On-line Learning Architectures

March 2017

Tarek M. Taha

Electrical and Computer Engineering Department
University of Dayton
C. Yakopcic, T. M. Taha, G. Subramanyam, and R. E. Pino, "Memristor SPICE Model and Crossbar Simulation Based on Devices with Nanosecond Switching Time," IEEE International Joint Conference on Neural Networks (IJCNN), August 2013. [BEST PAPER AWARD]
Memristor Backpropagation Circuit

- Online training via backpropagation circuits
- The same memristor crossbar implements both forward and backward passes
Socrates: Online Training Architecture

- Multicore processing system
- **Implements backpropagation based online training**
- Two versions: 1) memristor core and 2) fully digital core
- Has three 3D stack memory for storing training data

---

**Memristor learning core**

**Digital learning core**
We verified the system functionality by implementing the digital system on an FPGA.

NC = Neural Core  
R = Router

Actual images to and out of FPGA based multicore neural processor:
Training Efficiency

Training compared to GTX980Ti GPU

Energy Efficiency:
- Digital: 5900x
- Memristor: 70000x

Speedup:
- Digital: 14x
- Memristor: 7x
- Batch processing on GPU but not on specialized processors

<table>
<thead>
<tr>
<th>Accuracy(%)</th>
<th>GPU</th>
<th>Digital</th>
<th>Memristor</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>MNIST</strong></td>
<td>99%</td>
<td>97%</td>
<td>97%</td>
</tr>
<tr>
<td><strong>COIL-20</strong></td>
<td>100%</td>
<td>98%</td>
<td>97%</td>
</tr>
<tr>
<td><strong>COIL-100</strong></td>
<td>99%</td>
<td>99%</td>
<td>99%</td>
</tr>
</tbody>
</table>
Inference Efficiency

Inference compared to GTX980Ti GPU

Energy Efficiency:
- Digital: 7000x
- Memristor: 358000x

Speedup:
- Digital: 29x
- Memristor: 60x

Memristor learning core is about 35x smaller in area:
- Digital: 0.52 mm$^2$
- Memristor: 0.014 mm$^2$
- Studying training using memristor crossbars needs to be done in SPICE to account for circuit parasitics.
- Simulating one cycle of a large crossbar in can take over 24 hours in SPICE. (training requires thousands of iterations and hence is nearly impossible in SPICE).
- Developed a fast (~30ms) algorithm to approximate SPICE output with over 99% accuracy.
- Enables us to examine learning on memristor crossbars.
Memristor for On-Line Learning

- On-line learning requires “highly tunable” or “slow” memristors
- This does not affect inference speed
LiNbO$_3$ Memristor for Online Learning

- Device is quite slow: order of tens of millisecond switching time.
- Useful for backpropagation training.

Switching speed of devices and minimum programming pulse needed in neuromorphic training circuits.

<table>
<thead>
<tr>
<th>Approx. Switching Time</th>
<th>Switching Voltage</th>
<th>Minimum Pulse Width Required</th>
</tr>
</thead>
<tbody>
<tr>
<td>10ns</td>
<td>6</td>
<td>1ps</td>
</tr>
<tr>
<td>10ns</td>
<td>4.5</td>
<td>10ps</td>
</tr>
<tr>
<td>100ns</td>
<td>4.5</td>
<td>100ps</td>
</tr>
<tr>
<td>1µs</td>
<td>4.5</td>
<td>1ns</td>
</tr>
<tr>
<td>10µs</td>
<td>4.5</td>
<td>10ns</td>
</tr>
</tbody>
</table>
Unsupervised Clustering

- We extended the backpropagation circuit to implement auto-encoder based unsupervised learning in memristor crossbars.

- These graphs show the circuit learning and clustering data in an unsupervised manner.
Application: Cybersecurity

- The autoencoder based unsupervised training circuits were used to learn normal network packets.
- When the memristor circuits were presented with anomalous network packets, these were detected with a 96.6% accuracy and a 4% false positive rate.

- Could also implement rule based malicious packet detection (similar to SNORT) in a very compact circuit.

Regex: `user\s[^\n]{10}`
Application: Autonomous Agent for UAVs

- Cognitively Enhanced Complex Event Processing (CECEP) Architecture

- Geared towards autonomous decision making in a variety of applications including **autonomous UAVs**

- Exploring implementation on:
  - IBM TrueNorth processor
  - Memristor circuits
  - High performance clusters: CPUs and GPUs
Parallel Cognitive Systems Laboratory

Research Engineers:
• Raqib Hasan, PhD
• Chris Yakopcic, PhD
• Wei Song, PhD
• Tanvir Atahary, PhD

Doctoral Students:
• Zahangir Alom
• Rasitha Fernando
• Ted Josue
• Will Mitchell
• Yangjie Qi
• Nayim Rahman
• Stefan Westberg
• Ayesha Zaman
• Shuo Zhang

Master’s Students:
• Omar Faruq
• Tom Mealy

Sponsors:

http://taha-lab.org