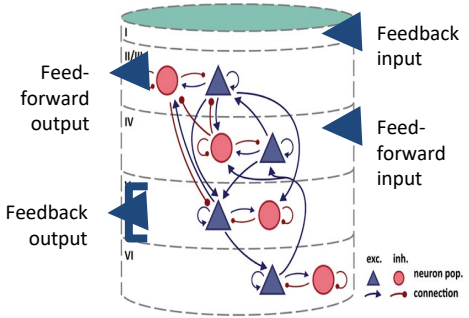
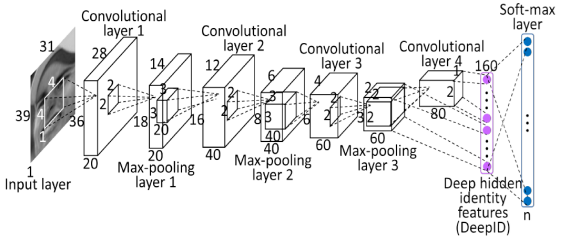




Brains, Minds & AI

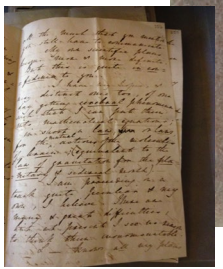
Steve Furber CBE FRS FREng
Professor Emeritus
The University of Manchester

MANCHESTER 1824
The University of Manchester

Brains: 200 years ago…

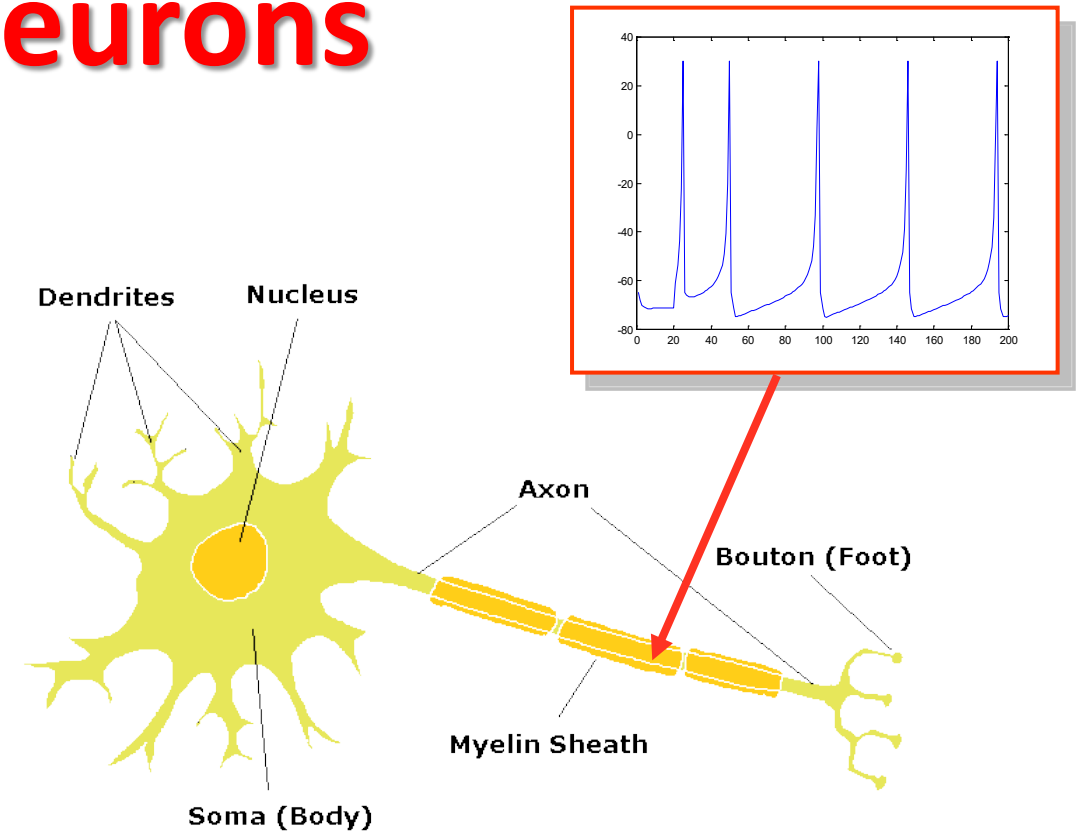
- Ada Lovelace, b. 10 Dec. 1815

"*I have my hopes, and very distinct ones too, of one day getting cerebral phenomena such that I can put them into mathematical equations--in short, a law or laws for the mutual actions of the molecules of brain. …. I hope to bequeath to the generations a calculus of the nervous system.”*



