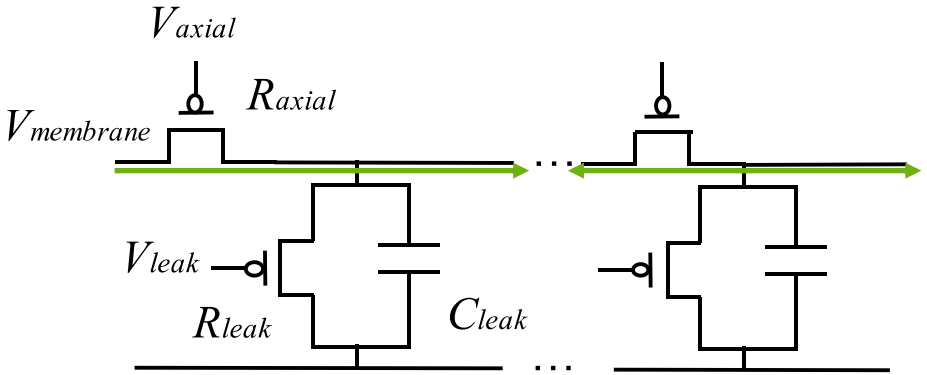
Several methods to implement in hardware

Almost compute-on-wire





Using Resistors & Capacitors to implement Dendrite Chain



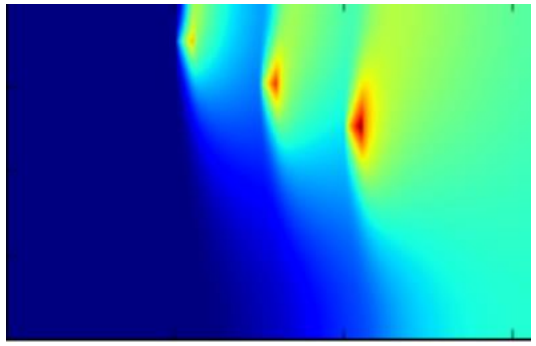
Using CMOS:
Subthreshold Transistors to Implement Dendrite Chain

DENDRITIC UTILITY

Custom hardware is needed to leverage Dendrites

- CMOS based subthreshold based dendrites have been demonstrated to work
- Exploration of beyond CMOS devices as well
  - Memristors, SONOS floating-gate, and more…

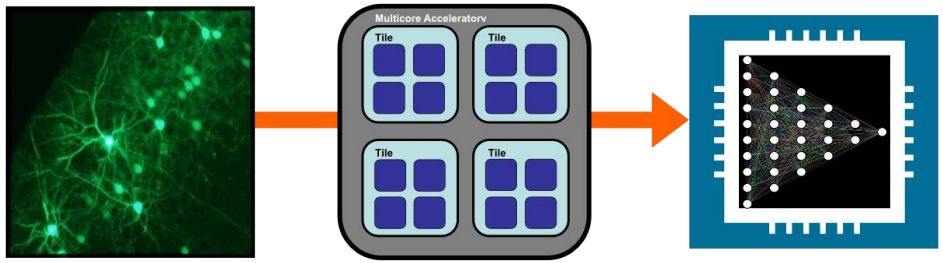
snnTorch



The chicken & egg of novel AI

- In order to justify novel hardware adoption, good software use-cases must exist
- But software developers will use the best current hardware and libraries

An easy-to use dendrite layer in a major ML library could help experimentation and development of dendrite and spiking networks



