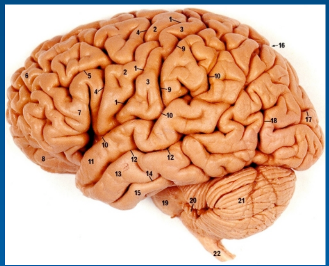
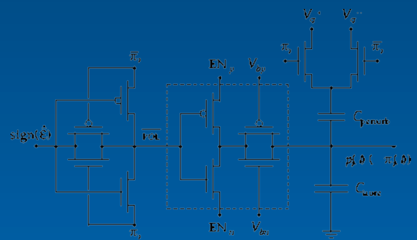
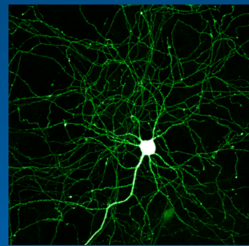
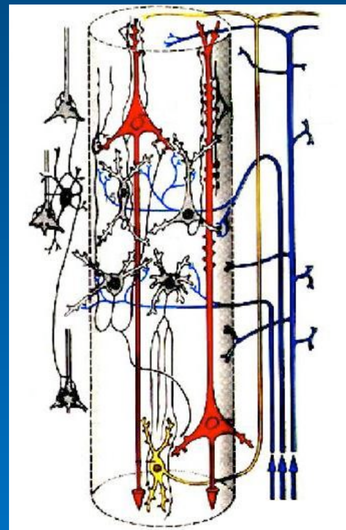
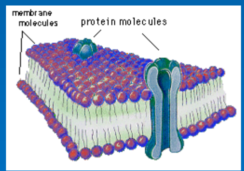
μGC4: Building Brains

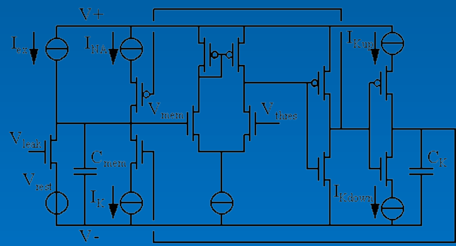












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Objective

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.

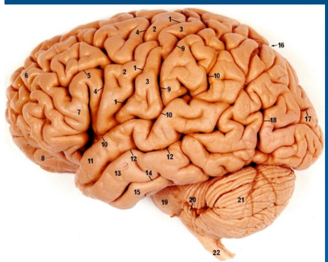
The brain is not a computer

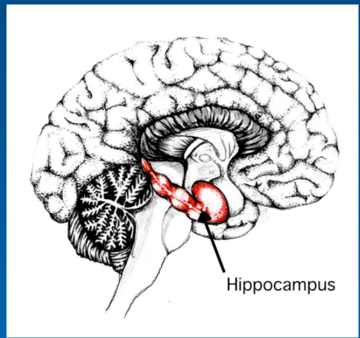
Electronic Computer		*Neural System*
Designed	Information Coding	Evolved
Logic levels (digital) Voltages/currents (analogue)	Signal Coding	Spike trains Chemical Signalling
0 to 3 volts (varies)	Signal Levels	-100 to +75mV Concentration levels and gradients
Transistors (+ other devices)	Active Elements	Ionic Channels Membrane morphology channel distribution
Electrons	Conduction Elements	Multiple species of ion Neuromodulators, Neurotransmitters

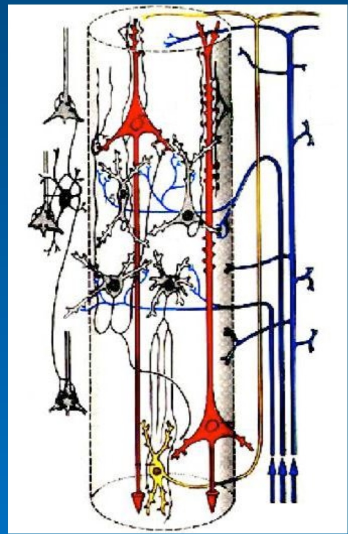
Signals and operation

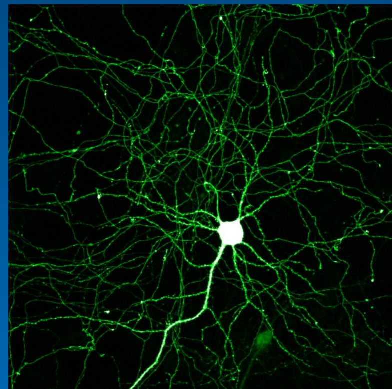
0-2,3,or 5 v: alternatively, small currents	Input/Output Signal Levels	Spiking: 75mv spikes: also neurochemicals
Digital Analogue / 0-2,3,or 5v cts I or V	Internal Signal Levels	Ionic concentrations, neuromodulator levels, local depolarisation (Voltage across membrane)
Electron and electrical behaviour in doped silicon	Basis	Behaviour of ions and neuromodulators in aqueous solution. Protein (in membrane) conformation.

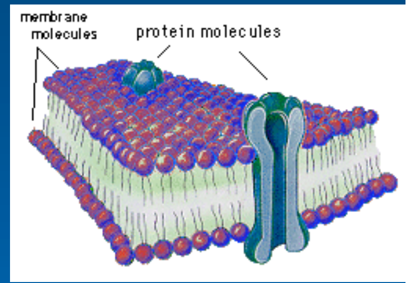
Possible ways forward: levels

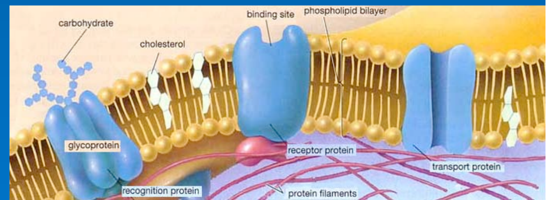






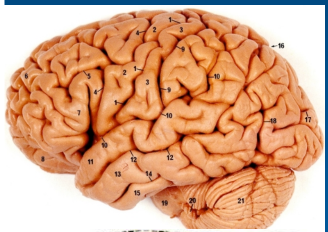


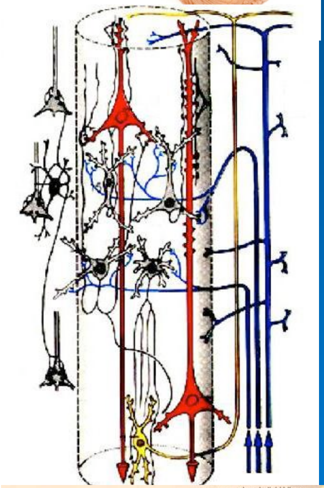


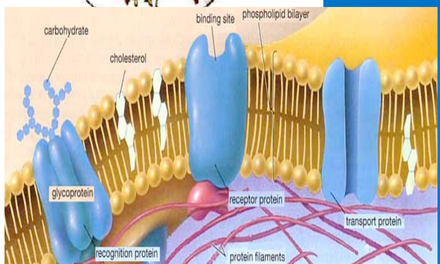


- Brains are multi-level systems
  - Whole brain, brain region, cortical column, neuron, membrane, ion channel
  - Which level(s) do we build at?

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