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Virtual, October 10-21, 2020

CAS

Metaplasticity in Multistate Memristor Synaptic Networks

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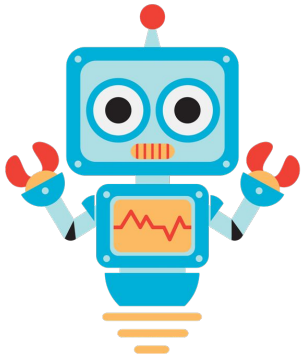
Rochester Institute of Technology

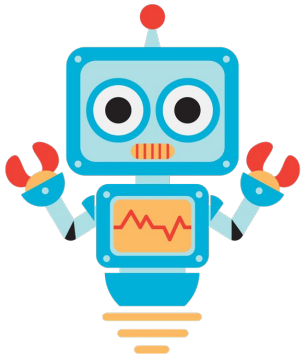
Motivation

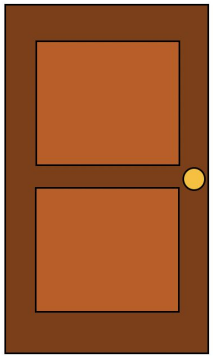


A Robot...

[1] https://commons.wikimedia.org/wiki/File:Robot-clip-art-book-covers-feJCV3-clipart.png

Motivation

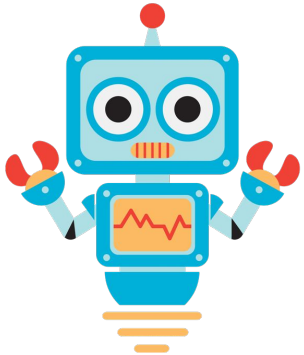


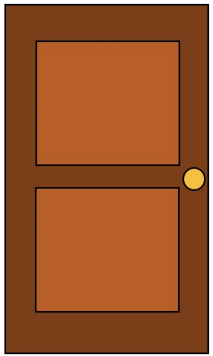


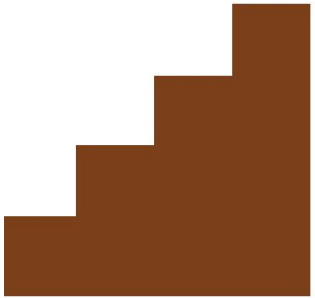
……trained to open a doorknob...

[1] https://commons.wikimedia.org/wiki/File:Robot-clip-art-book-covers-feJCV3-clipart.png

Motivation



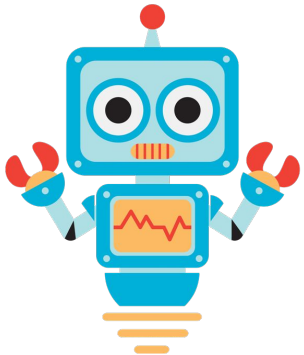


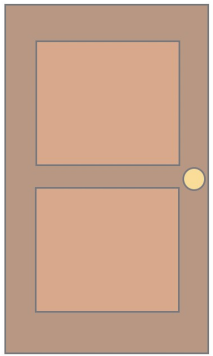


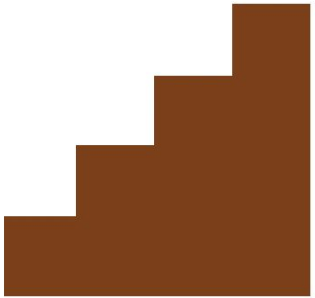
... learns to climb the stairs next.

[1] https://commons.wikimedia.org/wiki/File:Robot-clip-art-book-covers-feJCV3-clipart.png

Motivation





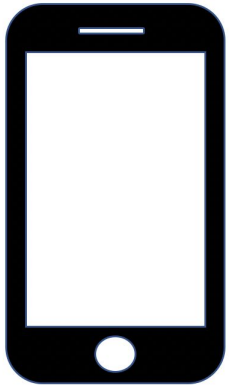


The robot forgets how to open a doorknob!

