

Lecture 14: Neuromorphic Systems

Overview

- History
- Real & Neuromorphic Neurons
- Silicon implementation techniques
- Applications of Neuromorphic Systems
- Timeliness

History

- Research into neuromorphic systems part of larger field of computational neuroscience
- Term 'neuromorphic' started off meaning 'neuron-like' (late 80's)
- another definition: 'mimic(ing) specific neurobiological functions'
- Neuromorphic systems are implementations in silicon of systems whose architecture and design are based on neurobiology.
- Earliest neuromorphic systems were concerned with providing an engineering approximation to some aspects of sensory systems, such as, the detection of sound in the auditory system, or detection of light in the visual system (
- More recently, work on robot control systems, on modeling various types of neurons, and on including adaptation in hardware systems.
- Also, research not restricted to one specific implementation technology

Real & Neuromorphic Neurons

- Real neurons - remarkably complex entities
- May be modelled in many way - emphasizing learning, or neural geometry, or ionic channels; - and using differential equations or simple discrete time
- Considerable success has been shown, with very simple neuron models, such as threshold units or logistic units, for performing interesting computation - However, these units are unable to model any of the behaviours of the neuron over time - hence, too simple for use as models for systems which need to process time varying environmental data, or for controlling movement over time
- Recently, considerable interest in more complex neural models, such as integrate & fire neurons or spike response neurons, which permit modelling of processing of time-varying data.

Real & Neuromorphic Neurons

- However, real neurons much more complex - at most basic level, they have many different charge carriers (such as Na^+ , Ca^+ , K^+ ions), and many varieties of channels whose precise properties depend on both local depolarisation & on presence or absence of other neuromodulator chemicals.
- Further, real neurons have spatially extended processes for both input (dendrites) & output (axons).
- Question: How can one hope to produce any useful model based on 'real' neurons using electronic circuitry (whose only charge carrier is the electron & the only active element is the transistor)?

Real & Neuromorphic Neurons

- *Answer 1:* Each technology must make use of whatever active processes it can support, there are a plethora of these in biological systems but only a few in electronics. However, in electronics, one can achieve complex behaviour by combining no. of elements into circuits, which can run in real-time.
- *Answer 2:* One should consider modelling *what* the neural system is doing rather than *how* it is achieving its results. That is, one can model how the overall architecture achieves its results (thus retaining e.g. massive parallelism typical of neurobiological systems) without modeling ionic channels, or even synapses. Indeed even the neurons might disappear, replaced by functions approximating their apparent behaviour.
- *Jury is still out on exactly what requires to be simulated in order to capture important aspects of real neural computation - mimicing neurobiological function doesnot need to entail precise emulation of original neural system.*

Silicon implementation technologies

- CMOS (Complementary Metal-Oxide Semiconductor) is the dominant electronic technology for implementation of neuromorphic systems.
- This technology allows integration of large numbers of transistors (also known as Very Large Scale Integration, VLSI) onto a silicon device (single chip).
- CMOS VLSI may be operated in either analogue or digital modes, or combination of both.
- Most neuromorphic research uses analogue VLSI techniques - by careful use of analogue characteristics of transistors, arithmetic functions such as addition, multiplication, exponential, logarithmic & tanh functions may be implemented using relatively few transistors.

Where might NS be applied

- Neuromorphic systems (NS) offer possibility of small low-power devices which can process real data directly: that is, data which has been sensed directly, perhaps using a transducers (also part of the chip)
- Since, no human intervention between energy source & transducer, these systems can be applied to sensing for independent robots.
- In addition, they can be applied to prosthetics -e.g hearing aids
- Also, in motor control, permitting control of robot manipulators
- For both above applications, real-time & low-power characteristics of NS are crucial
- Current PCs are static, their inputs mediated by humans via KB etc
- NS represent part of vehicle for moving PCs off the desk & out into the environment, for processing real 'dirty' data on-line

Timeliness?

- NS not entire now, so why recent increased interest?
- Answer:* There has been convergence of work in neuroscience, neural networks and chip design.
- In Neuroscience, we now better understand both operation of neuron (at spike/axon/dendrite/axon & synapse/neuro-transmitter levels) as well as importance of particular specialized structures (e.g. retina or organ of corti) at sensory neural surfaces.
- Research on neural networks has shown that one can use networks of relatively simple neural models to implement complex data transforms - also one can use VLSI techniques to implement some of these networks, but this has also clarified limitations in terms of interconnections of large no. of active elements.
- Chip design is now a mature subject, and some of concepts (such as design rules & re-use of cells) that made digital VLSI straightforward can now be applied to analogue VLSI.
- Convergence in above three areas has allowed engineers to produce circuits to embody some of the design strategy which neurobiology has evolved

Summary

- Neuromorphic systems are implementations in silicon of systems whose architecture and design are based on neurobiology.
- This growing area proffers exciting possibilities such as sensory systems which can compete with human senses, pattern recognition systems that can run in real-time and neuron models that can truly emulate living neurons.
- Neuromorphic systems are at the intersection of neuroscience, computer science and electrical engineering.