Neurons

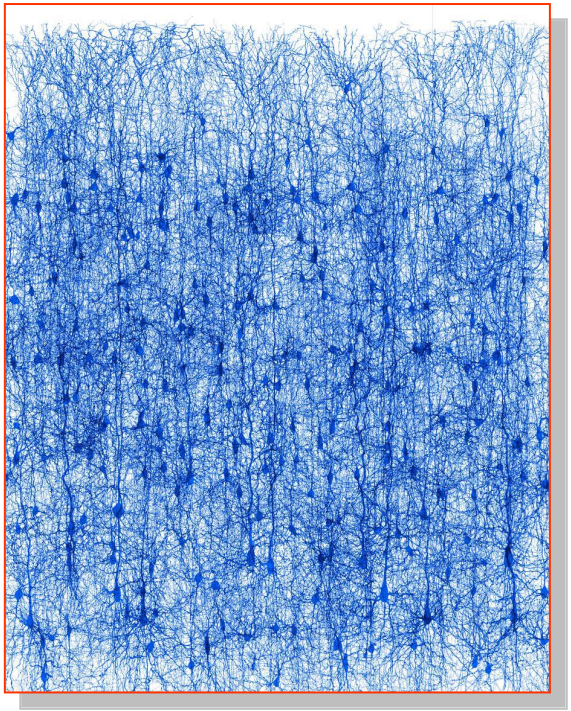
- Multiple inputs (dendrites)
- Single output (axon)
  - digital “spike”
  - fires at 10s to 100s of Hz
  - output connects to many targets
- Synapse at input/output connection



(www.ship.edu/ ~cgboeree/theneuron.html)

Neurons

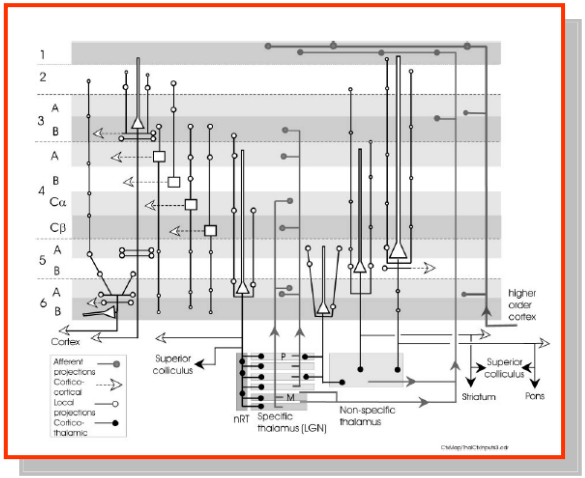
- A flexible biological control component
  - very simple animals have a handful
  - bees: 850,000
  - humans: 10^{11}



(photo courtesy of the Brain Mind Institute, EPFL)

Neurons

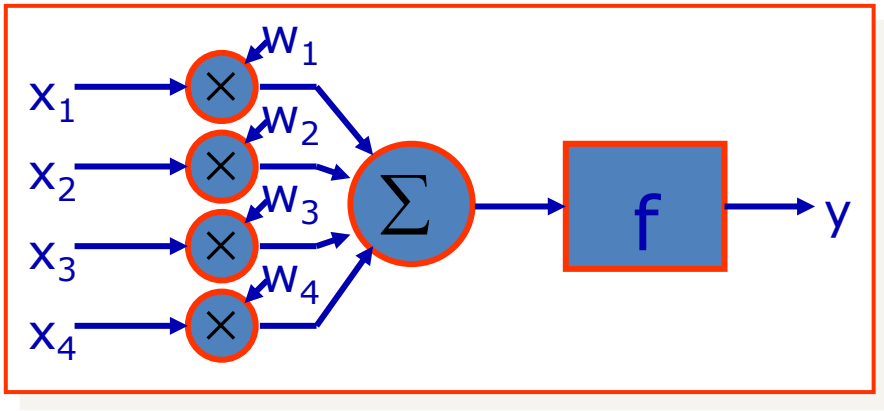
- Regular high-level structure
  - e.g. 6-level cortical microachitecture
    - low-level vision, to
    - language, etc.
- Random low-level structure
  - adapts over time