[1] https://commons.wikimedia.org/wiki/File:Robot-clip-art-book-covers-feJCV3-clipart.png

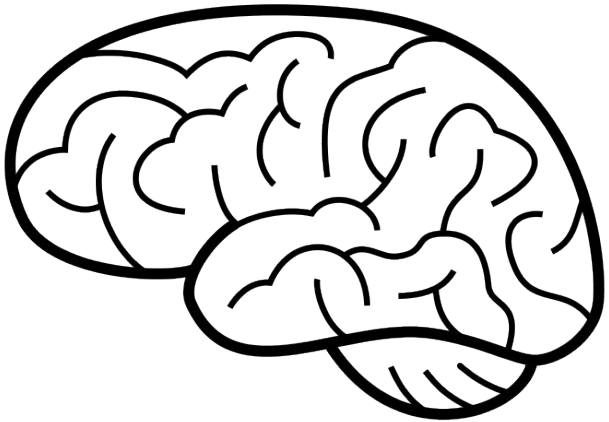
Motivation

Resource-constrained platforms prohibit heavy-duty solution



[2] https://pixabay.com/illustrations/thing-things-gadget-drone-drones-5389680/

Motivation



- Metaplasticity is deemed crucial for memory retention in biological synapses
- Incorporating metaplasticity in synaptic devices can lead to energy-efficient neuromorphic systems

[3] https://commons.wikimedia.org/wiki/File:IIIBalesIIIlogo.gif

Contribution

- To emulate binary metaplastic synapses leveraging device characteristics of memristor
- To demonstrate its efficacy in a 5 by 3 crossbar circuit architecture
- To conduct high level simulation of a 128 by 128 network incorporating hardware constraints

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Simple vs. Metaplastic Binary Synapse

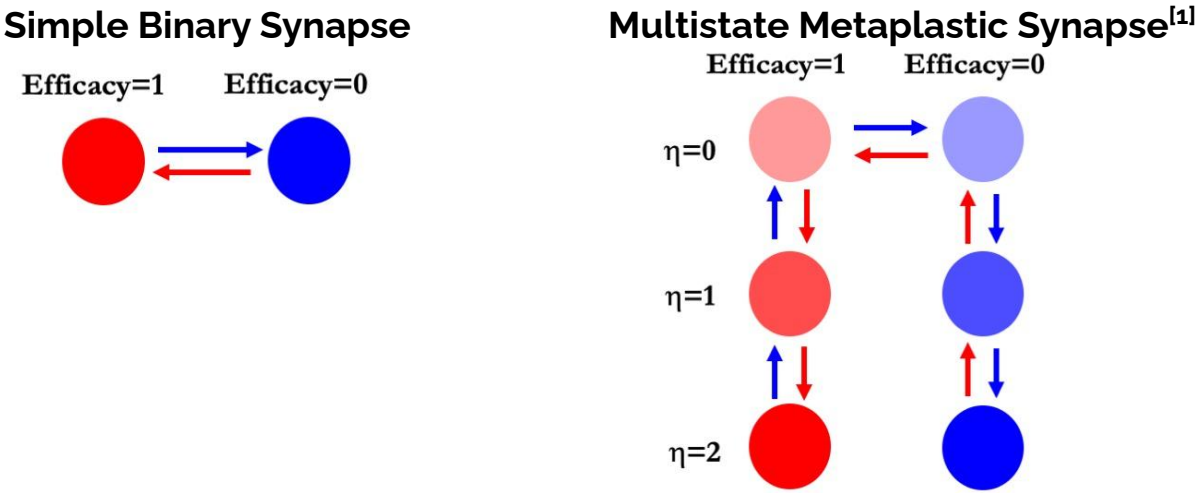

Fig: Simple and Metaplastic binary synapses

[4] C. Leibold and R. Kempter, "Sparseness constrains the prolongation of memory lifetime via synaptic metaplasticity," Cerebral Cortex, vol. 18,no. 1, pp. 67–77, 2007

Analysis of the Effects of Metaplasticity on Continual Learning

Experimental Set-up

- Feedforward network, N_{in} neurons are connected to N_{out} neurons through sparsely connected synapses (c % connectivity)
- Input patterns has f % activity
- McCullogh-Pitts neuron with threshold $cfN_{in}/2$
- Training through perceptron learning rule
- Learning accuracy and mean accuracy is observed