DENDRITE ENABLED SPIKING LIBRARY

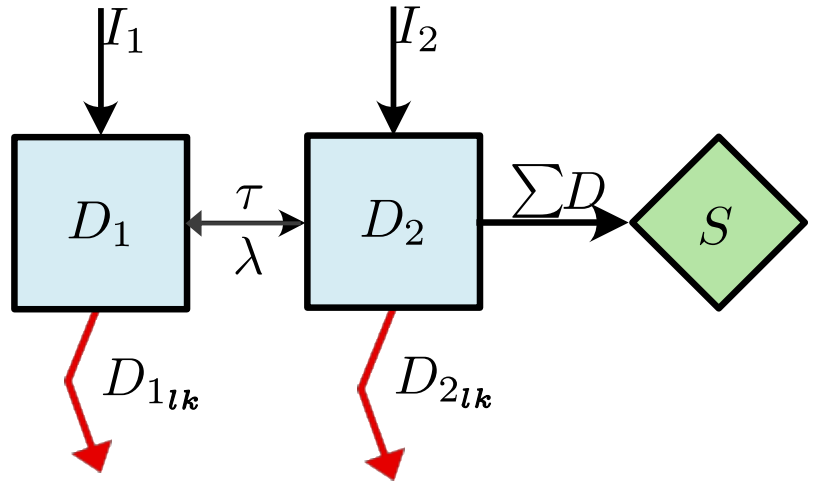
Implemented Torch library with a dendritic chain
- Simplified version of the complex ODE dendrite solution
- Wrapped dynamics into a set of constants and parameters

Dendrites support SNNTorch & Non-Spiking Torch

Provides a trainable 1-D chain of dendrites

- Spiking or continuous output
  - Works with SNNTorch models or PyTorch models

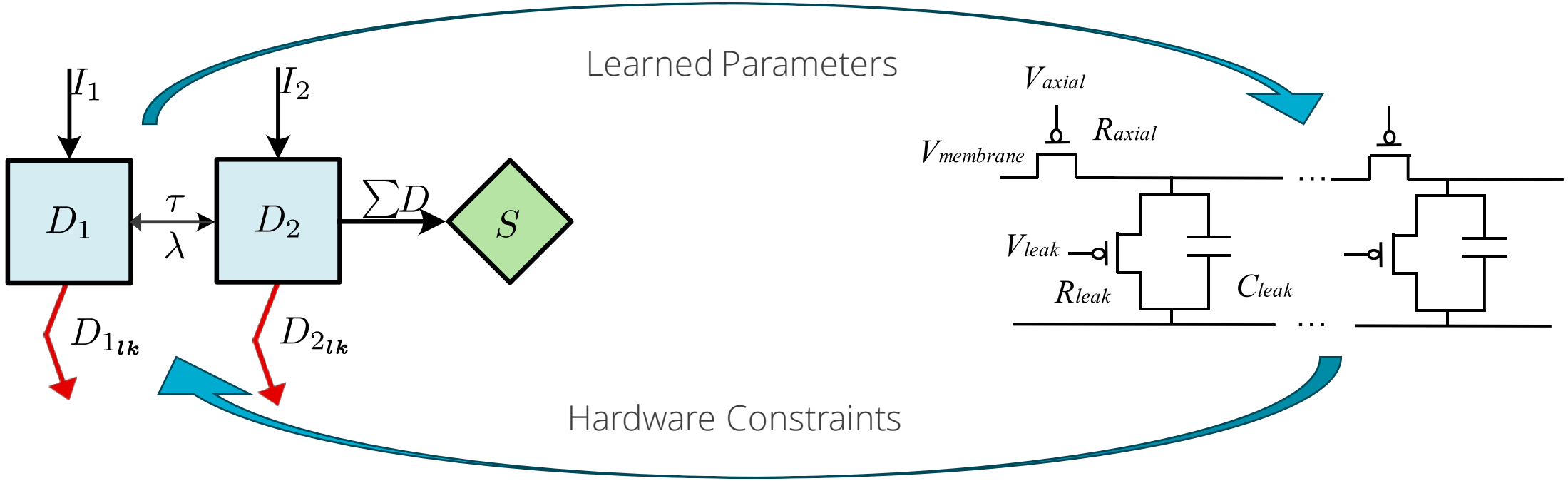
Value	Type
Lambda	"Spatial" constant: Represents Distance
Tau	"Temporal" constant: Capacitance and Resistance
Leak	Signal loss for each tap
Input Weight	Increases or Decreases signal strength



