Execution Model: Neuromorphic Computing

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2015-12-07

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informatik die zukunft

Outline

1 Introduction

2 Benefits

3 State of the Art

4 Upcoming Technologies

5 Conclusion

6 Literature

Introduction

We all have a high performance computer in our bodies

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The brain

Figure: Model of a brain [Nuf]

The Human Brain

- Consists of ~85 billion neurons
- Neurons connected to ~10000 synapses
  - All neurons connected via 3-4 synapses
- Neurons fire at up to ~1 kHz

- Performance of up to about 1 PFlop/s
- Energy consumption of a dim lightbulb

What & Why

- What is Neuromorphic Computing?
  - Hardware concept
  - Mimics nervous systems/brains

What & Why

- What is Neuromorphic Computing?
  - Hardware concept
  - Mimics nervous systems/brains
- Why do we need Neuromorphic Computing?
  - Engineering lessons to be learned
  - Better suited for special tasks
  - Lots of applications

Benefits

Efficiency for special tasks in terms of...

- ...speed
- ...energy
- ...space

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Better than traditional computation
by orders of magnitude!

High performance computer 'K', Japan

Figure: Supercomputer 'K' by RIKEN [Ins13]

High performance computer ’K’, Japan

- Peak Performance: ~11.3 PFlop/s
- Power Consumption: ~12.7 MW
- Memory: ~1.5 PB

Brain simulation on 'K'

- Researchers simulated 1 second of 1% of brain activity
  - It took ~40 minutes
  - Consumed ~30.5 Gigajoule or ~8,500 kWh
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All this with a very simplified model of neurons and synapses

Speed efficiency

Assuming linear scaling

- It would take 66h 40min to simulate 1 second brain activity
- Even though performance of 'K' ∼10 times bigger than brain

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A Human Brain is ~**240,000** times faster than 'K'

Energy efficiency

Again, assume linear scaling

- Would use up 850 MWh to simulate 1 second brain activity
- The brain would only consume 6 mWh

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Human brains are ~**140 million** times more energy efficient than 'K'

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Assume every synapse represents one bit

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- Results in a storage capacity of 50 Terabyte

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It's not that easy to calculate brain storage capacity

(estimates at **2.5 Petabyte**)

Realization

Neuromorphic computation hardware is realized...

- Using digital or analog circuits
- Which mimic nervous systems/brains
- Very large scale integrated in microchips

Components of neuromorphic chips

- Analog or digital processor cores
- Chip interface
- Asynchronous package routing system
- Fault tolerance relaying
- Architecture specific parts

Asynchronous processing & fault tolerance

Asynchronous processing

- Event driven processing of packages
- Lessens energy consumption by orders of magnitude
- Weakens/eliminates Von-Neumann-Bottleneck

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Fault tolerance:

- Rerouting around broken neurons
- Implemented on chip

Current teams and projects

- Human Brain Project (HBP)
  - SpiNNaker
  - Spikey
- Systems of Neuromorphic Adaptive Plastic Scalable Electronics (SyNAPSE)
  - TrueNorth

Human Brain Project - SpiNNaker

- Short for "Spiking Neural Network Architecture"
- Entirely digital signal processing
- Chip utilises 18 ARM9 processors
- Die area of only 102 mm^2
- Functional SpiNNaker prototype chip in 2009
- First fully functional chips delivered in 2011

The SpiNNaker Chip

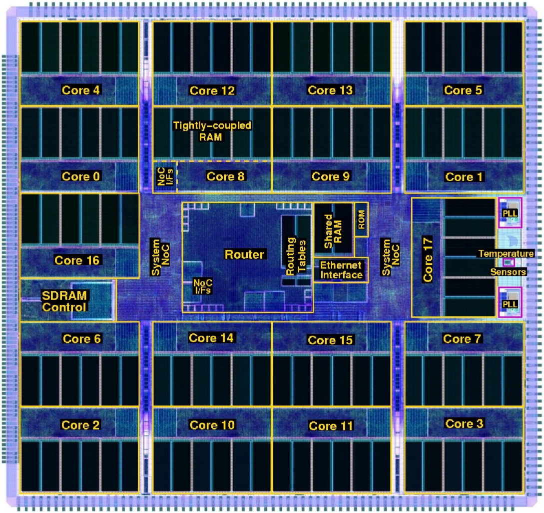

Figure: SpiNNaker Chip [Adv12b]

