Physical Neural Networks

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COSC 594
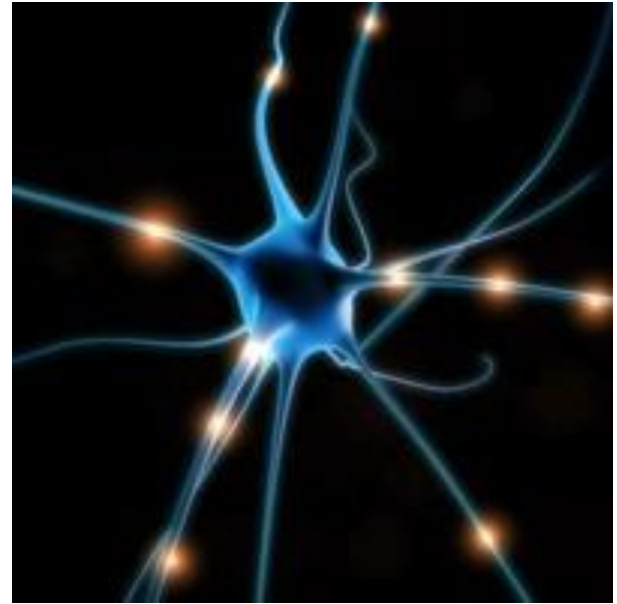
Presentation Overview

- 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.

[1]. Google Trends. https://trends.google.com/trends/?geo=US

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A

POWER 5
Pentium 4
POWER 4
AMD K7
POWER 3
POWER 2
8086
80286
80486
4004   80386
Pentium

Ivy Bridge
AMD K8
Core 2 Duo
Itanium 2
POWER 6
POWER 7
Cell
Pentium M
Itanium 2-DC
Pentium III
Pentium II
AMD K6
Pentium Pro
AMD K5