SNNTORCH DENDRITE LIBRARY

Abstract dendrite implementation

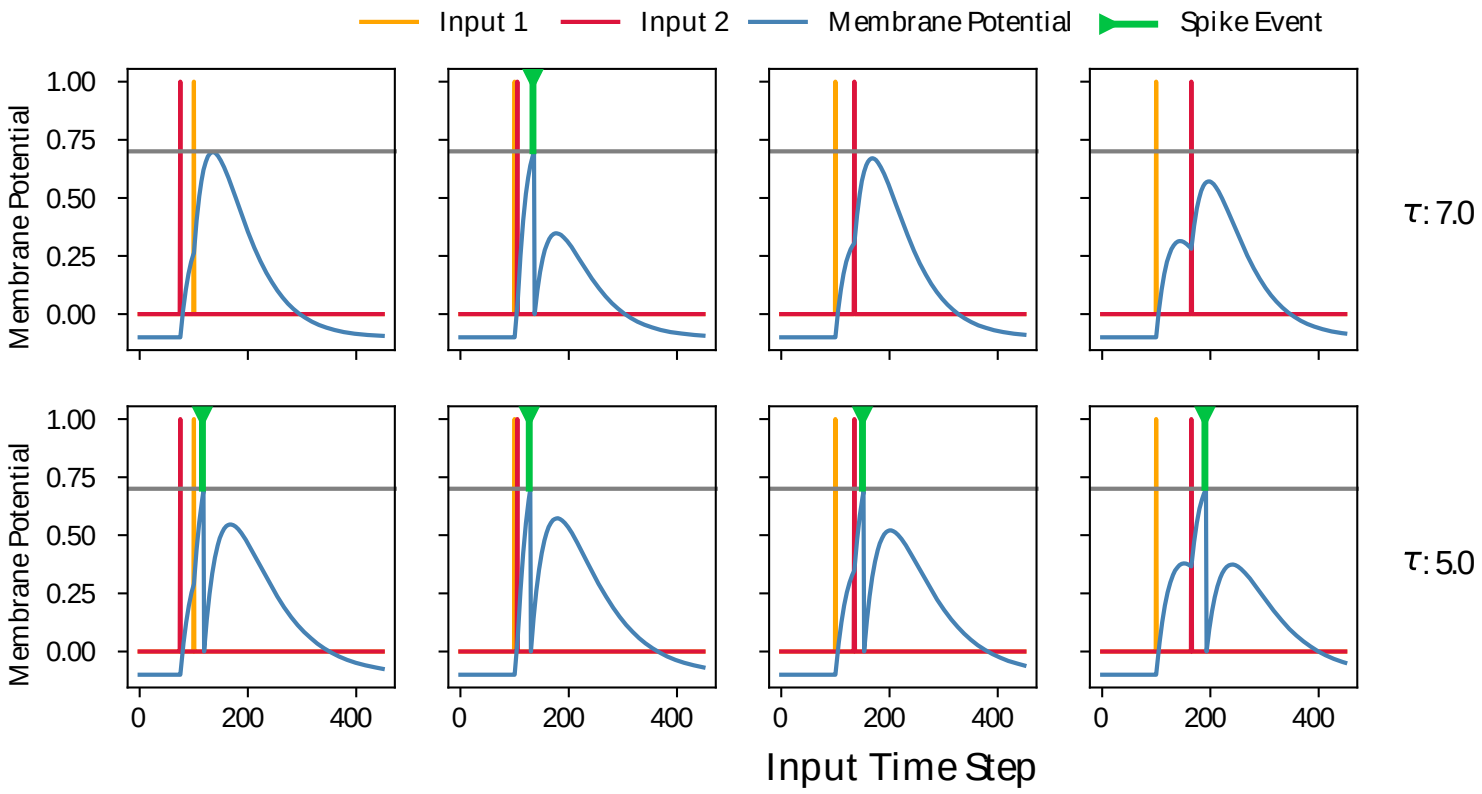
- Based on analog hardware design
- Goal to enable ML training that is transferrable to dendritic hardware
  - Hardware constraints (number of taps, possible fixed values, etc.) to software
  - Learned parameters to hardware