The SpiNNaker machine

- 1 million processor cores
- 1 billion neurons
- 1 trillion synapses
- Consumes less than 50KW on average
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Considerably better than 'K' but still not quite human-brain-level

Human Brain Project - Spikey

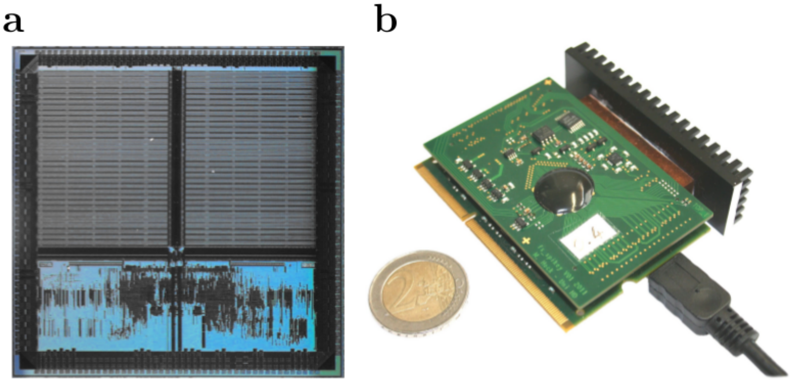


Figure: Spikey chip (a) and system with chip under sealing (b) [T+15]

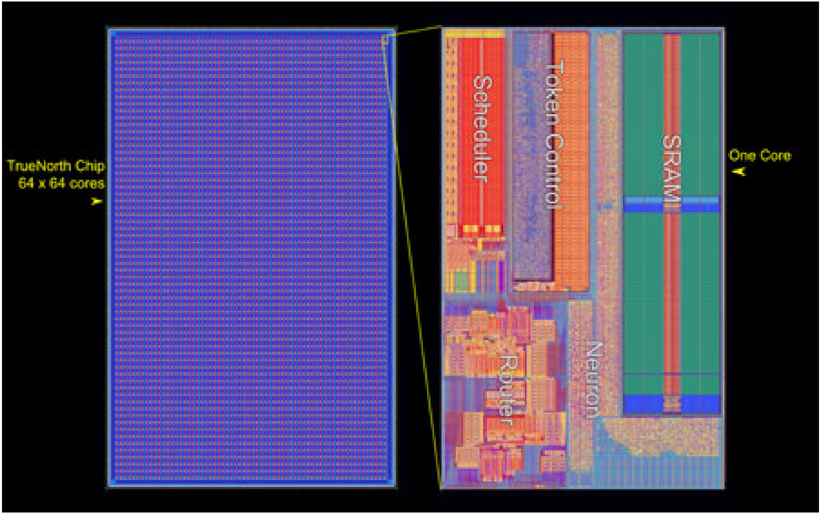
Human Brain Project - Spikey

- 25 mm^2 VLSI chip
- Analog hardware neuron and synapse realization
- Emulates 382 neurons with 256 synapses each
- Firing frequency of neurons 10^4 to 10^5 times higher than brain
- Even though analog, no memristors

SyNAPSE - TrueNorth

- Chip simulates 1 million neurons and 256 million synapses
- Consists of 4096 cores
- All digital approach
- Consumes less than 70 mW while simulating neural networks
- Already built systems of 16m neurons and 4b synapses
- Goal of 4b neurons and 1t synapses system, consuming 4KW

SyNAPSE - TrueNorth



The Memory Resistor

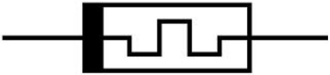


Figure: Symbol of a memristor [Jos14]

- Two terminal fundamental circuit Element
- The more intensely it is used, the lesser its resistance
- Raising resistance again by reversing current
- Remembers resistance when voltage turned off (non-volatile)