Experimental Results: Learning

Binary synapses show better learning ability compared to multistate synapses

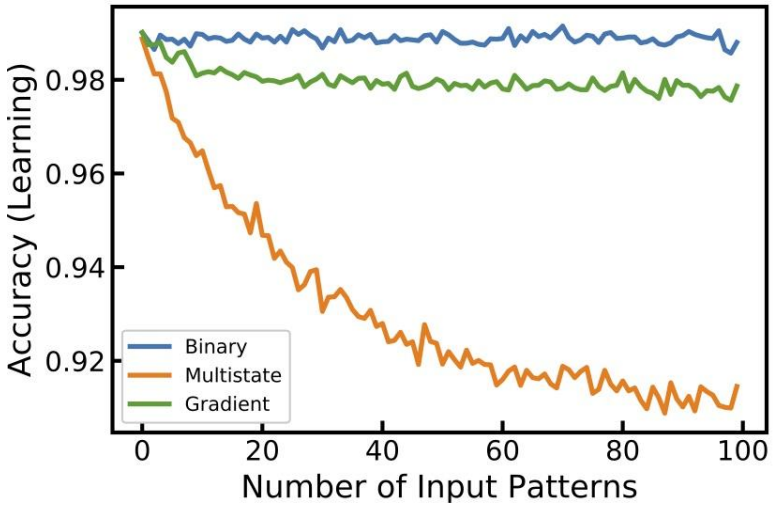

Fig: Learning accuracy of different synapses

Experimental Results: Mean Accuracy

Metaplastic synapses show much slower decay in mean accuracy

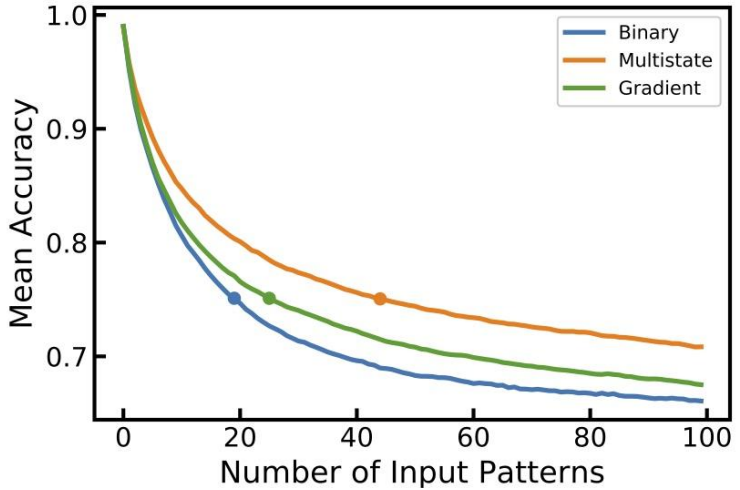

Fig: Mean accuracy of different synapses

Effect of Network Size: Learning

Increasing network size reduces the drop in learning accuracy

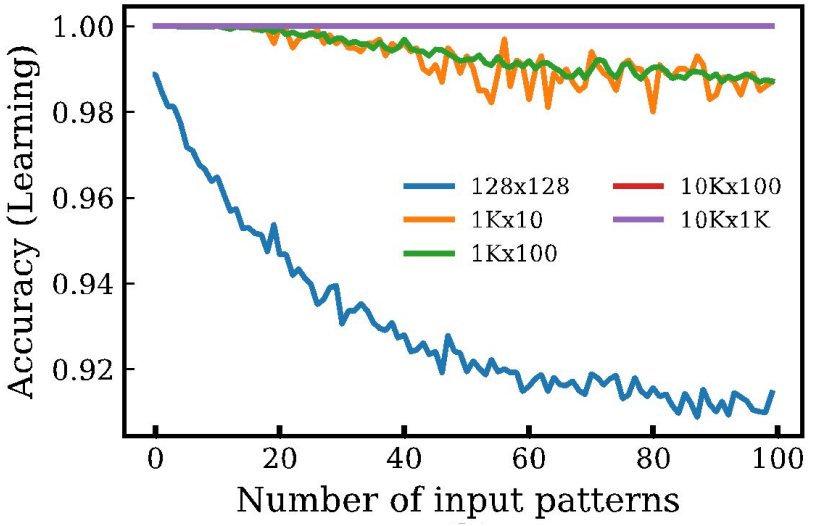

Fig: Effect of network size on learning accuracy

Effect of Network Size: Mean Accuracy

Increasing network size improves the mean accuracy

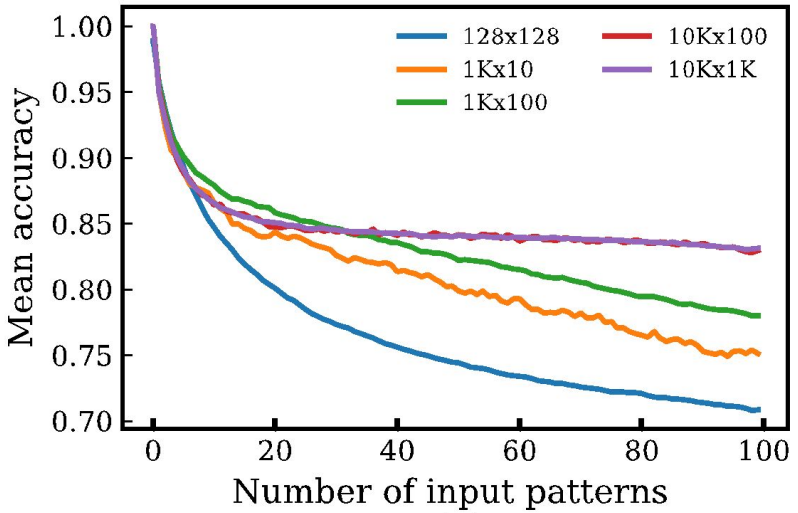

