The *SpiNNaker* Project

Steve Furber

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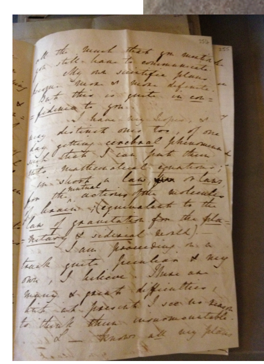
The University of Manchester

200 years ago…

- Ada Lovelace, b. 10 Dec. 1815

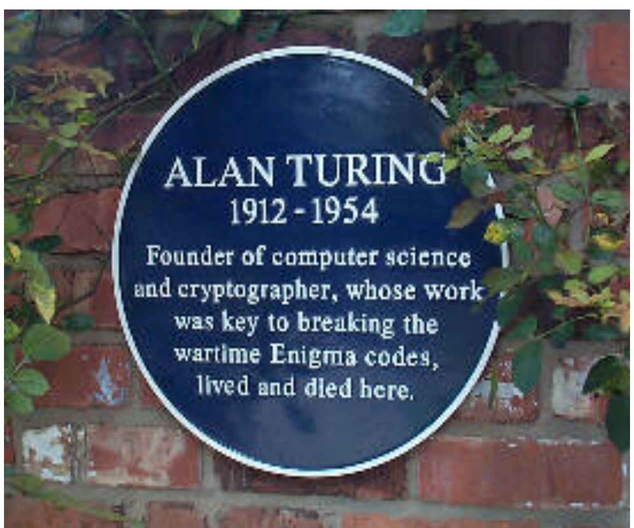
"I have my hopes, and very distinct ones too, of one day getting cerebral phenomena such that I can put them into mathematical equations--in short, a law or laws for the mutual actions of the molecules of brain. …. I hope to bequeath to the generations a calculus of the nervous system."



Outline

- 63 years of progress
- Building brains
- The ***SpiNNaker*** project
- Making connections
- Building machines
- Sudoku dreams
- Plans and prospects