Brain

B

Memory Wall / Bottleneck

Neurons   Bus   Synapses

CPU   Memory

C

Neuron Synapses
Communication

Neuron Synapses
Communication

Neuron Synapses
Communication

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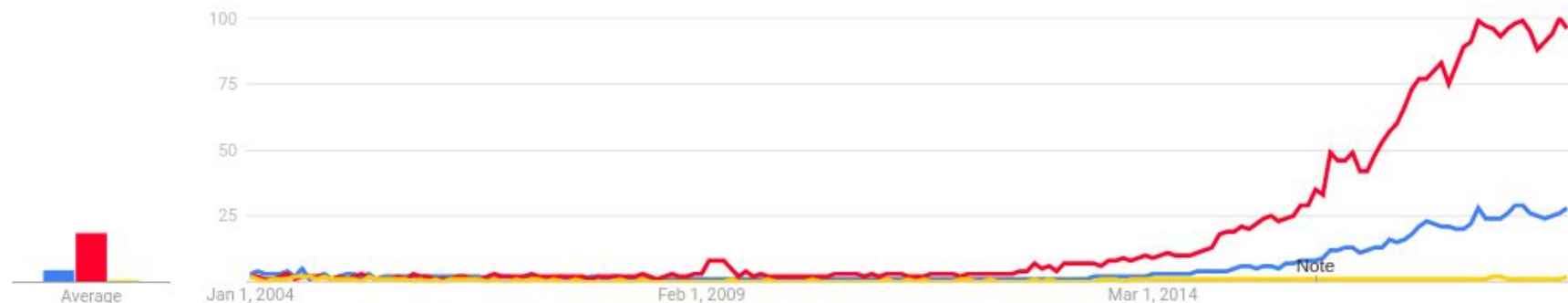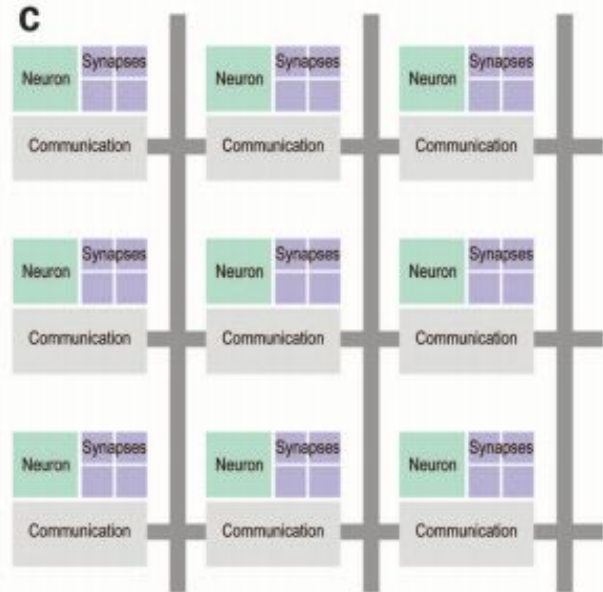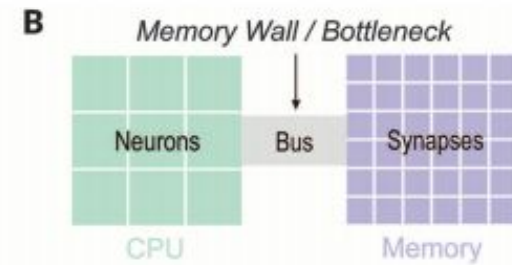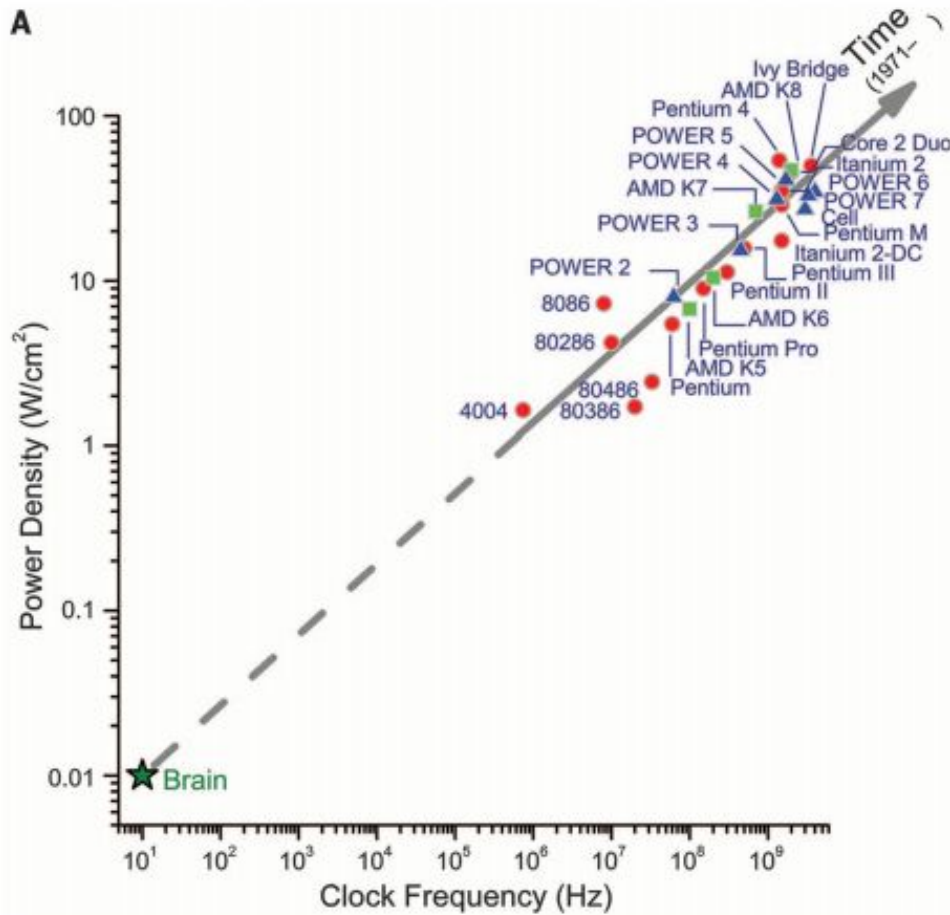
Why use <u>physical</u> neural networks?

