Biologically Plausible Deep Learning by Dendritic Gating of Plasticity

RUTGERS–NEW BRUNSWICK
Aresty Research Center for Undergraduates

RUTGERS
Center for Advanced Biotechnology and Medicine

Yash Chennawar[1], Michael Cheng[2], Anshul Voleti[1], Alessandro Galloni[1], Aaron Milstein[1]

[1]Center for Advanced Biotechnology and Medicine, Rutgers, The State University of New Jersey

[2]Department of Neuroscience, Amherst College, Amherst, MA

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Introduction

- **Artificial Neural Networks** (ANNs) are good at recognizing patterns, but they follow rules that are not biologically plausible.
- A standard learning rule used in machine learning is **backpropagation**, which uses gradient descent. It follows the weight update rule:

$$\Delta W \sim \frac{\partial Error}{\partial W} \sim \frac{\partial Error}{\partial A_{post}} \times A_{pre}$$

- This is not biologically plausible since it uses **nonlocal error**.
- We hypothesize that separate **soma** and **dendrite** compartments can be used to compute local error[1,2,3]. Learning rules based on this were then compared to backprop as a benchmark on a non-linear classification task.
- We first tested this idea in our "**dendritic temporal contrast**"[4] model:

$$N \sim D_B - D_F;\ \ \Delta W \sim N \times A_{pre}$$
$$A_{post} \leftarrow A_{post} + N$$

  - This model compares top-down input before and after a teaching signal (nudge) is applied.
- We extended this further by using **interneurons**. Here, a comparison is made between top-down input and lateral current input to dendrites:

$$N \sim D_B = I_{TD} - I_{Int};\ \Delta W \sim N \times A_{pre}$$

Legend:

W: Weights (synaptic strength)
A: Activity (firing rate of neuron)
N: Nudge (teaching signal)
D: Dendritic state
B: Backward pass
F: Forward pass
I_{TD}: Top-Down Input
I_{Int}: Interneuron Input

