Physical Neural Networks

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Presentation Overview

- Motivation and Context
- Historical Perspective
- State-of-the-Art
- Future Prospects
What are physical neural networks?

Physical Neural Networks can be broadly described as any physical circuit built to emulate the neural connections of a brain.
Why use neural networks?

Neural networks have been successful both because of their parallelism that enabled implementation on GPUs and because of their versatility at a variety of tasks, from beating humans at games, identifying photos, and natural language processing.
[7] A million spiking-neuron integrated circuit with a scalable communication network and interface. DOI: 10.1126/science.1254642
Why use physical neural networks?

- Energy Considerations drive modern computing advances, and physical neural nets could improve energy efficiencies.
- “Torturing the medium”
- Offers a new paradigm for computing
Why use physical neural networks?

Historical and extrapolated switching energy. Figure. Frank (2005b, slide 9)

Proposal For Neuromorphic Hardware Using Spin Devices. Mrigank Sharad, Charles Augustine, Georgios Panagopoulos, Kaushik Roy
Advantages/Disadvantages

Physical Neural Networks (PNNs) are still being developed, so their advantages and disadvantages are commensurate with other developing technologies. The most important features are:

- “economy of scale”
- Energy savings
- Flexibility in training (both good and bad)
- New paradigm
How do neural nets work?

By adding enough nodes, a neural network can learn \textbf{any} relationship between the training set and the output.
How do physical neural nets work?

Modern chips are:

• Asynchronous
• Spiking neuron
• Integrated with von Neumann machines
• Large scale

Fig. 4. Benchmarking power and energy. (A) Example network topology used for benchmarking power at real-time operation. Nodes represent cores, and edges represent neural connections; only 64 of 4096 cores are shown. (B) Although power remains low (<150 mW) for all benchmark networks, those with higher synaptic densities and higher spike rates consume more total power, which illustrates that power consumption scales with neuron activity and number of active synapses. (C) The total energy (passive plus active) per synaptic event decreases with higher synaptic density because leakage power and baseline core power are amortized over additional synapses. For a typical network where neurons fire on average at 20 Hz and have 128 active synapses (marked as * in (B) and (C)), the total energy is 26 pJ per synaptic event.

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How do physical neural nets work?

Emulation of neural network using spin-CMOS hybrid circuit: In each neuron, the MTJ acts as the firing site, i.e., the nucleolus; DWM stripe can be compared to cell body and its spin polarization state is analogous to electrochemical potential in the neuron cell body which affects ‘firing’, the CMOS detection unit can be compared to axon that transmits electrical signal to the receiving neuron, and finally a weighted transistor acts as synapse as it determines the amount of current injected into a receiving neuron.

Proposal For Neuromorphic Hardware Using Spin Devices. Mrigank\` Sharad, Charles Augustine, Georgios Panagopoulos, Kaushik Roy
Historical Perspective

- 1943. McCulloch and Pitts model neurons with electrical circuits
- 1948. Turing describes “Intelligent Machinery” with artificial neurons
- 1949. Hebb writes “The Organization of Behavior” and notices that neural pathways are strengthened at each use.


Historical Perspective

• 1959. Widrow and Hoff develop “ADELINE” and “MADALINE” (Multiple ADAdaptive LINear Elements). MADALINE used an adaptive filter that eliminates echoes on phone lines.
• 1972. Kohonen and Anderson independently describe arrays of analog PNNS

Historical Irony

John von Neumann suggested the imitation of neural functions by using telegraph relays or vacuum tubes.

What is being done now?

- 2014. IBM has published a neuromorphic chip, “True North”, that implements 1 million neurons.

[7] A million spiking-neuron integrated circuit with a scalable communication network and interface. DOI: 10.1126/science.1254642

[8] Loihi: A Neuromorphic Manycore Processor with On-Chip Learning. DOI: 10.1109/MM.2018.112130359
What is being done now?

The design process for the True North Chip.

[7] A million spiking-neuron integrated circuit with a scalable communication network and interface. DOI: 10.1126/science.1254642
What are some prospects for Physical Neural Networks?

- Compilers
- Accessibility
- “Economy of Scale”
- Integration with von Neumann architecture
- Physical implementation of algorithms
- plasticity
What are some prospects for Physical Neural Networks?

Neuromorphic computing is continuing:
• BRAIN initiative proposed by Obama administration
• True North and Loihi
• Medical/Computer Science interest
• DARPA/DOD/DOE
References

https://trends.google.com/trends/?geo=US

[2] Historical and extrapolated switching energy. Figure. Frank (2005b, slide 9)

References

References

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[8] Loihi: A Neuromorphic Manycore Processor with On-Chip Learning. DOI: 10.1109/MM.2018.112130359