- 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 <u>physical</u> neural networks?
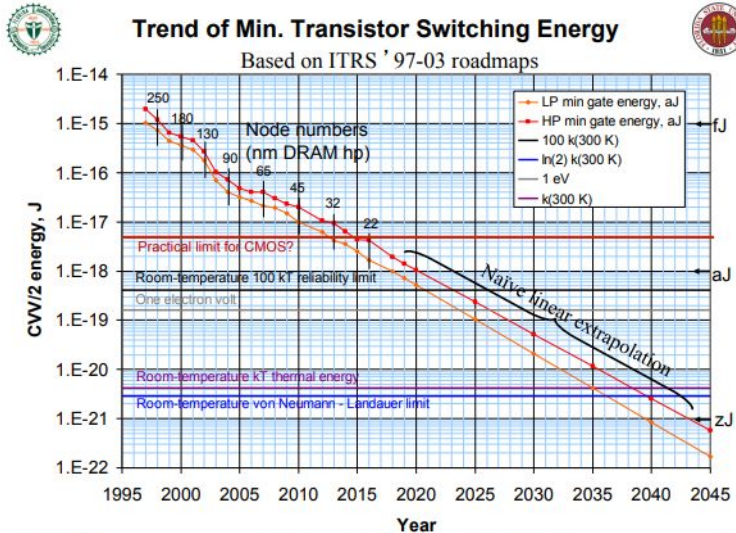
Historical and extrapolated switching energy.
Figure. Frank (2005b, slide 9)
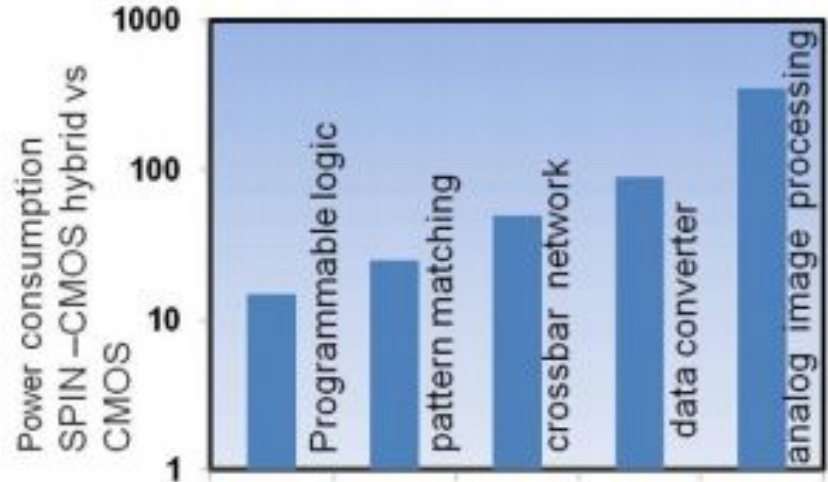
Proposal For Neuromorphic Hardware Using
Spin Devices. Mrigank` Sharad, Charles
Augustine, Georgios Panagopoulos,
Kaushik Roy

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?
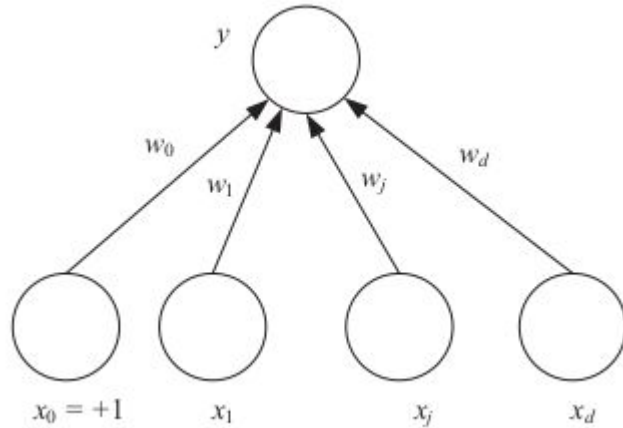
$$o_i = \mathbf{w}_i^T \mathbf{x}$$

$$y_i = \frac{\exp o_i}{\sum_k \exp o_k}$$

By adding enough nodes, a neural network can learn **any** relationship between the training set and the output.

[4] Introduction to Machine Learning. Alpaydin. 3rd Edition. Pg 271.

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How do physical neural nets work?