Fig: Effect of network size on mean accuracy

Effect of Activity and Connectivity

Sparse input activity is conductive to high mean accuracy

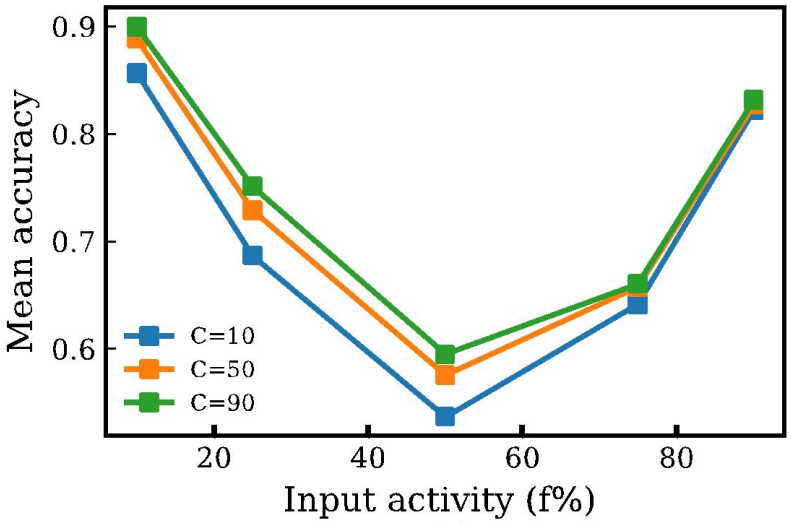

Fig: Effect of activity and connectivity on mean accuracy

Observations

- Better accuracy in detecting patterns learned over lifetime
- Degradation in learning ability
- Suitable for large networks

Realization of Metaplastic Synapse with Memristor

Metaplasticity with Memristor

- Inherent device characteristics of memristor can be utilized to realize metastates
- Non-ideal effect
  - Difference of conductance across metastates of same efficacy
  - Cycle to cycle variability