65 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

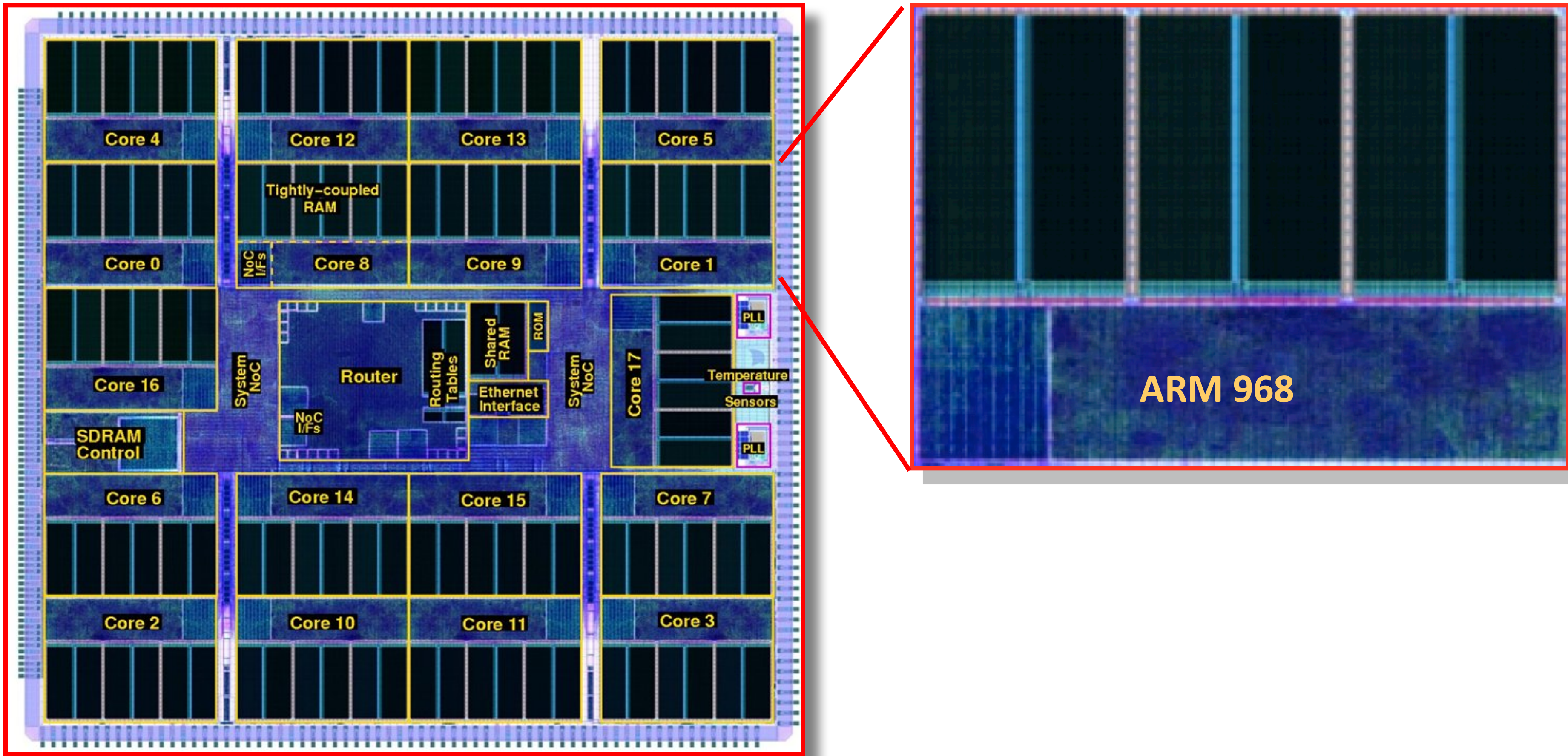
1. *The Imitation Game.*

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 sought in a statistical survey such as a Gallup poll. But this is absurd. Instead of attempting such a definition I shall replace the

Manchester Baby (1948)

SpiNNaker
Biologically Inspired Massively Parallel Architectures

SpiNNaker CPU (2011)



63 years of progress

- ***Baby:***
  - used 3.5 kW of electrical power
  - executed 700 instructions per second
  - 5 Joules per instruction
- ***SpiNNaker ARM968 CPU node:***
  - uses 40 mW of electrical power
  - executes 200,000,000 instructions per second
  - 0.000 000 000 2 Joules per instruction

25,000,000,000 times better than Baby!

(James Prescott Joule born Salford, 1818)

Jevons paradox

1865 "The Coal Question"

- James Watt's coal-fired steam engine was much more efficient than Thomas Newcomen's…
- …and coal consumption ***rose*** as a result

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Bio-inspiration

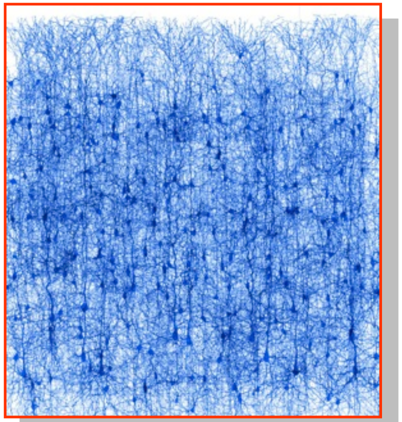
- Can massively-parallel computing resources accelerate our understanding of brain function?
- Can our growing understanding of brain function point the way to more efficient parallel, fault-tolerant computation?