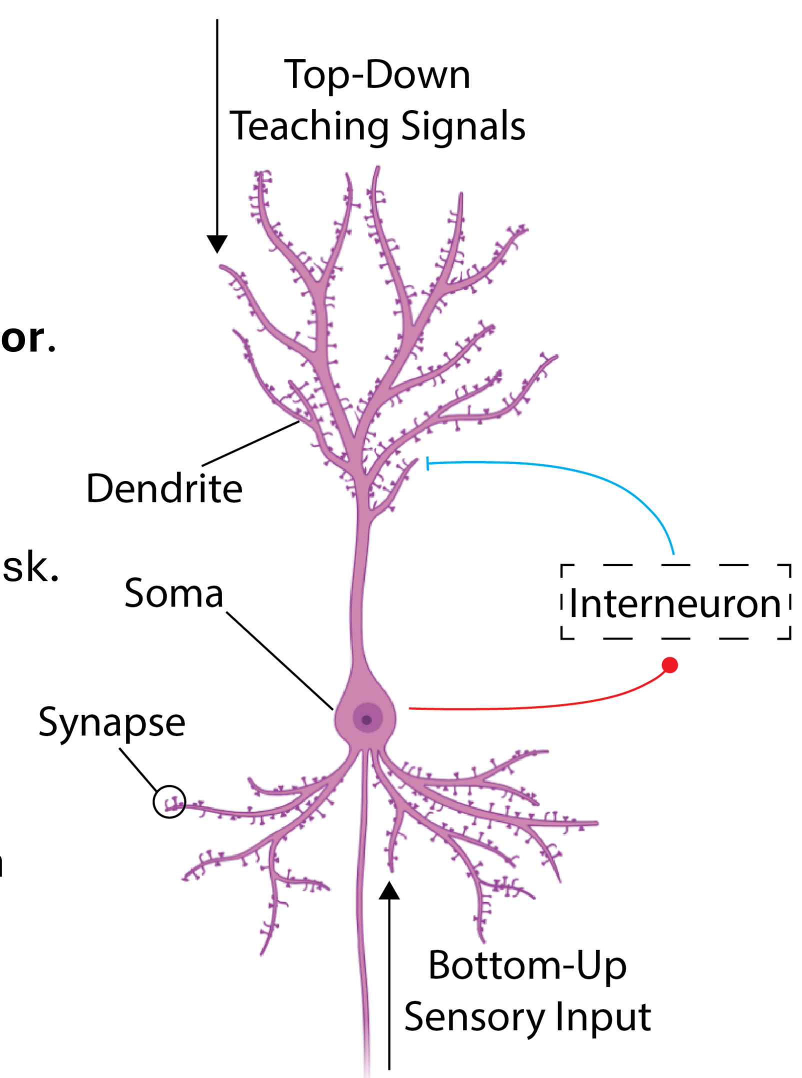

Fig 1: Neuron compartmentalized into soma and dendrite, with lateral interneuron connection. Example neuron in one layer of ANN.