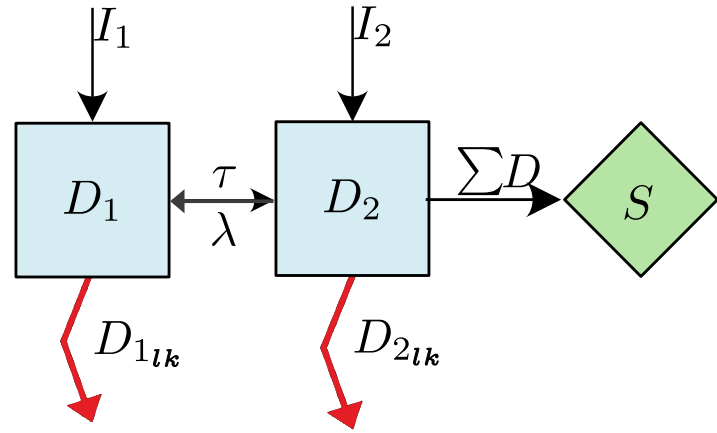


DENDRITIC COMPUTATION – BASIC COINCIDENCE NETWORK

A single dendrite-enabled neuron is capable of basic coincidence detection

The nonlinear temporal dynamics allow for a “time-based AND gate”

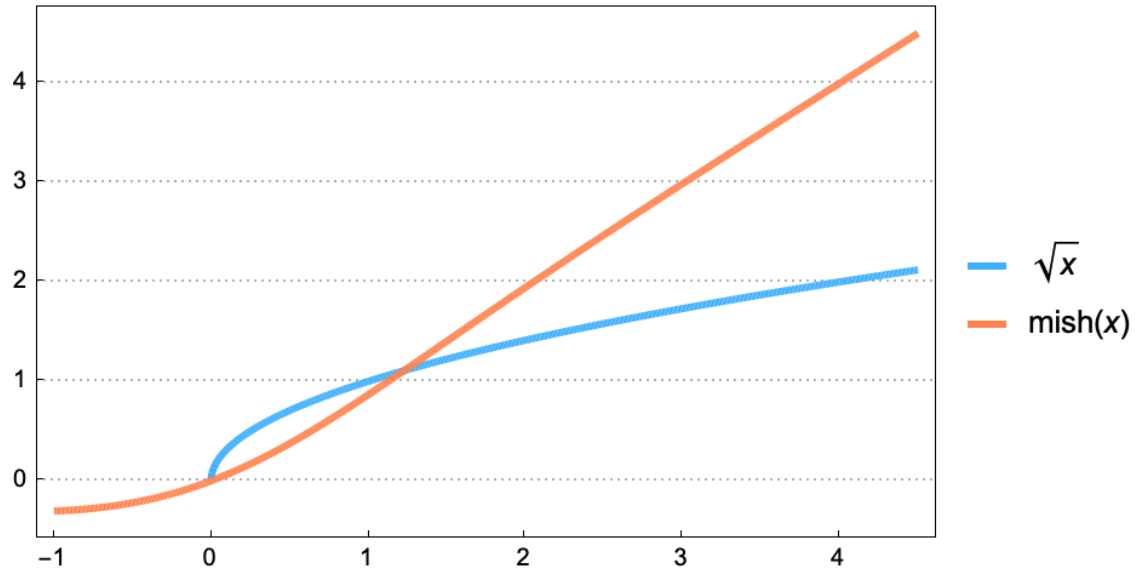




DENDRITE + SNN NETWORKS

- Learn a pair of nonlinear functions using SNNs
- Based on example spiking networks from the SNNTorch library

- Learn two functions:
  - √x
  - Mish(x)
- Collected a set of 1,000 random samples of each function
  - *> 0 and ≤4*
- Trained all networks for 100 epochs