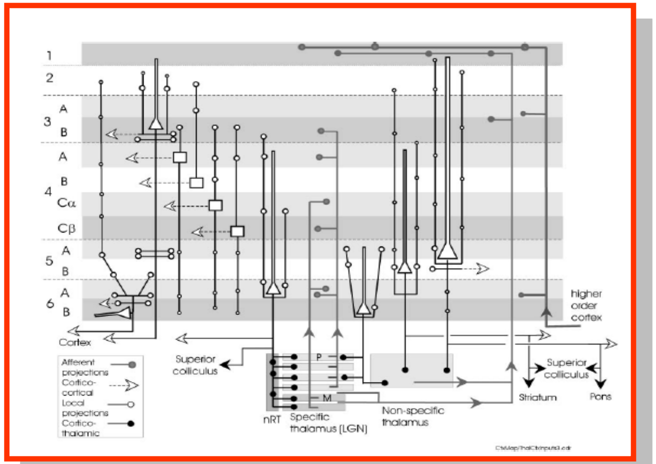
Building brains

- Brains demonstrate
  - massive parallelism (10^{11} neurons)
  - massive connectivity (10^{15} synapses)
  - excellent power-efficiency
    - much better than today's microchips
  - low-performance components (~ 100 Hz)
  - low-speed communication (~ metres/sec)
  - adaptivity – tolerant of component failure
  - autonomous learning

Building brains

- Neurons
  - multiple inputs, single output (c.f. logic gate)
  - useful across multiple scales (10^2 to 10^{11})
- Brain structure
  - regularity
  - e.g. 6-layer cortical 'microarchitecture'





SpiNNaker

Biologically Inspired Massively Parallel Architectures

MIT Technology Review

10 BREAKTHROUGH TECHNOLOGIES

Agricultural Drones
Relatively cheap drones with advanced sensors and imaging capabilities are giving farmers new ways to increase yields and reduce crop damage.

Ultraprivate Smartphones
New models built with security and privacy in mind reflect the Zeitgeist of the Snowden era.

Brain Mapping
A new map, a decade in the works, shows structures of the brain in far greater detail than ever before, providing neuroscientists with a guide to its immense complexity.

Neuromorphic Chips
Microprocessors configured more like brains than traditional chips could soon make computers far more astute about what's going on around them.

Genome Editing
The ability to create primates with intentional mutations could provide powerful new ways to study complex and genetically baffling brain disorders.

Microscale 3-D Printing
Inks made from different types of materials, precisely applied, are greatly expanding the kinds of things that can be printed.

Mobile Collaboration
The smartphone era is finally getting the productivity software it needs.

Oculus Rift
Thirty years after virtual-reality goggles and immersive virtual worlds made their debut, the technology finally seems poised for widespread use.

Agile Robots
Computer scientists have created machines that have the balance and agility to walk and run across rough and uneven terrain, making them far more useful in navigating human environments.

Smart Wind and Solar Power
Big data and artificial intelligence are producing ultra-accurate forecasts that will make it feasible to integrate much more renewable energy into the grid.

Neuromorphic Chips

Microprocessors configured more like brains than traditional chips could soon make computers far more astute about what's going on around them.

Breakthrough	Why It Matters	Key Players
An alternative design for computer chips that will enhance artificial intelligence.	Traditional chips are reaching fundamental performance limits.	+ Qualcomm + IBM + HRL Laboratories + Human Brain Project

http://www.technologyreview.com/featuredstory/526506/neuromorphic-chips/

Top 10 emerging technologies of 2015

WORLD ECONOMIC FORUM

SpiNNaker
Biologically Inspired Massively Parallel Architectures

The 2015 list is:

1. Fuel cell vehicles
2. Next-generation robotics
3. Recyclable thermoset plastics
4. Precise genetic engineering techniques
5. Additive manufacturing
6. Emergent artificial intelligence
7. Distributed manufacturing
8. 'Sense and avoid' drones
9. Neuromorphic technology
10. Digital genome