Methods

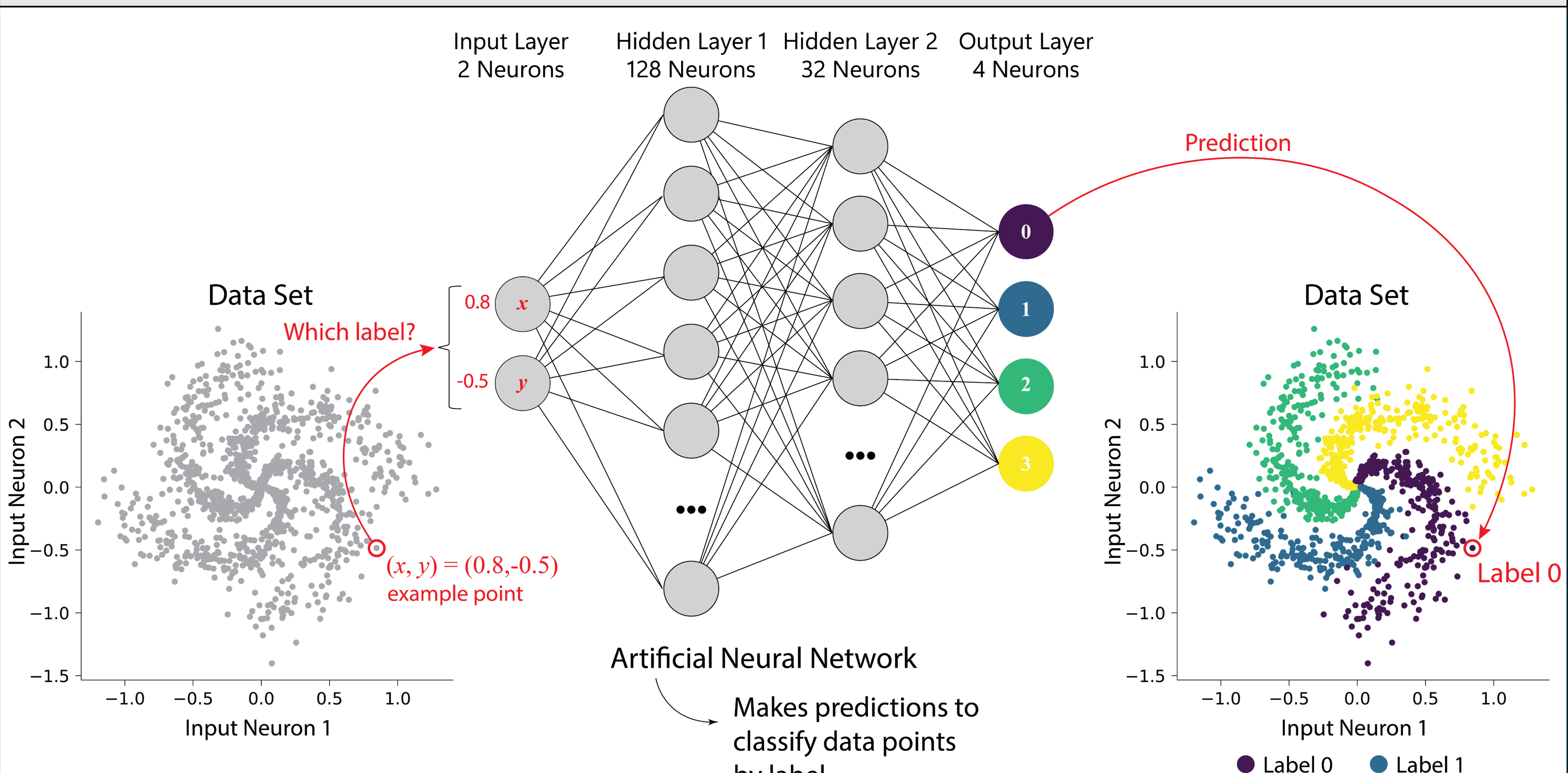

Fig 2: ANN Architecture and spiral dataset used

- Developed neural network with PyTorch in Python 3.
- Trained network with data points from data set.
- Optimized hyperparameters with Optuna.