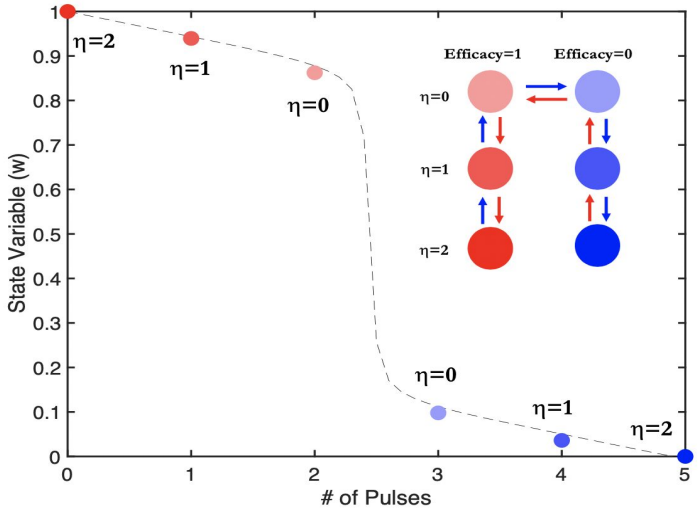

Fig: Multistate model mapped onto memristor device

[5] Y. Jiang, J. Kang, and X. Wang, "RRAM-based parallel computing architecture using k-nearest neighbor classification for pattern recognition,"Scientific reports, vol. 7, p. 45233, 2017

Experimental Results: Learning

Multistate synapse realized with memristor also shows degradation in learning accuracy

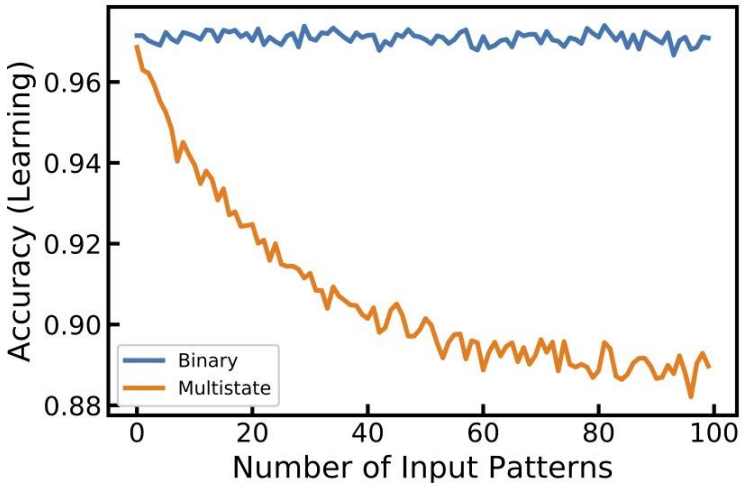

Fig: Learning accuracy for memristor synapses

Experimental Results: Mean Accuracy

Mean accuracy drops below the empirical threshold much slower in multistate model