9. Neuromorphic technology

Computer chips that mimic the human brain

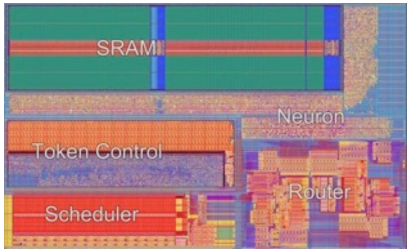
Even today's best supercomputers cannot rival the sophistication of the human brain. Computers are linear, moving data back and forth between memory chips and a central processor over a high-speed backbone. The brain, on the other hand, is fully interconnected, with logic and memory intimately cross-linked at billions of times the density and diversity of that found in a modern computer. Neuromorphic chips aim to process information in a fundamentally different way from traditional hardware, mimicking the brain's architecture to deliver a huge increase in a computer's thinking and responding power.

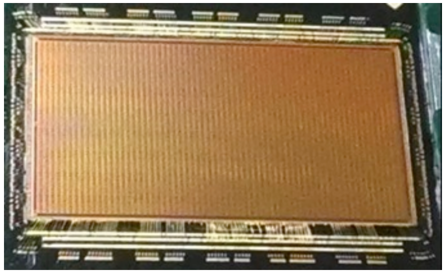
Miniaturization has delivered massive increases in conventional computing power over

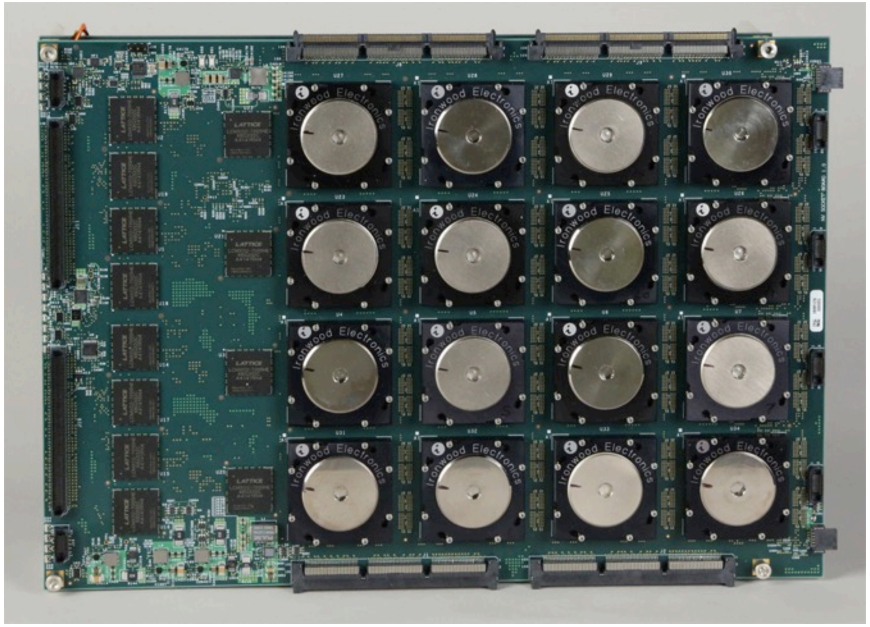
https://agenda.weforum.org/2015/03/top-10-emerging-technologies-of-2015-2/

IBM TrueNorth

- 4,096 digital neurosynaptic cores
  - one million configurable neurons
  - 256 million programmable synapses
  - ~70mW
  - over 400 Mbits of embedded SRAM
  - 5.4 billion transistors
- 16 TrueNorth Chips assembled into a 4x4 mesh
  - 16 million neurons and 4 billion synapses.

