Memristive Nanowire Neural Networks

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Why Neuromorphic Hardware?

- Enable cheap, scalable AI
- Give us valuable insights into how biological brains operate

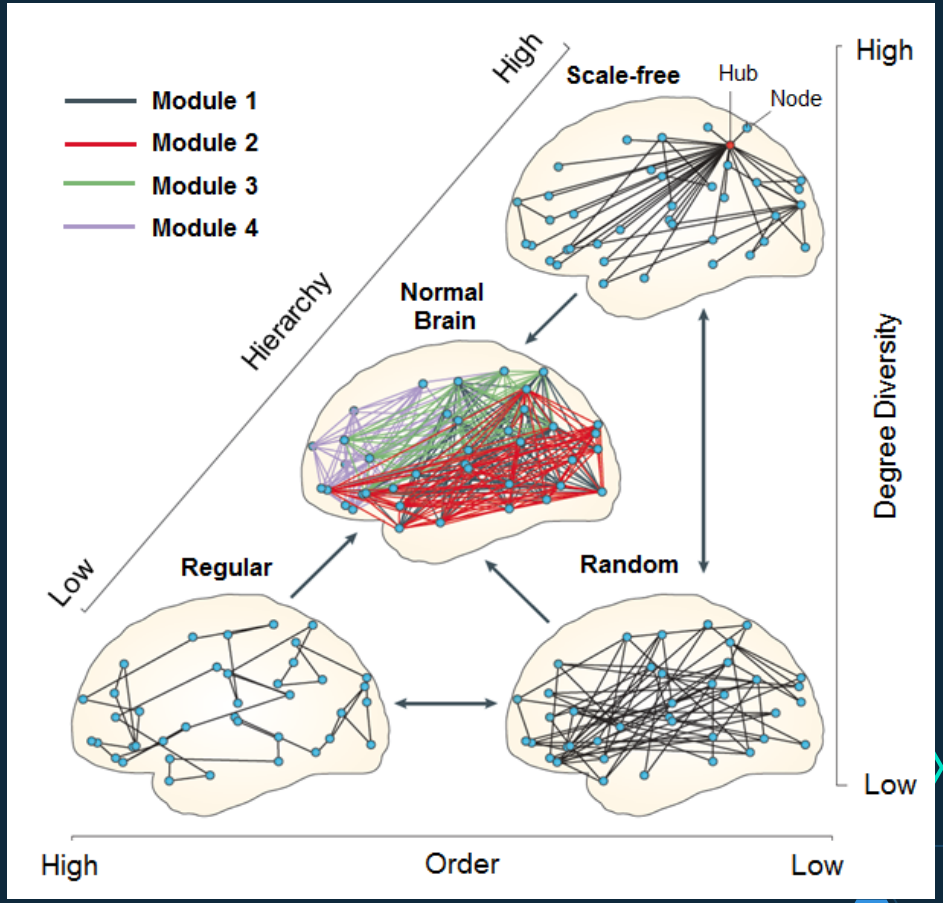
So What’s Stopping Us?

The human brain has about 10^{11} neurons. If these would all be mutually interconnected, this would result in 10^{22} synapses, an unimaginable number for which there is simply no physical space.

Francky Catthoor - imec

How does the brain do it?

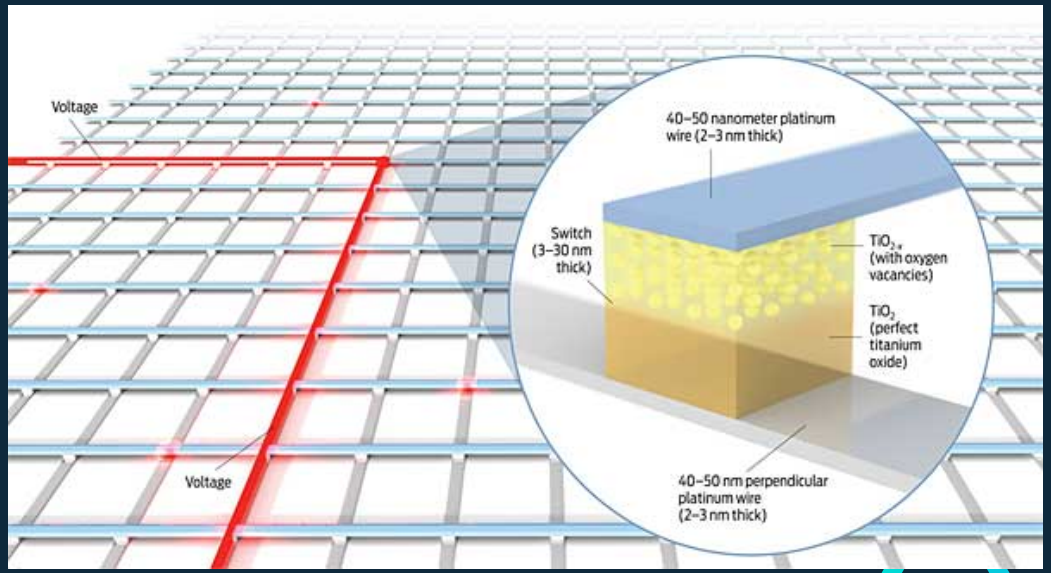
- Dense, random local connectivity
- Gradually more sparse long-distance connections