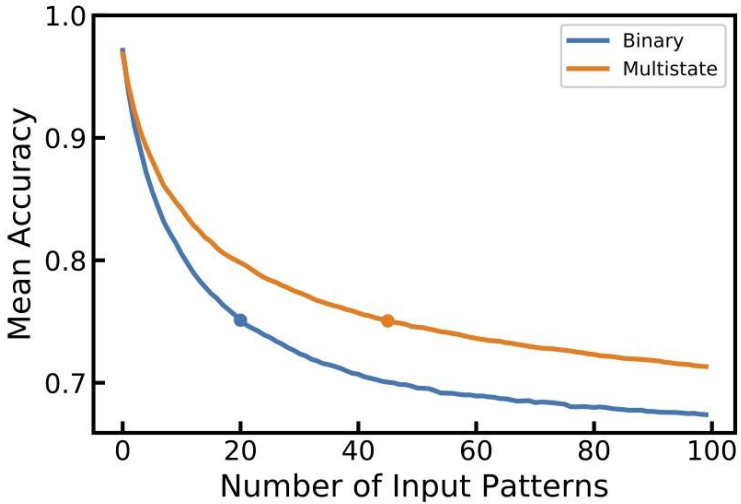

Fig: Mean accuracy for memristor synapses

System Architecture for Metaplastic Synapse with On-device Learning

Network Architecture

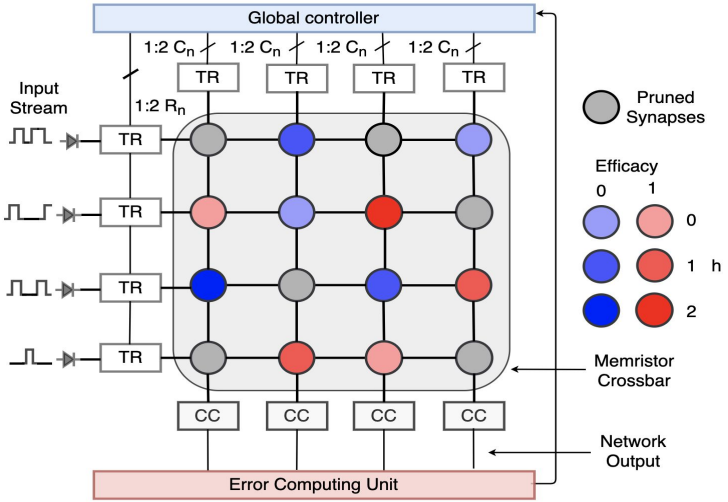

Fig: Proposed system architecture

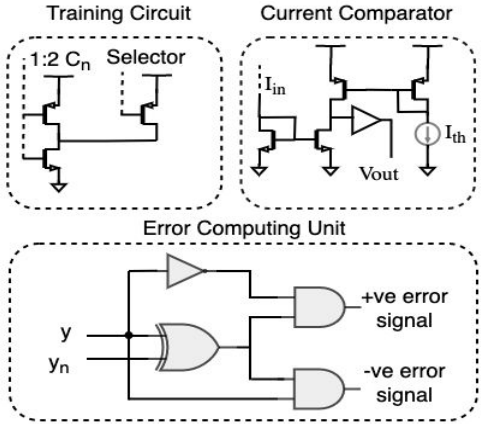

Fig:The training circuit, current comparator and the error computing unit

[6] Zyarah, A. M., Soures, N., Hays, L., Jacobs-Gedrim, R. B., Agarwal, S., Marinella, M., & Kudithipudi, D. (2017, May). Ziksa: On-chip learning accelerator with memristor crossbars for multilevel neural networks. In *2017 IEEE International Symposium on Circuits and Systems (ISCAS)* (pp. 1-4). IEEE

Training scenario

- Synapses in metalevel 0 change conductance level
- Synapses at higher metalevel remain in same conductance level but change metalevel

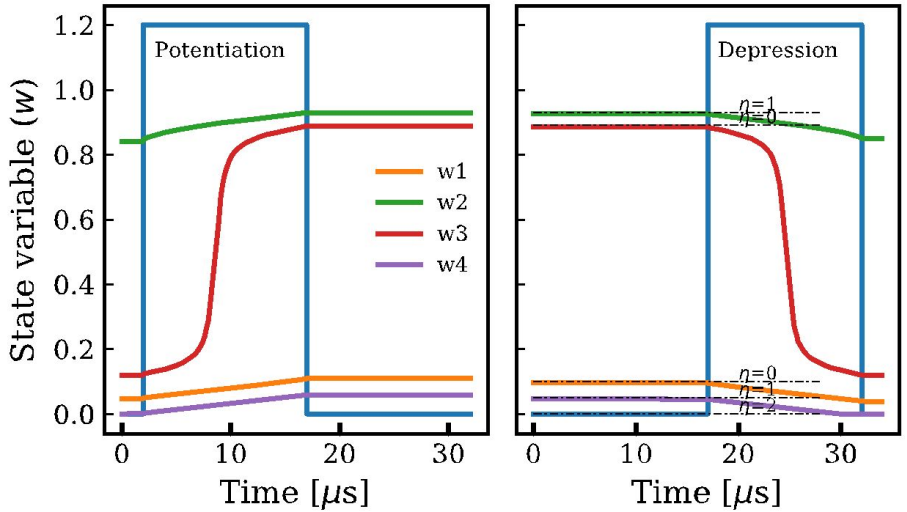

Fig: Change in metaplastic synapses with potentiation and depression

Summary

- Multistate metaplastic model is emulated using device characteristics of memristor
- High level simulation with hardware constraints shows the efficacy of the synaptic model in a 128 × 128 crossbar
- A small scale crossbar is simulated in Cadence Virtuoso

Thank you!