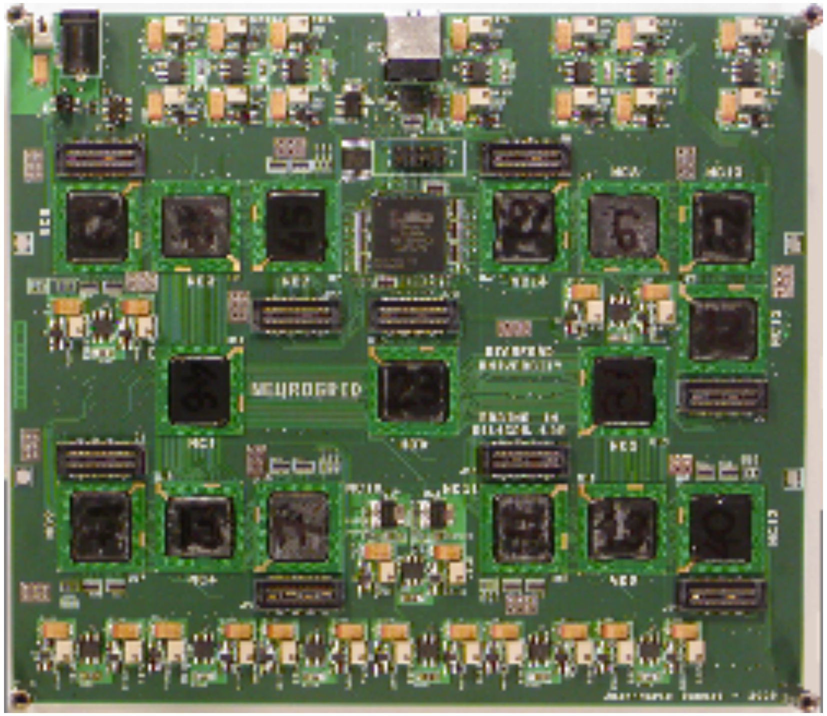






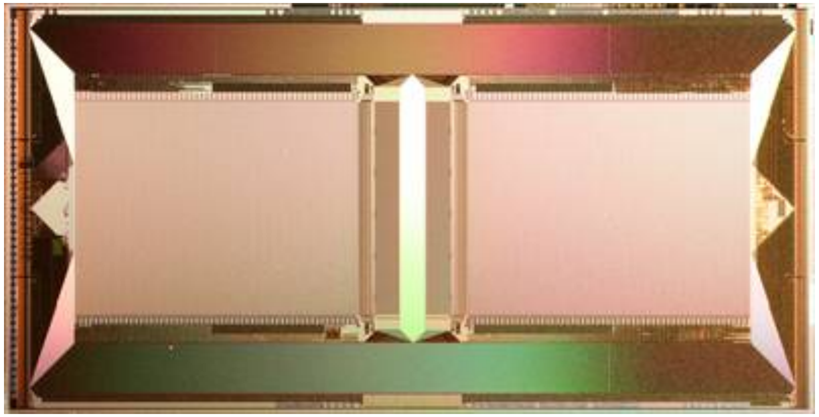
Stanford Neurogrid

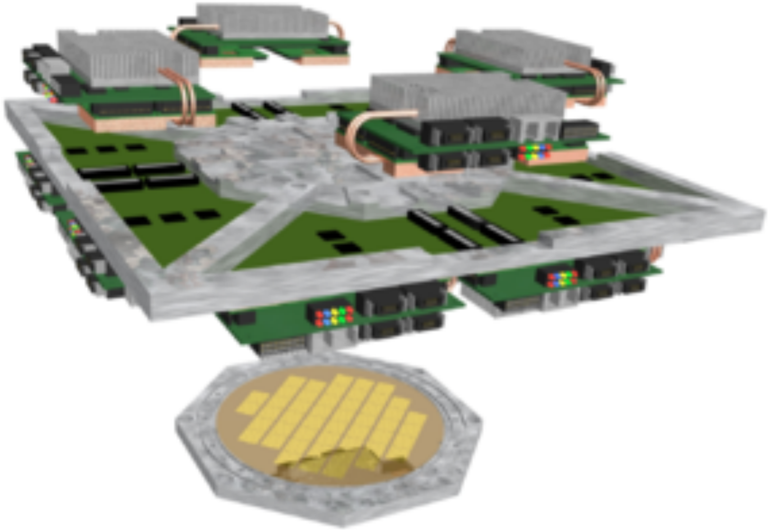
- Neurocore Chip
  - 65k neurons
  - each with two compartments and a set of configurable silicon ion channels
- Sixteen Neurocores are assembled on a board
  - million-neuron Neurogrid