Modern chips are:

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

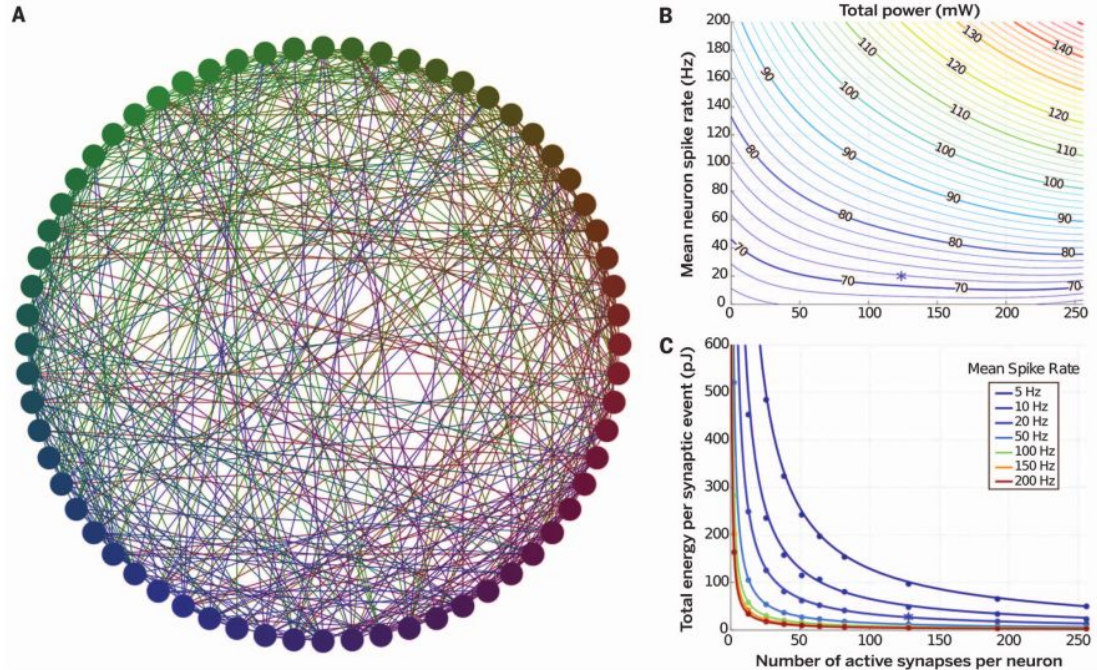**Fig. 4. Benchmarking power and energy.** (**A**) Example network topology used for benchmarking power at real-time operation. Nodes represent cores, and edges represent neural connections; only 64 of 4096 cores are shown. (**B**) Although power remains low (<150 mW) for all benchmark networks, those 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.

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

How do physical neural nets work?

Can implement __mathematically identical__ processes in physical neural nets
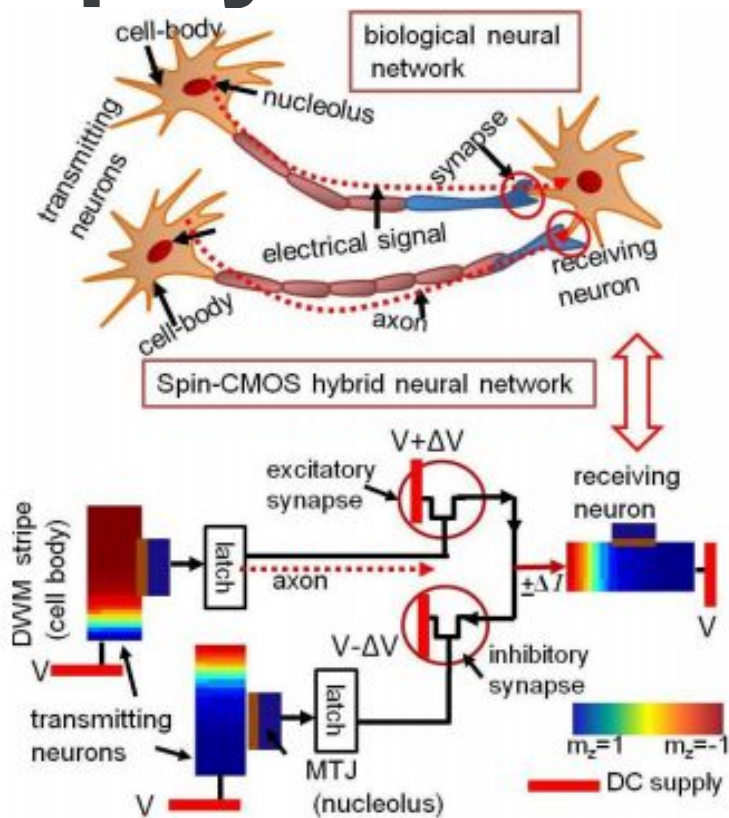
Emulation of neural network using spin-CMOS hybrid circuit: In each neuron, the MTJ acts as the firing site, i.e., the nucleolus; DWM stripe can be compared to cell body and its spin polarization state is analogous to electrochemical potential in the neuron cell body which affects 'firing', the CMOS 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.