(faculty.washington.edu/rhevner/Miscellany.html)

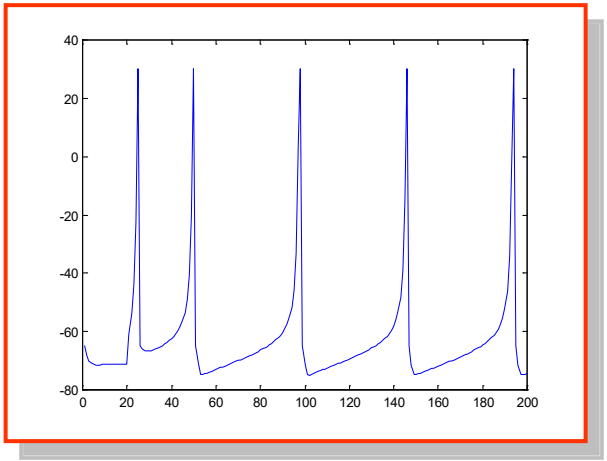
Neural computation

- To compute we need:
  - *Processing*
  - *Communication*
  - *Storage*
- Processing:
  abstract model
  - linear sum of weighted inputs
    - ignores non-linear processes in dendrites
  - non-linear output function
  - learn by adjusting synaptic weights



Neural communication

- Spikes
  - biological neurons communicate principally via ‘spike’ events
  - asynchronous
  - information is only:
    - which neuron fires, and
    - when it fires

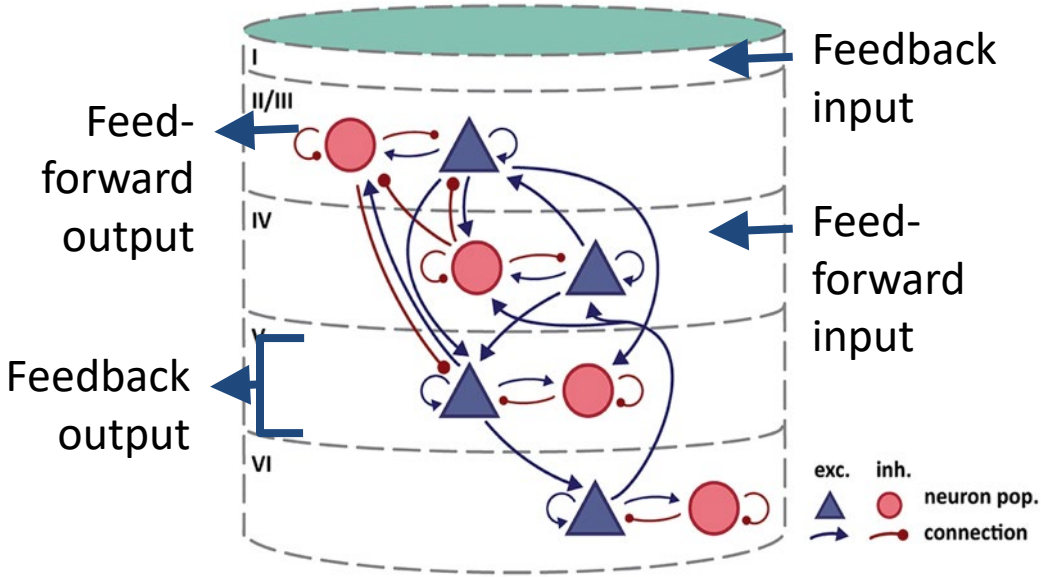


Neural storage

- Synaptic weights
  - stable over long periods of time
    - with diverse decay properties?
  - adaptive, with diverse rules
    - Hebbian, anti-Hebbian, LTP, LTD, ...
- Axon ‘delay lines’
- Neuron dynamics
  - multiple time constants
- Dynamic network states
- Structural plasticity
- Neurogenesis
- …?

