μGC4: Building Brains
Objective

Microelectronic designs and architectures that deliver very high levels of performance for this area, and thereby help test hypotheses and explore the wider space of asynchronous event-coupled dynamical systems
Neurobiologically inspired electronic systems

• Why?
  – Animal brains have capabilities which outperform current electronic systems
    • Sensory perception and sensorimotor systems
    • Planning
    • Robustness in the face of changing environments
    • Resilience to partial failures
  – Understanding neural systems by building models which display the same characteristics
    • Baseline for replicating/improving performance
    • Also of interest both to computational and clinical neurophysiologists
Impact

- Enabling much larger neural models to be simulated than is possible at present. This is likely to be a significant contribution to the higher-level GC of understanding the architecture of brain and mind, whose impact upon humanity would be dramatic.

- Breakthroughs in the robustness and power-efficiency of electronic systems.

- Understanding how to build reliable systems on unreliable platforms is both timely and vital to the future progress of the technology.
The brain is not a computer

**Designed**
- Logic levels (digital)
- Voltages/currents (analogue)
- 0 to 3 volts (varies)
- Transistors (+ other devices)
- Electrons

**Evolved**
- Spike trains
- Chemical Signalling
  - -100 to +75mV
- Concentration levels and gradients
- Ionic Channels
- Membrane morphology channel distribution
- Multiple species of ion
- Neuromodulators, Neurotransmitters

**Information Coding**

**Signal Coding**

**Signal Levels**

**Active Elements**

**Conduction Elements**

**Neural System**

**Electronic Computer**
Signals and operation

- **Input/Output Signal Levels**
  - 0-2,3, or 5 V: alternatively, small currents
  - Digital Analogue: 0-2,3, or 5V cts I or V

- **Internal Signal Levels**
  - Electron and electrical behaviour in doped silicon

- **Basis**
  - Spiking: 75mv spikes: also neurochemicals
  - Ionic concentrations, neuromodulator levels, local depolarisation (Voltage across membrane)
  - Behaviour of ions and neuromodulators in aqueous solution. Protein (in membrane) conformation.
Possible ways forward: levels

- Brains are multi-level systems
  - Whole brain, brain region, cortical column, neuron, membrane, ion channel
  - Which level(s) do we build at?
Level choices

- Whole brain level: complete system level.
- Brain region level: subsystem level. But which subsystem?
- Cortical column level: interacting neurons. Cortical microcircuits
- Neuron level: what sort of neuron are we working with? Asynchronous spiking? Multi-compartment?
- Membrane/ion channel level: complex interactions between ions, ion channels and neuromodulators
Foothill projects

– build architectures to facilitate the construction of real-time neural and neuromorphic systems – the building blocks for the next stage;
– sensory fusion systems for visual, auditory, etc, input;
– reconfigurable architectures and tools to support generic neural modelling experiments;
– untangling the developmental trail – neural plasticity and epigenesis;
– massively parallel digital computation for neural modelling;
– developing low-power brain-inspired analogue circuits;
– efficient simulation at multiple levels of abstraction;
– understanding the bounds of microelectronic technology.
Related projects

• Hugo De Garis: building a brain through evolving hardware.
  – StarLab (2000-2001)

• Blue Brain project
  – Detailed biologically accurate modelling
  – Literally building a brain by replicating it (parts of it) electronically
  – See http://bluebrain.epfl.ch/
Implementation technologies

• VLSI
  – Analogue, digital, mixed. Asynchronous spikes, noise based systems.
• Reconfigurable Architectures
• Others?
  – Novel architectures
    • Hybrid (electronic/neural systems) ?
  – Genetic manipulation
    • Ion channel knock-outs
  – Nanofabrication