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

Current Methods

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

Memristive Nanowire Neural Networks (MN$^3$)

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Connectivity

Random

Distance Dependent

Modular

Variable Degree
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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