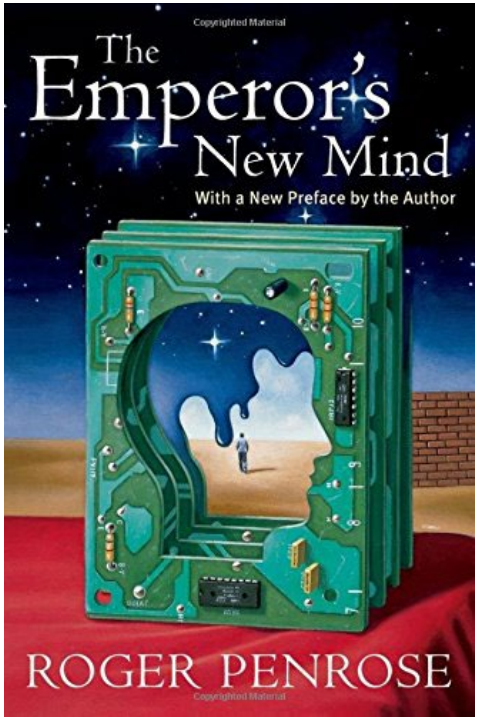
Brains: cortex - structure

- Spiking neurons
- Complex information flow
- Two-dimensional cortical structure
- Sparse connectivity
  - < 10%



Minds

- There is little doubt that the mind builds upon the brain
- Is it simply an emergent property of a suitably large & organised brain?
- Does it require something beyond the Newtonian physics of the “standard” brain model?



Consciousness

- How does subjective experience emerge from the brain?
- How does consciousness relate to the physical world?
- How does the conscious (awake) brain differ from the unconscious (asleep) brain?