C.J. Stam, *Nature Reviews Neuroscience* (2015).

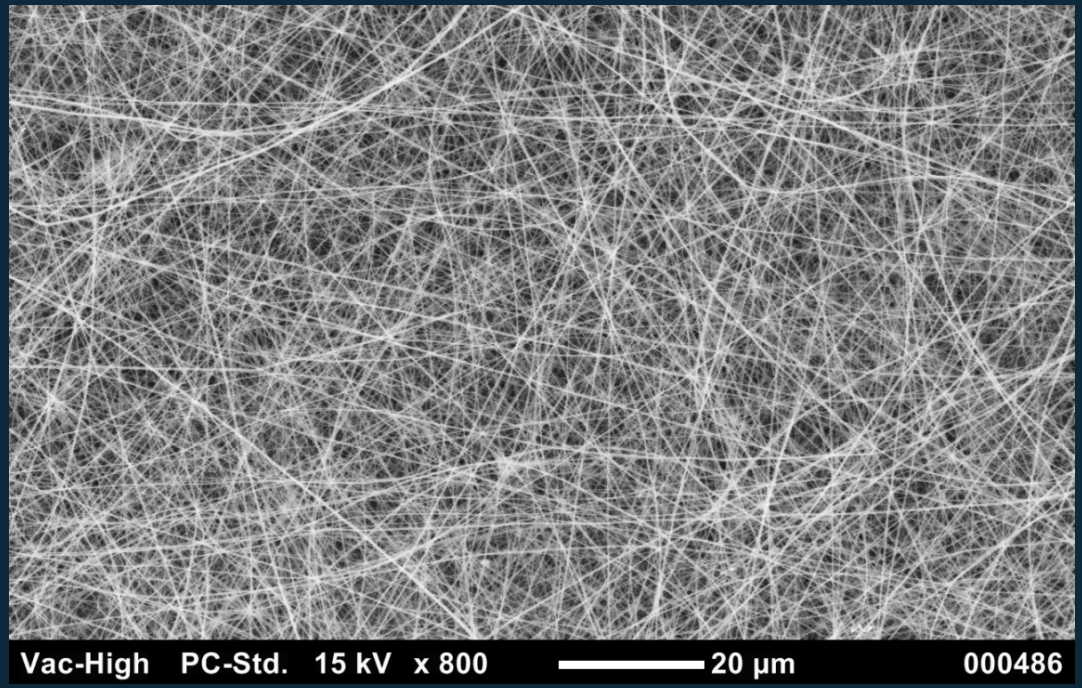
Current Methods

- Most current designs based on crossbar arrays
- Fully connected lattices scale quadratically in number of neurons



R.S. Williams, *IEEE Spectrum* (2008).

Memristive Nanowire Neural Networks (MN^3)



J.C. Nino and J.D. Kendall - PCT/US2015/034414, (2015).