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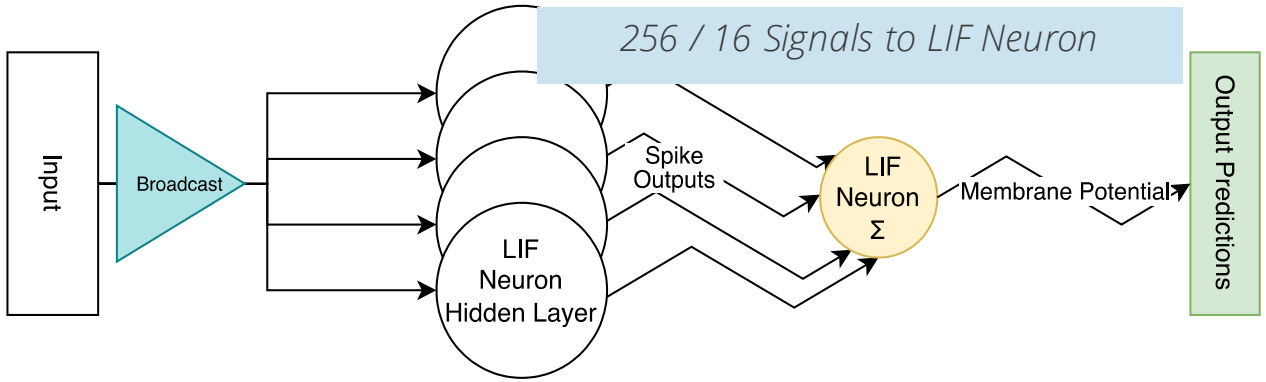
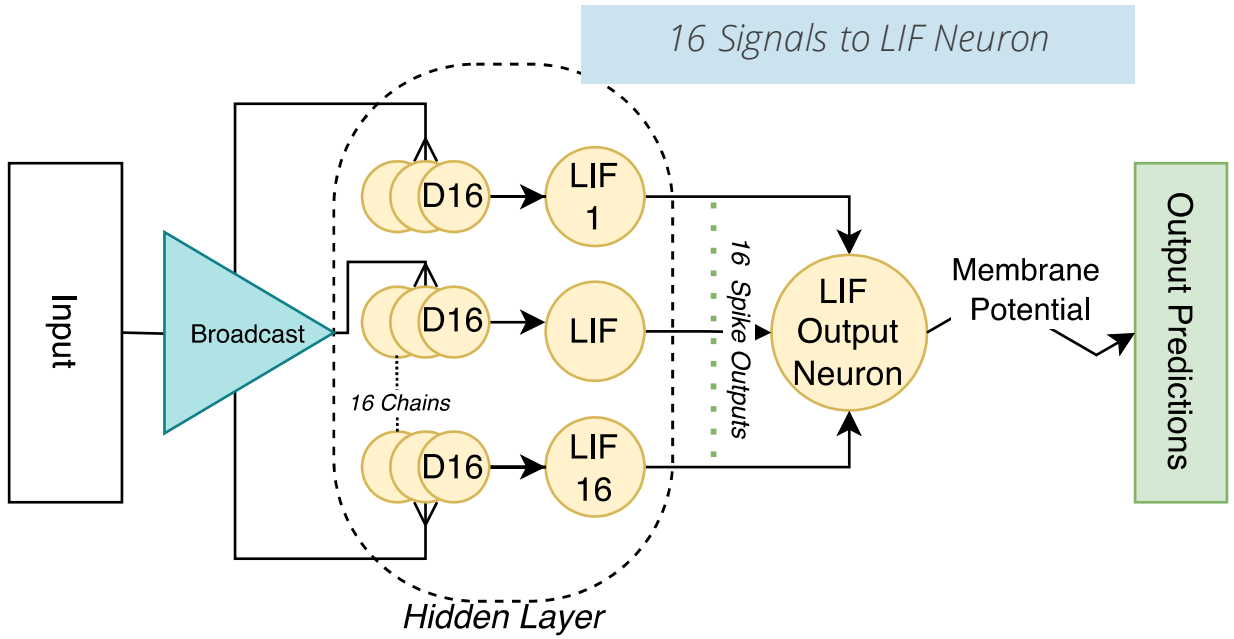




