Introduction

- Neuromorphic hardware uses the concept of VLSI systems consisting of electronic analog circuits to imitate neurobiological architecture in the nervous system.
- The term, *Neuromorphic*, is used to describe analog, digital, analog/digital VLSI, and any other software system implementing models of neural systems.
- Hardware perspective: neuromorphic computing made possible by oxide-based memristors, threshold switches, and transistors.
- Topic of neuromorphic computing targets researchers in multiple fields such as computational neuroscience & machine learning.
Motivation

- Neuromorphic hardware paves a path towards human-level artificial intelligence

- Despite years of research into AI, there still remain several tasks that humans find simple that computers cannot do, but today’s concept of neuromorphic chips offer a path to realizing human-level artificial intelligence
Key features

Desirable Computation

How information is portrayed

Robustness against local failures

Emphasizes Learning and Development

Facilitate Evolutionary Change

Future of AI is neuromorphic

More Efficient in Energy and Execution Speed
Low Power Consumption

- Neuromorphic chips require far less power to process AI algorithms
  - One neuromorphic chip made by IBM contains 5 times as many transistors as a standard Intel processor, but consumes just 70 milliwatts of power whereas an Intel processor would require anywhere from 35 to 140 watts (up to 2000 times more power)
- Human brain consumes only 20 watts of power whereas a supercomputing complex is capable of simulating a small fraction of the brain consume millions of watts
  - Computers operate at higher frequencies than the brain & power consumption grows with the cube of frequency
  - Digital circuitry consumes more power than analog
  - Today’s chips require all signals be perfectly synchronized by a central clock, requiring a timing distribution system, complicating circuit design & thus increasing power consumption by up to 30%
Low Power Consumption

- Copying the brain’s energy efficient features makes for economic sense and is the motivation behind development of neuromorphic chips
  - Low frequencies
  - Massive parallelism
  - Analog signals
  - Asynchronicity
Fault Tolerance

- Neuromorphic chips are fault-tolerant like the brain
  - If a few components fail, chip continues to function normally

- Some neuromorphic chip designs can maintain defect rates as high as 25%
  - Very different from today’s computer hardware where failure of a single component results in making the entire chip unusable

- Need for precise fabrication have increased cost of chip production as component sizes have become smaller
  - Neuromorphic chips require lower fabrication tolerances & are cheaper to make
Developing Products

- Apple, Google, Microsoft, NVIDIA, Intel have created chips for image recognition & other deep learning tasks
- Intel have taken a step further
  - Experimental chip called “Loihi” uses neuromorphic tech that is modeled after the Human brain instead of raw computations
Background on Human Brain

- Brain function by relaying information with pulses or spikes & storing changes locally at synapse interconnections
- Pulses/spikes strengthen neural connections
- Keypoint: brain cells don’t function on its own
  - Activity of one neuron directly affects other neurons
  - Thus, groups of cells working together leads to learning and intelligence
How Intel’s Loihi Chip Work

- Instead of using logic gates, Intel uses “spiking neurons” as the core computing unit.

- “Spiking neurons” can pass along signals of varying strength just like the neurons in human brains and can also fire when necessary rather than being controlled by CPUs.

- Intel’s Loihi chip has around 130,000 simulated neurons with 130 million possible synaptic connections.
  - More complex than a lobster’s brain but way less than our own brains.
How Intel’s Loihi Chip Work

- Traditional CPUs process instructions based on clocked time
  - Info is transmitted at regular intervals
- By packing in digital equivalents of neurons, neuromorphics communicate in parallel and without dependence on clocked time through the use of spikes
  - Spikes are bursts of electric current that can be sent when necessary
- Like our brains, Loihi Chip’s neurons communicate by processing incoming flows of electricity
  - Each neuron is able to determine from incoming spike whether to send current out to the next neuron
Nengo

- Nengo: a compiler developers can use to build their own algorithms for AI applications that can operate on general purpose neuromorphic hardware
- Nengo is useful for its use of familiar Python programming language and its ability to put algorithms on various hardware platforms, including neuromorphic chips
  - Anyone with an understanding of Python can build sophisticated neural nets made for neuromorphic hardware
- Vision systems, speech systems, motion control & adaptive robotic controllers have been built with Nengo
Spaun

● Most impressive system built using Nengo

● A project in 2012 that achieved international praise for the most complex brain model ever simulated on a computer

● Spaun proved that computers could be made to easily interact with the environment & perform human-like cognitive tasks such as recognizing photos and controlling a robot arm that writes down what it sees

● By using neuromorphics, Spaun has been run 9000x faster, using less energy than it would on CPUs
Issues
---

- Basis of neural networks is heavily backed up through simplified mathematical models of how the brain’s neurons operate.

- Today’s hardware isn’t efficient for simulating network models even though any mathematical model can be simulated on today’s computers:
  - Due to fundamental differences between how the brain function vs. how digital computers function.
Issues

- Issue is being dealt with by implementing designs built around the crossbar latch
  - Crossbar latch: a grid of nanowires connected by ‘latching switches’
- Electronic devices called *somas* are critical in role of neuron’s cell body of adding up the inputs and firing an output
- *Somas* can imitate neurons with several different levels of sophistication based on what is required for the task at hand
Issues

- Somas can communicate through spikes
  - Spikes: short lived electrical impulses
  - There are evidences that spike train timing in the brain carries important information & is critical for certain types of learning
References

- http://www.wired.co.uk/article/ai-neuromorphic-chips-brains