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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.

[5] Neural Networks: History. Eric Roberts.
https://cs.stanford.edu/people/eroberts/
[6] "Intelligent Machinery". Alan Turing.

Historical Perspective

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

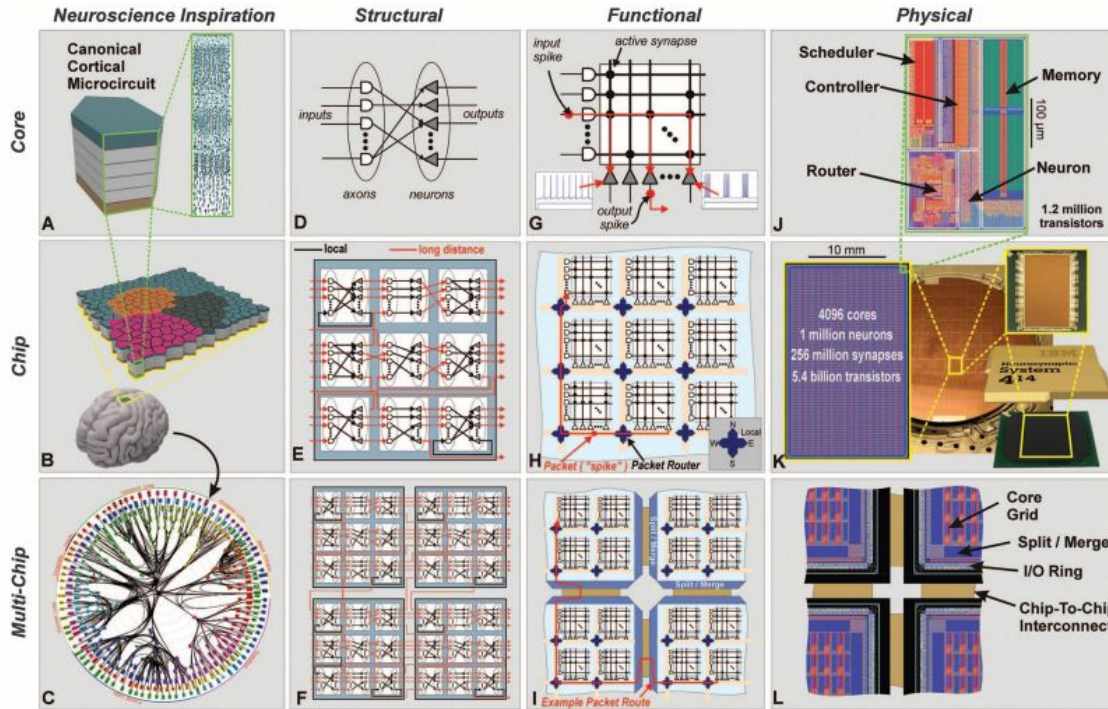[5] Neural Networks: History. Eric Roberts.
https://cs.stanford.edu/people/eroberts/

Historical Irony

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

[5] Neural Networks: History. Eric Roberts.
https://cs.stanford.edu/people/eroberts/

What is being done now?

- 2014. IBM has published a neuromorphic chip, "True North", that implements 1 million neurons.
- 2017. Intel has released a neuromorphic chip, "Loihi", that has adaptive self-modifying parallelism.

[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

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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

[1]. Google Trends. https://trends.google.com/trends/?geo=US

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

[3] Proposal For Neuromorphic Hardware Using Spin Devices. Mrigank` Sharad, Charles Augustine, Georgios Panagopoulos, Kaushik Roy

References

[4] Introduction to Machine Learning. Alpaydin. 3rd Edition. Pg 271.

[5] Neural Networks: History. Eric Roberts. https://cs.stanford.edu/people/eroberts/

[6] "Intelligent Machinery". Alan Turing. http://www.alanturing.net/turing_archive/archive/l/l32/L32-002.html

References

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

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