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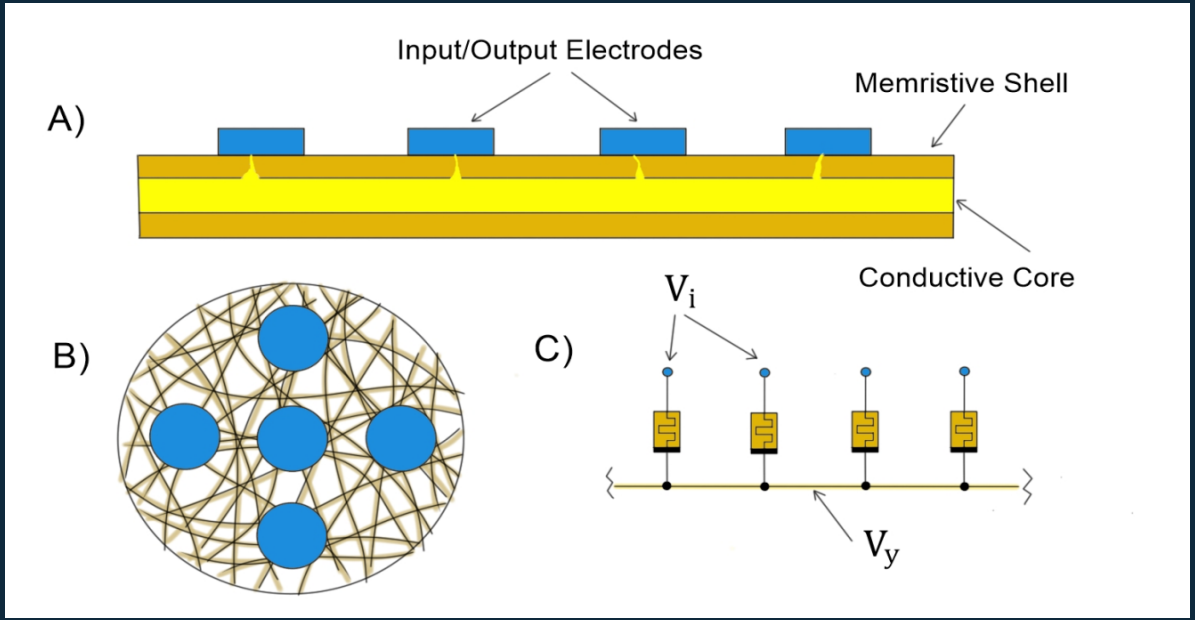
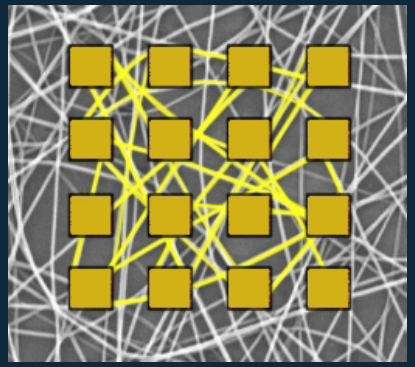


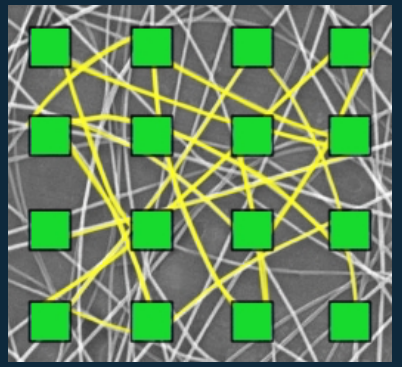
J.C. Nino and J.D. Kendall - PCT/US2015/034414, (2015).