Heidelberg HiCANN

- Wafer-scale analogue neuromorphic system
- 8” 180nm wafer:
  - 200,000 neurons
  - 50M synapses
  - 10^4x faster than biology





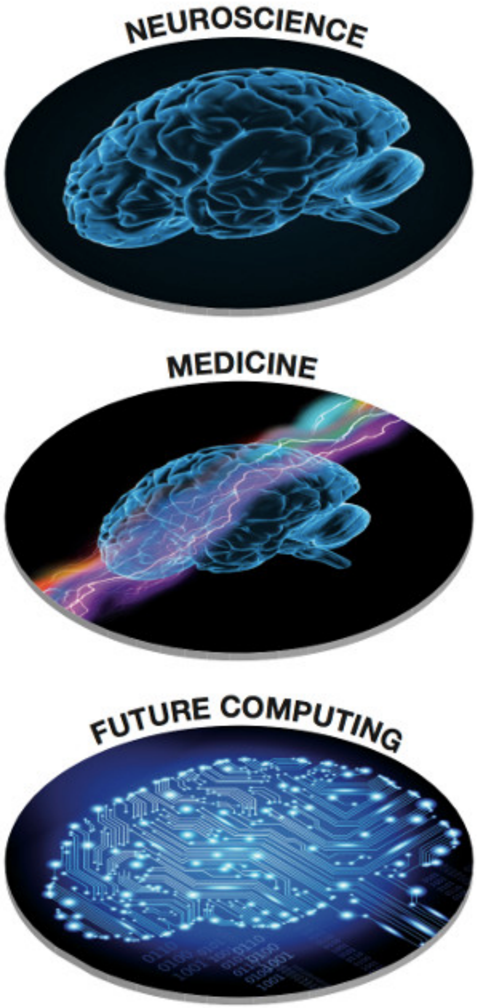
Human Brain Project

The Human Brain Project

- An EU ICT Flagship project
  - headline €1B budget
    - €54M initial funding
      - 1st October 2013 to 31st March 2016
      - ~€900k to UoM
    - next 7.5 years funded under H2020
      - subject to review of ramp-up phase after 18 months
  - 80 partner institutes, 150 PIs & Cis
    - Open Call extended this
  - led by Henry Markram, EPFL

The Human Brain Project

- Research areas:
- Neuroscience
  - neuroinformatics
  - brain simulation
- Medicine
  - medical informatics
  - early diagnosis
  - personalized treatment
- Future computing
  - interactive supercomputing
  - neuromorphic computing