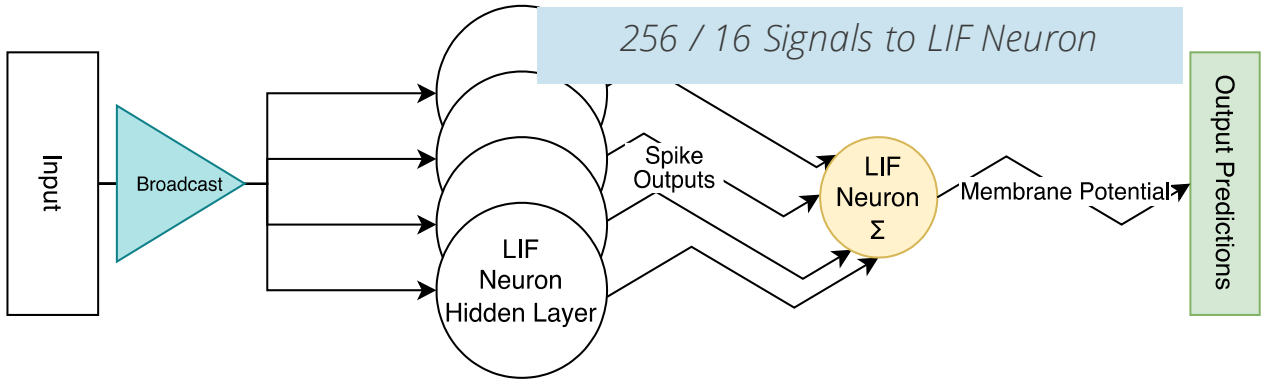
- Created three networks:
- 256 LIF Hidden Layer network
  - Sends 256 spikes to the output neuron
- 16 LIF Hidden Layer network
  - Sends 16 spikes to the output neuron
- 16x16 Dendrite Layer
  - Sends 16 spikes to the output neuron

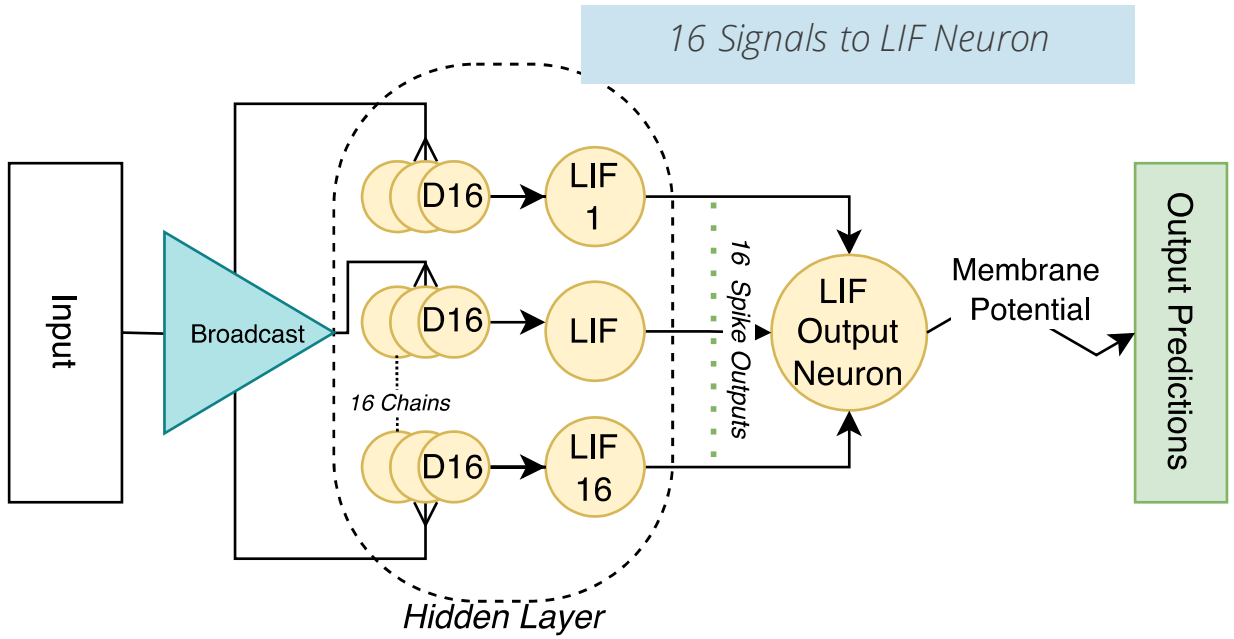
Compare signals sent to output layer against accuracy