Connectivity

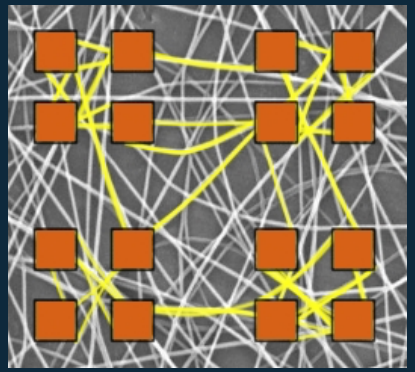
Random



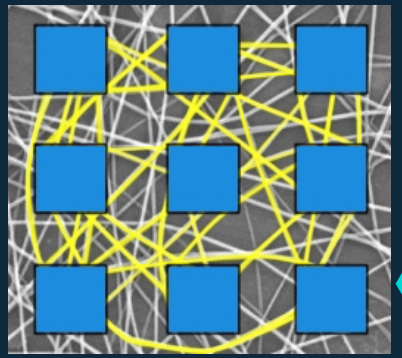
Distance Dependent



Modular

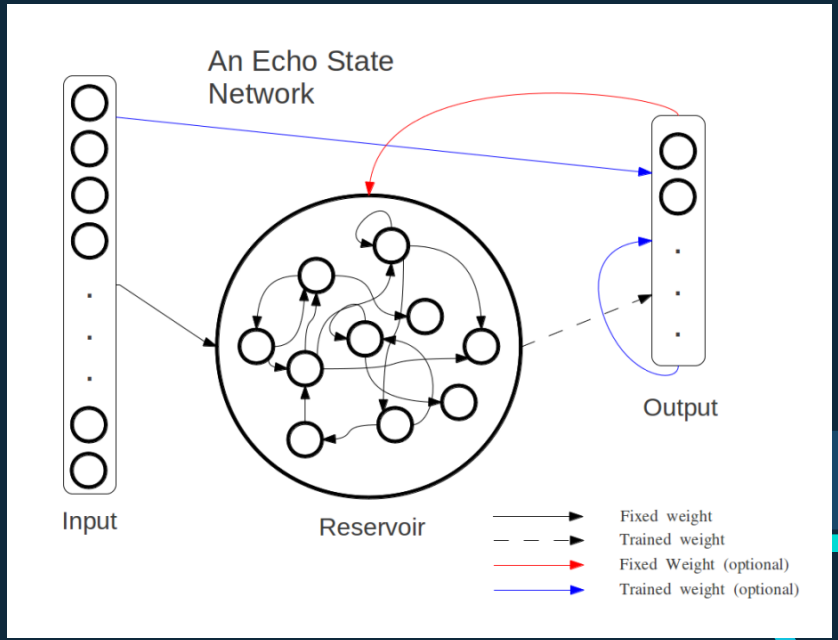


Variable Degree



Reservoir Computing

- We can use the network as the reservoir in an echo state network.
- Simulated memristive reservoir can perform classification of spoken digits.



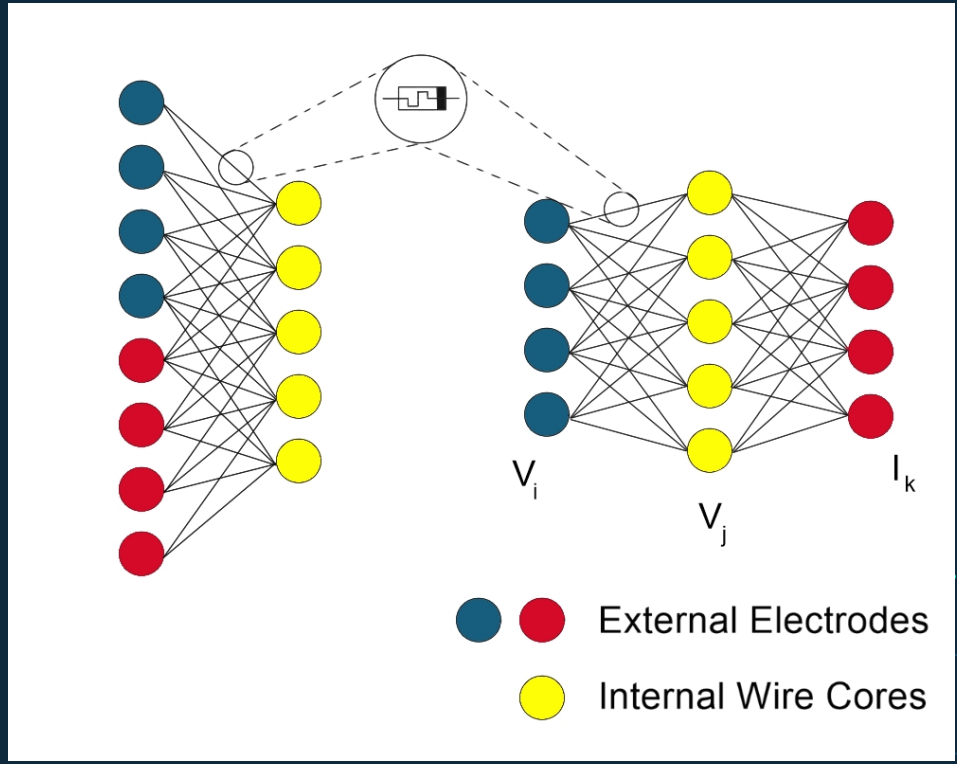
http://www.simbrain.net/Documentation/docs/Pages/Network/network/echostatenetwork.html