AI: 70 years ago…

VOL. LIX. No. 236.] [October, 1950

MIND

A QUARTERLY REVIEW

OF

PSYCHOLOGY AND PHILOSOPHY

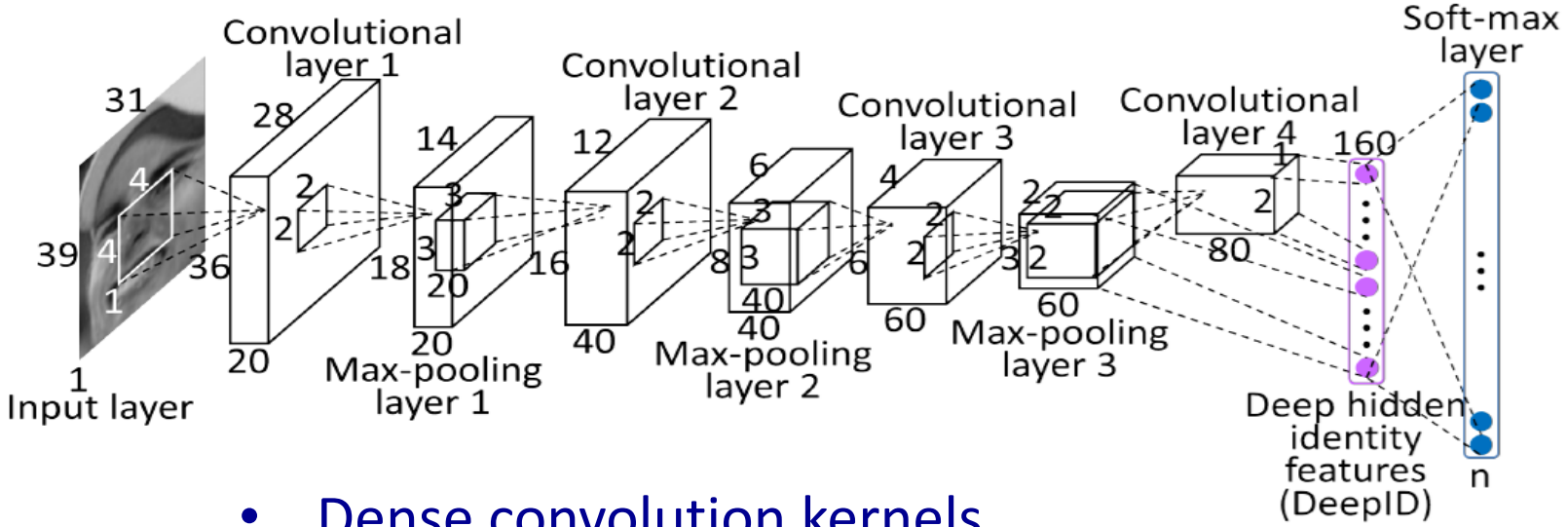
I.—COMPUTING MACHINERY AND INTELLIGENCE

BY A. M. TURING

1. *The Imitation Game.*

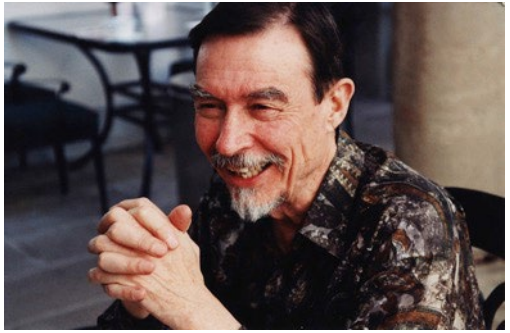
I PROPOSE to consider the question, 'Can machines think?' This should begin with definitions of the meaning of the terms 'machine' and 'think'. The definitions might be framed so as to reflect so far as possible the normal use of the words, but this attitude is dangerous. If the meaning of the words 'machine' and 'think' are to be found by examining how they are commonly used it is difficult to escape the conclusion that the meaning and the answer to the question, 'Can machines think?' is to be

ConvNets - structure



- Dense convolution kernels
- Abstract neurons (no spikes)
- Feed-forward connections (mainly)
- Trained through backpropagation

