NEUR30004 Lecture Notes
Lecture 1

- Let's start with some basic characteristics of the brain
- How big is the brain, by which we really mean, how complex is it?
- How many neurons, how many connections (synapses), how many interconnections?
- Also likely to be important: to what extent and in what circumstances, can the patterns of interconnection change?

Start with the easy question: How many brain cells are there?

- Although there are lots of claims for how many neurons and other cells a human brain, most of these are fairly baseless estimates and not really critically questioned (partly because we don't know how important it is, but suspect its not crucial in terms of what a brain can do).
- But there have been recent sensible approaches to this, using the *isotropic fractionator*:
  - The isotropic fractionator (method)
    1. Isolate all nuclei (grind up brain)
    2. Stain DNA with fluorescent dye
    3. Count sample using flow cytometry – sample x brain volume = total cells
    4. Stain subsample for neuronal nuclear marker, count to get proportion of neurons

  - We can see from the above diagram that the brain is heterogeneous – the number of neurons in different parts of the brain is widely different
  - Proportion of mass doesn't equal proportion of neurons
  - Overall, equal numbers of neurons and non-neuronal cells
  - Ratio varies across brain

	Total neurons	% of total	% of mass	Non-neuronal cells
Cortex*	16 billion	19%	82%	60 billion
Cerebellum	69 billion	80%	10%	16 billion
Rest of brain	0.7 billion	0.8%	7.8%	8 billion
Total	86 billion	100%	100%	85 billion

*Commissural = 138 x 10^6 fibres cross CC

Synapses

- Neurons have a lot of synaptic connections
- Cortical neurons estimated to each have around 7000 synaptic inputs → this is why their dendrites are quite long
- A trillion (10^{12}) synapses per cubic centimetre
  - This means that we have around 1.5×10^{14} total synapses in the cortex
- Critical questions are: who synapses with who, and what determines this (i.e. both the initial state and the dynamics)?
  - A trillion synapses mean that the number of possibilities of combinations is even greater
  - One thing that we can compare this enormity of possibilities is to computers

- How many elementary functional operations can a brain do in a given time?
- How many "operations" does the human brain perform?
- Estimates vary from 10^{14} instruction per sec to 10^{17} sec*
- A couple of months ago, Sunway TaihuLIght supercomputer was declared the world's most powerful computer (topping the Tianhe-2 by a factor of 2.7)
- 125-petaflops ($1{,}25 \times 10^{17}$), 40000 chips, 10.65 million processor cores custom chips
- The four key application domains for the Sunway TaihuLIght are:
  - Advanced manufacturing: CFD, CAE applications (i.e. design)
  - Earth system modelling and weather forecasting
  - Life science – in modelling complex systems
  - Big data analytics – i.e. genomes etc.

What about computers designed to reproduce aspects of brain function?

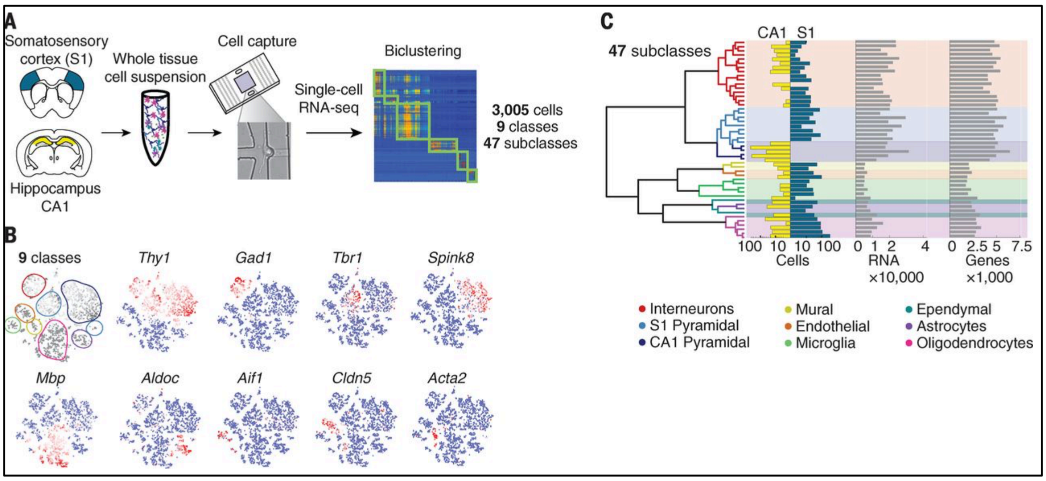
- IBM SyNAPSE chip (current DARPA project – to emulate the way neurons connect via interconnections)
- 5.4 billion transistors
- IBM also developing Blue Gene computer for scalable neural system stimulation in 4x4 arrays of SyNAPSE-developed chips

- Each chip has one million electronic "neurons" and 256 million electronic synapses between neurons

- =16 million neurons and 4096 million synapses, but note how eminently scalable this technology is
    - scalable = we can keep adding and adding to the existing number
- Mouse brain: 71 million neurons, ? synapses

- *Transhumanists* like Nick Bostron, not only believe that super-intelligent machines are probable, they postulate that the human brain may already be simulated in a computer. He (and other philosophers) have argued along these lines that:
- Three postulates lead to the conclusion that we are likely already living within a simulation
    1. *The human species is unlikely to go extinct before reaching the post-human stage*
    2. *Any post-human civilization is extremely likely to run significant number of simula0ons or (varia0ons) of their evolutionary history (cf The Sims)*
    3. *We are almost certainly living in a computer simula0on (cf The Matrix)*
- According to Nick, postulate (3) is likely to be true if (1) and (2) are true.
- Is this valid reasoning?
- And, regardless, are there in "in principle" reasons why it might not be possible to simulate a brain? Could we, now, simulate a brain?
- (*btw*. Nick also considers that in the "infinite worlds" model of the universe there is infinite good and infinite evil, so you can't change that by any finite amount of either. Are we cool with that?)

- Are all neurons the same? No. This is where real nervous systems and artificial ones are very different. Zeisel et al (2015 Science 347: 1138) did single cell *RNA seq* of 3005 cells(!), then a statistical analysis of the gene expression to cluster into common types.



- In S1 (somatosensory cortex): 7 types of pyramidal cell, 16 types of interneurons
- In CA1 (hippocampus): 2 types of projection neuron, 15 types of interneurons
- Also: 2 types of astrocytes, 6 types of oligodendrocytes, plus microglia, endothelia and ependymal cells.

Lecture 2 – Neural organisation

So, vision

- Our most dominant sense in terms of how much brain power is devoted to it and how strongly it drives our behaviour and beliefs.
- So we would assume evolutionary pressures to have delivered a veridical system of encoding the spatial relationships of the environments we find ourselves in.
- But we can readily see that veridical (*Or. L:* "true speaking") is an overstatement.
- Data compression – chunking is inevitable, and hopefully optimised – but it leaves gaps
- Not everything can top priority
- Data compression in visual pathway (in terms of information loss – there is a lot of convergence)
    - Retina detects 10^{10} bits. sec (much less than is available in visual scene)
    - 10^{8} bits' sec leave retina in optic nerve (approx. 10^{6} ganglion cell axons per eye)
    - 10^{4} bits sec appear in layer iv or V1 (primary visual cortex)
- And after V1? At some point information is added that is not from the retina
- We need to learn what we are seeing before we can see them – so what we see is not a perfect view of the world instead it is a reconstruction of the world based on how our systems work