Feedforward Operation

$$I_j = \sum_{i=1}^{N} G_{ij}(V_i - V_j) = 0$$

$$V_j = \frac{\sum_{i=1}^{N} G_{ij} V_i}{\sum_{i=1}^{N} G_{ij}} = \frac{\sum_{i=1}^{N} G_{ij} V_i}{G_j}$$

$$I_k = \sum_{j=1}^{M} G_{kj} V_j$$

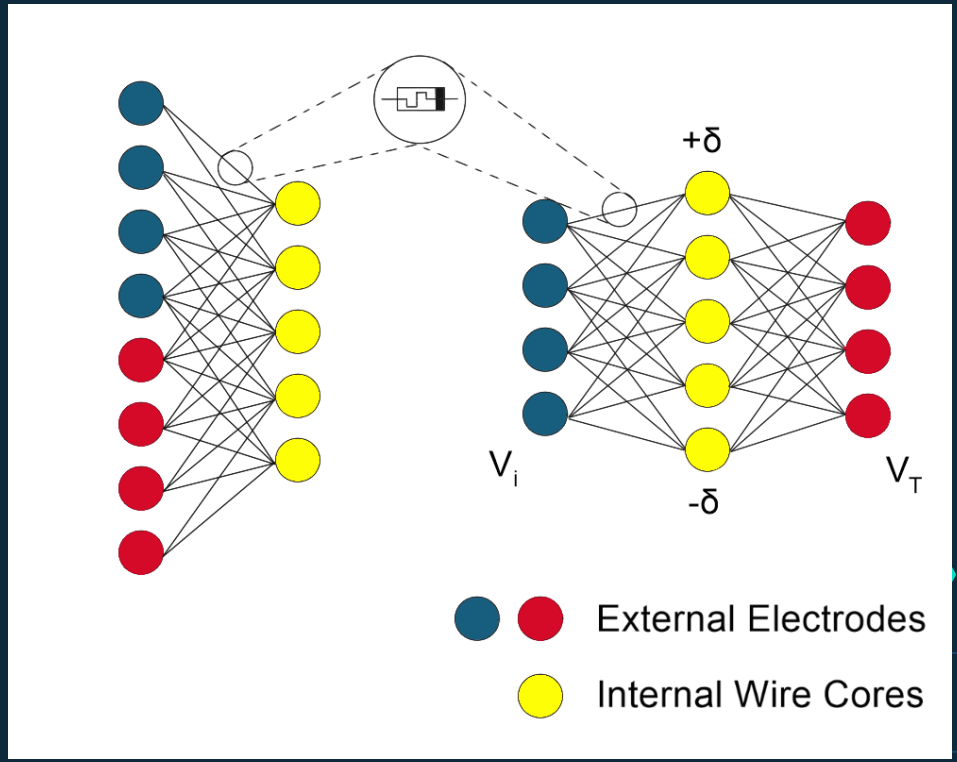


Backpropagation

$$\Delta G_{kj} = \alpha(T_k - I_k)V_j$$

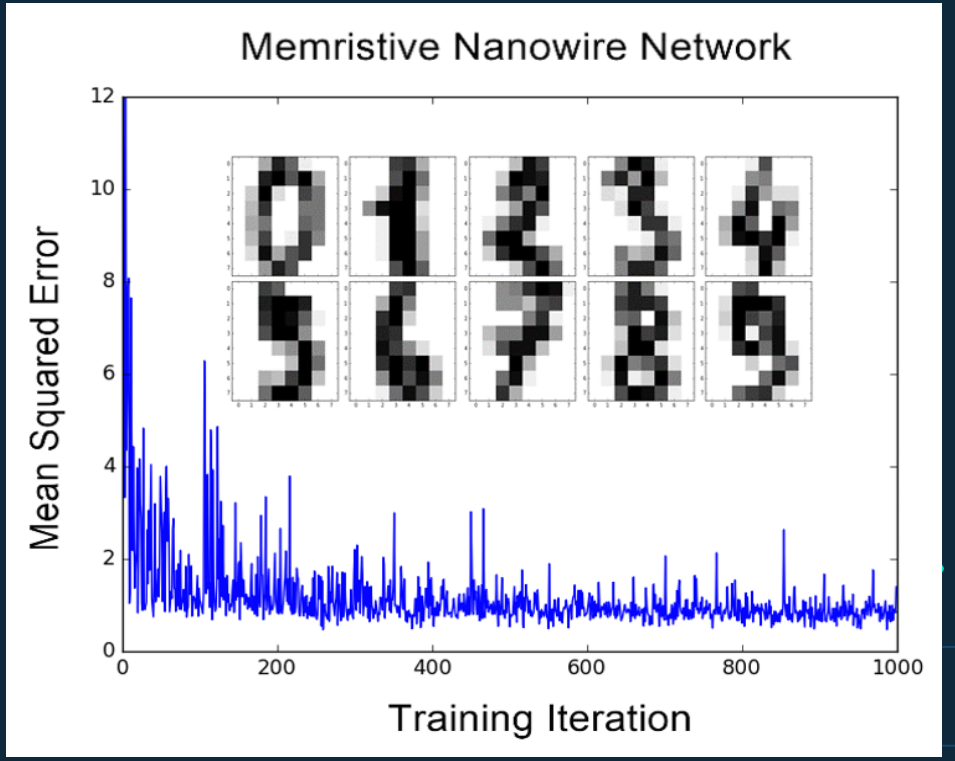
$$\Delta G_{ji} = \alpha\left(\sum_k G_{kj}(T_k - I_k)\right)V_i$$