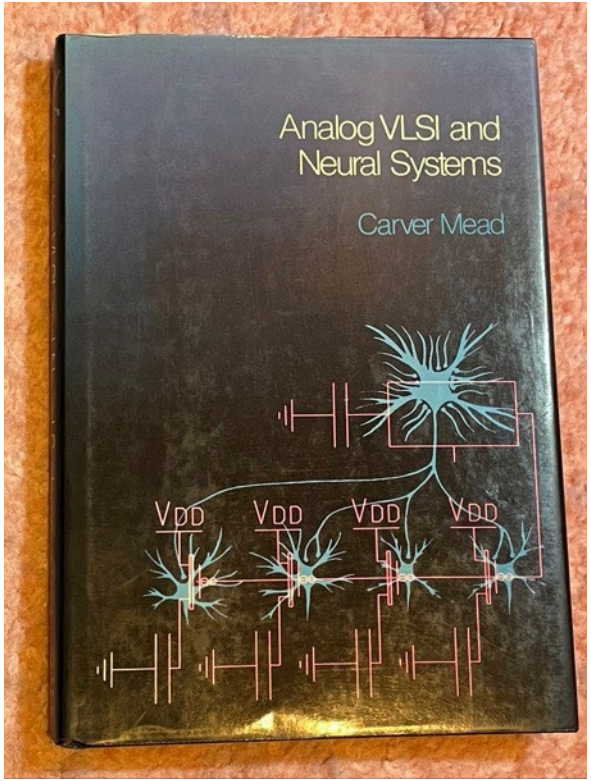
Neuromorphic Computing



Carver Mead

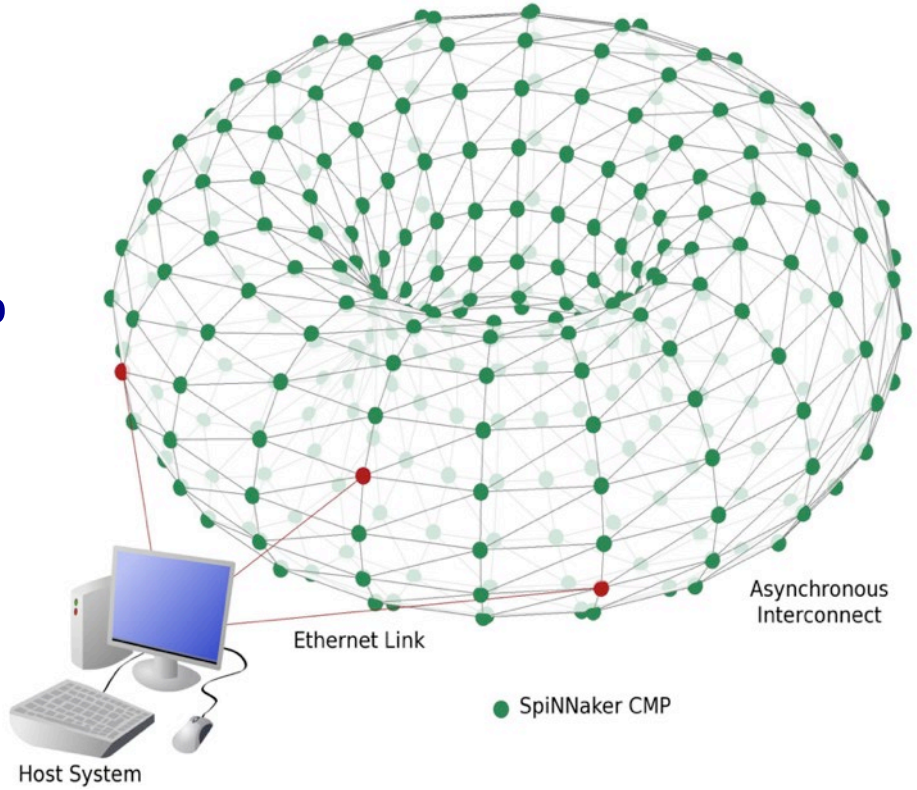
Caltech, 1980s

- observed analogy between ion channels in neurons and sub-threshold analogue transistor behaviour
- neuromorphic touch, hearing & vision sensors



SpiNNaker project

- A million mobile phone processors in one computer
- Able to model about 1% of the human brain…
- …or 10 mice!



Brains, Minds & AI

- The brain:
  - is “just” a (biological, messy) machine
    - very complex, but ultimately understandable?
  - whole human brain computer models are within our reach
- The mind:
  - an “emergent property” of the brain?
    - consciousness & self-awareness are unexplained
  - would consciousness emerge in a suitably complex and accurate computer model of the brain?

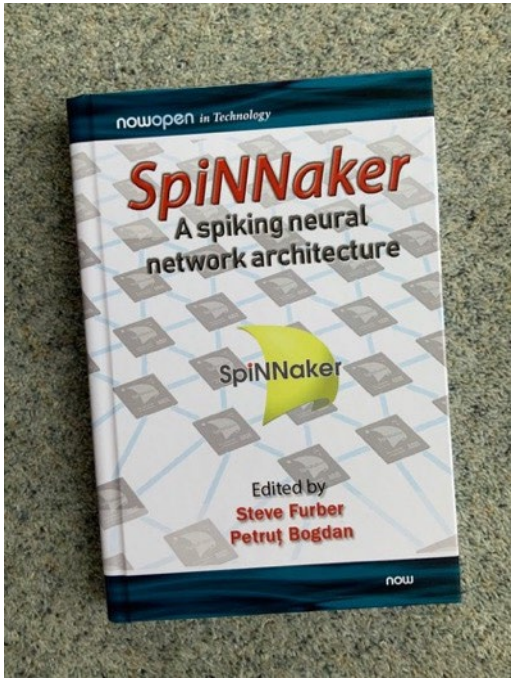
Brains, Minds & AI

- AI has advanced spectacularly over the last 20 years
  - it's now all around us:
    - search engines, speech input, language translation, semi-autonomous driving
- Human-like AI:
  - is still a long way off
    - it's proving much harder than Turing (and others) thought
    - understanding the brain should help?

SpiNNaker book

- Open Access in PDF form (i.e. free!)
  - over 100,000 downloads!
  - $90 on paper

20 years in conception and 15 in construction, the SpiNNaker project has delivered the world's largest neuromorphic computing platform incorporating over a million ARM mobile phone processors and capable of modelling spiking neural networks of the scale of a mouse brain in biological real time…



http://dx.doi.org/10.1561/9781680836523