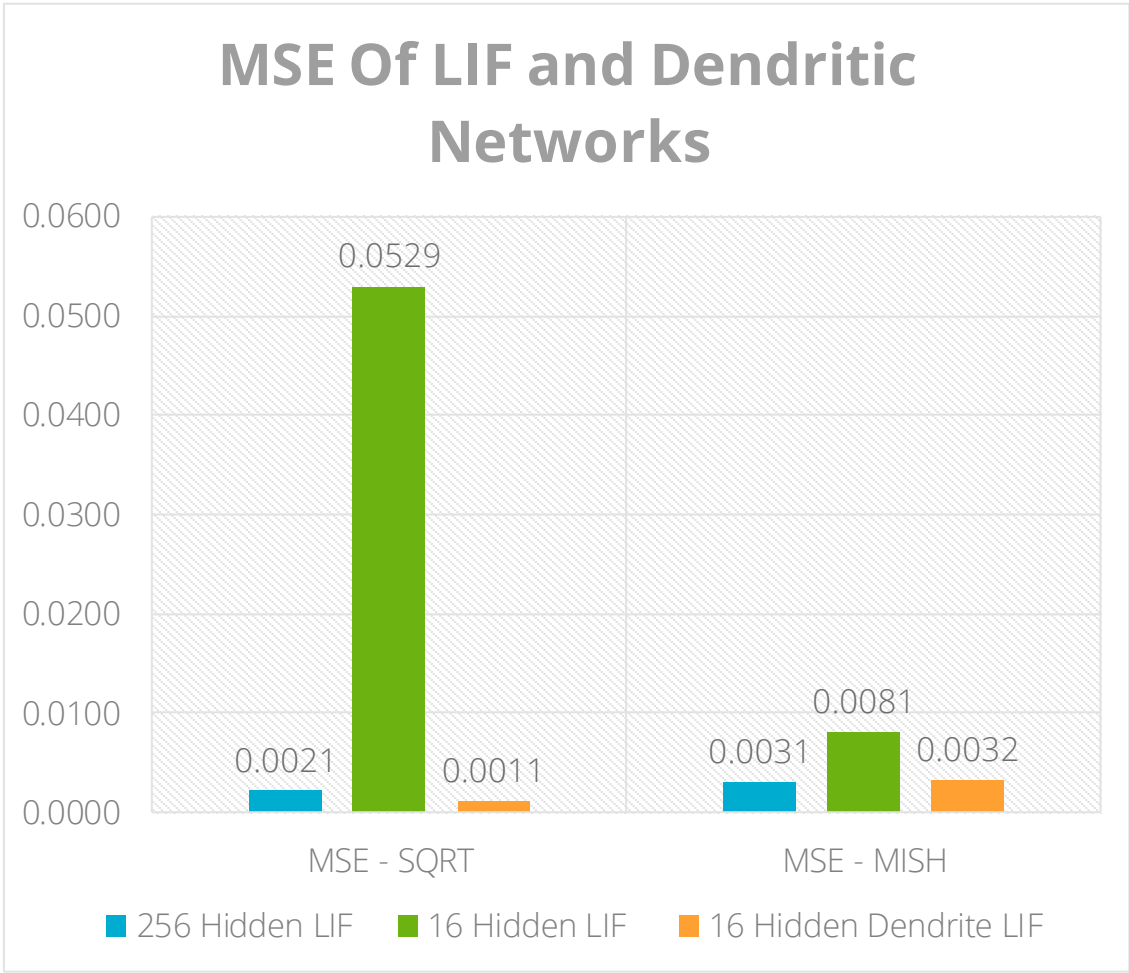
Tau and Lambda were learned:

- Maximum capacitance required in hardware ≤ 100pf

DENDRITE + SNN NETWORKS







FUTURE WORK

- Further develop links with Dendrite-SNN hardware simulations – SanaFe
- Work on a spiking self-attention network with dendrites:
  - Dendritic attention layer (Temporal coherence and context)
  - Dendritic pooling layers (More efficient summary layer)
- Other compelling network designs
- Release as stand-alone library or as SNNTorch add-on

SanaFe – Hardware Simulator

An in-progress tool to estimate timing and energy of neuromorphic systems. Currently supports Loihi. Dendrites are WIP

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