Memristor half adder

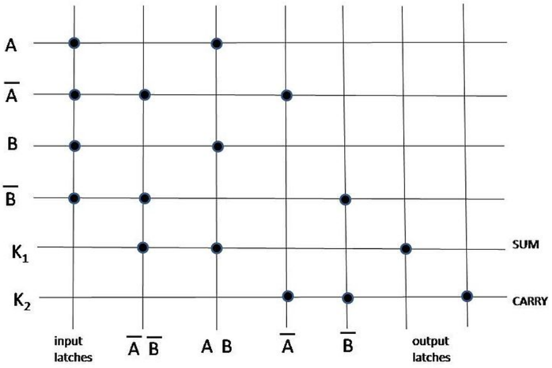
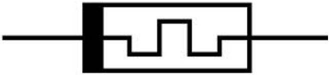


Figure: Crossbar latch architecture for half-adder [Blm08]

"The Machine" - Hewlett Packard

- Revolutionary computer architecture with usage of memristors
- 'K' uses 12,600 KW with 28.8 GUPS
- 'The Machine' should only consume 160 KW for 160 GUPS
- HP suggests 'The Machine' for exascale computing

The Memory Resistor



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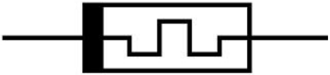

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Essentially a model of a synapse

The Neuristor

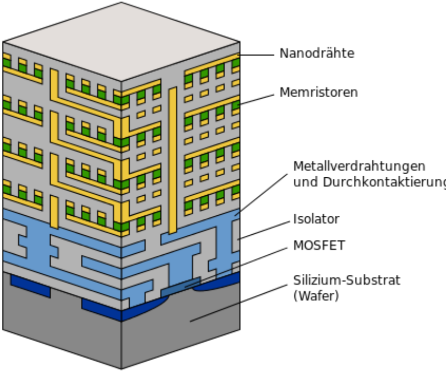

Figure: Neuristor concept [Mov14]

Memristors in Neuromorphic Computing

- One memristor is used for one synapse
- Memristors are fundamental circuit elements, therefore
  - small (cubes of 3nm edge length)
  - energy efficient
- Much faster than traditional approach of many transistors

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A very promising concept for Neuromorphic Computing

Prospect of Memristors in NC

- Current development of CrossNets in hybrid NC
- Faster processing rate than human brain
- Possibility of higher neuron density
- Higher but still manageble energy consumption

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University of California, Santa Barbara active research:

- 100 neuron memristive NC system
- Able to do simple image recognition tasks

Applications

- Further extension of Moore's Law
- Understanding the human brain
- Brain prosthetics for neurodegenerativ diseases
- Face, Speech, Object recognition
- Language interpretation
- Robotic terrain manuevering
- Virtually any tasks where humans are better than computers

Conclusion

- Neuromorphic computing is very young
- Has much potential to be revolutionary
- Breakthroughs expected in less than 15 years

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"As engineers, we would be foolish to ignore the lessons of a billion years of evolution"

— Carver Mead, 1993

Questions?

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Memristor - The missing element

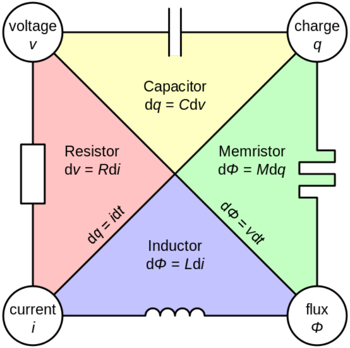

Figure: The four fundamental electronic variables and devices. [Par13]

Titanium Dioxide Memristor

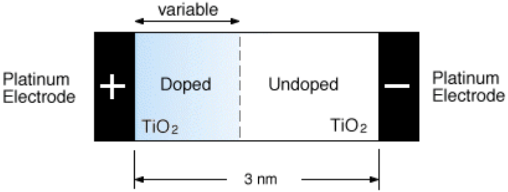

Figure: Titanium Dioxide Memristor [Jim10]