Results

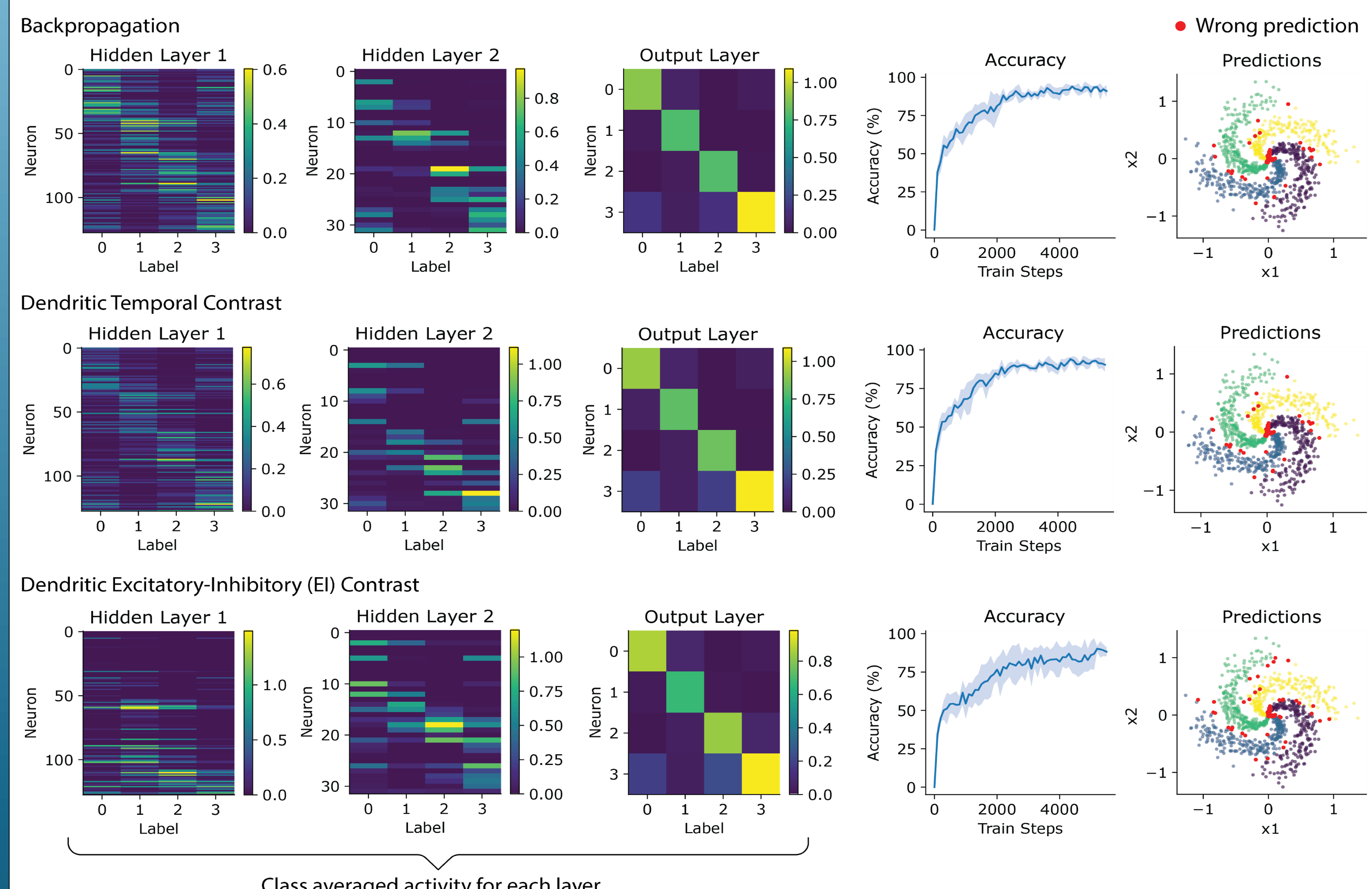

Fig 3: Summary plots for all 3 ANN configurations

Conclusions

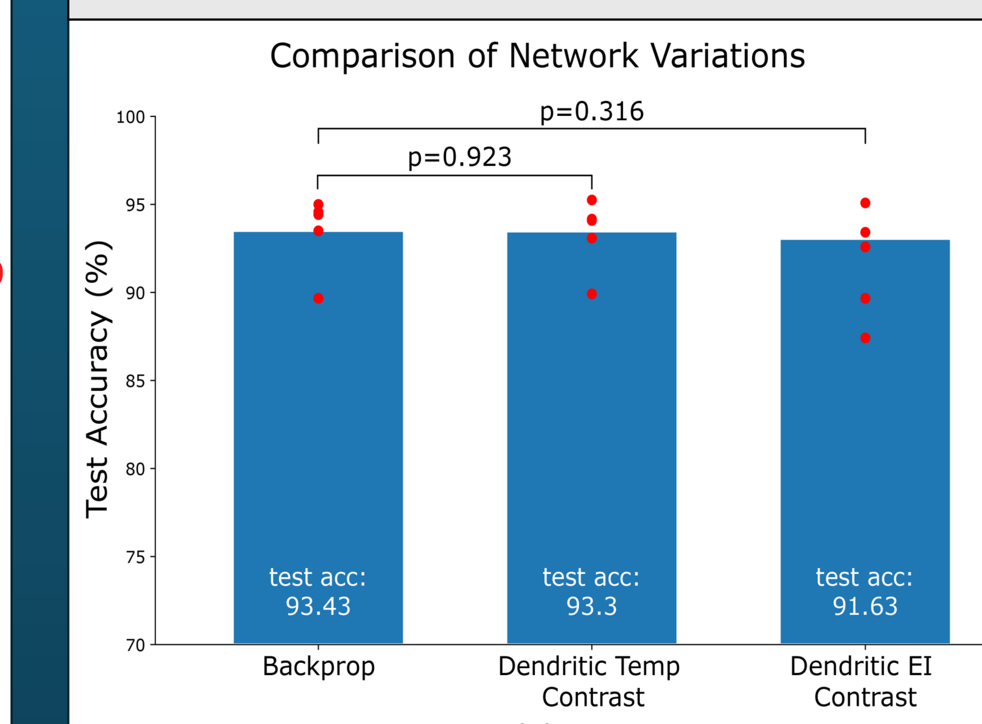

Fig 4: Comparison of validation accuracies for 3 ANNs, with p-values in comparison to Backprop

- Compartmentalizing neurons into dendrites and somas to pass error signals can be used to approximate backprop in a biologically plausible way.
- Dendrite-targeting interneurons effectively separate self-generated signals from true error signals, to accurately approximate the gradient.

Future Directions

1. Learn top-down weights on the backward pass instead of using the transpose matrix.
2. Use separate excitatory and inhibitory neurons to make network more biologically plausible.

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References

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