Apply a series of threshold voltages to update the weights

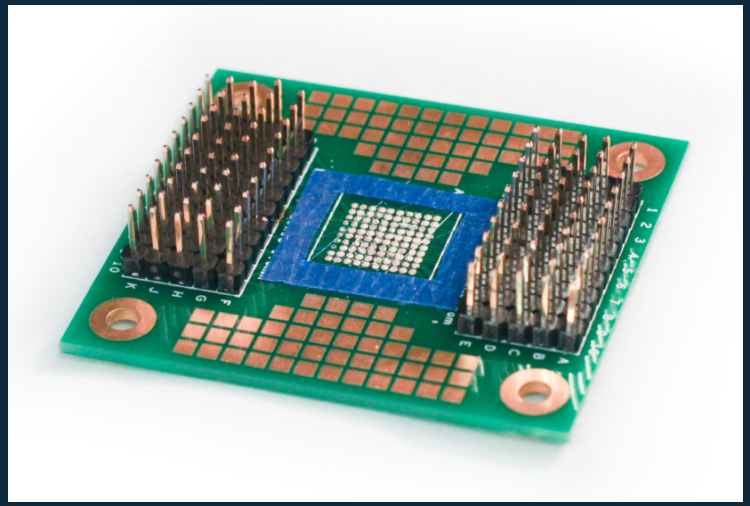


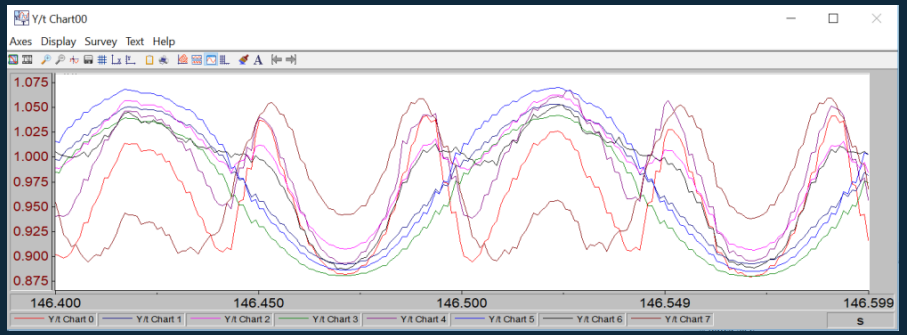
Backpropagation

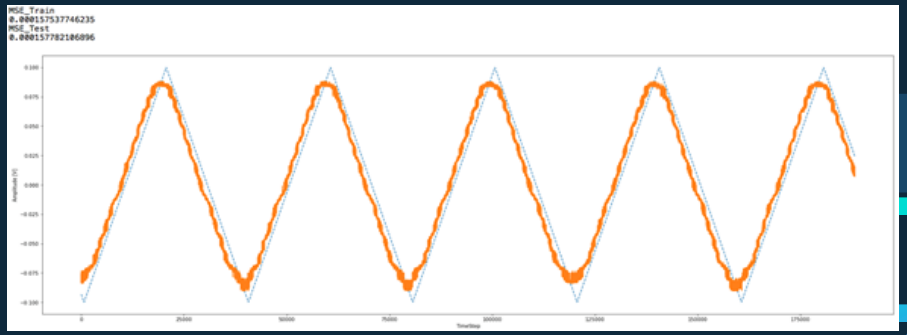
- Simulated a memristive nanowire network with metastable switch (MSS) memristors
- With our algorithm, we can achieve 90% accuracy on MNIST



Hardware Prototype







Future Work

- Implementation of backpropagation algorithm in hardware
- Classification of spoken and handwritten digits
- Nanoscale prototype with 100,000 neurons

Conclusion

- Fully scalable alternative to crossbar array
- Supports complex topologies such as small world and scale-free networks
- High neuron and synapse densities
- Trainable using backpropagation

Thank You!

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