Outline

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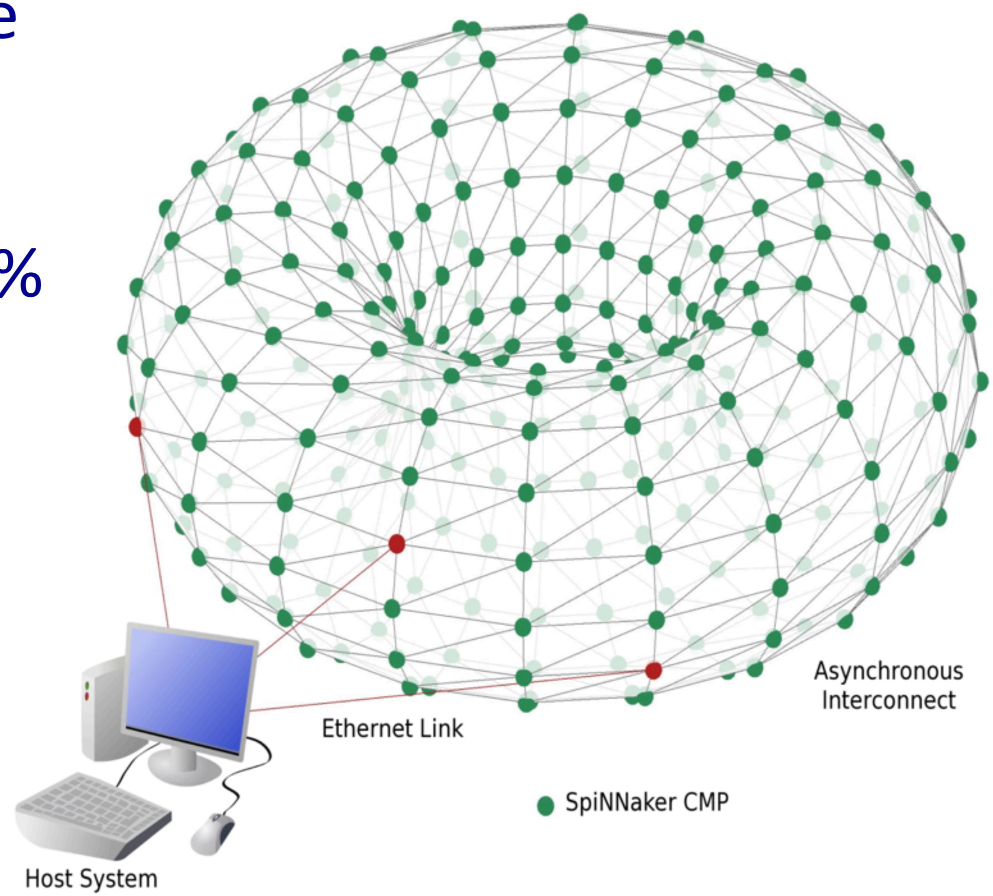
- Building brains
- **The *SpiNNaker* project**
- Making connections
- Building machines
- Sudoku dreams
- Plans and prospects

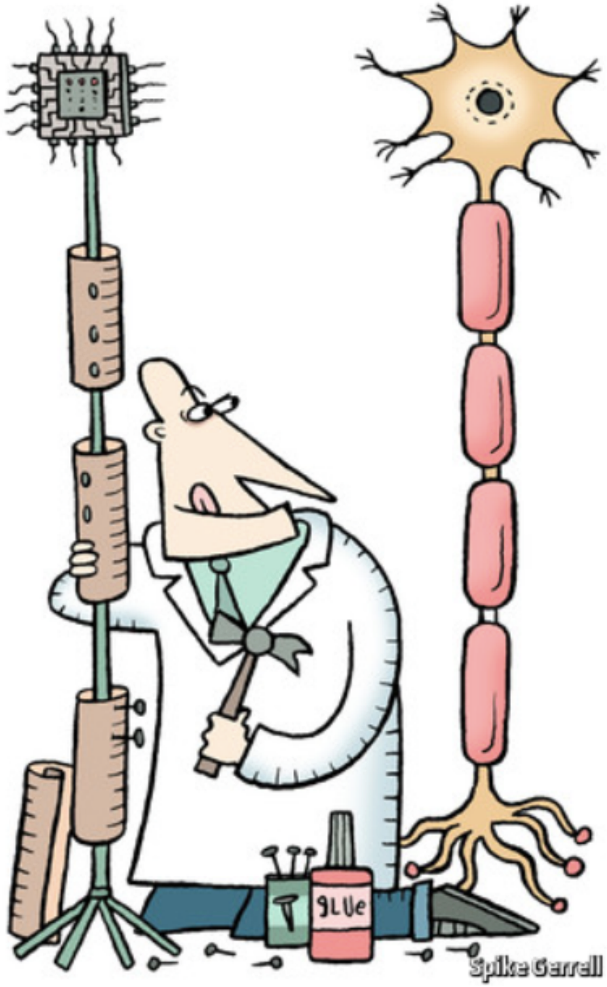
SpiNNaker project

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



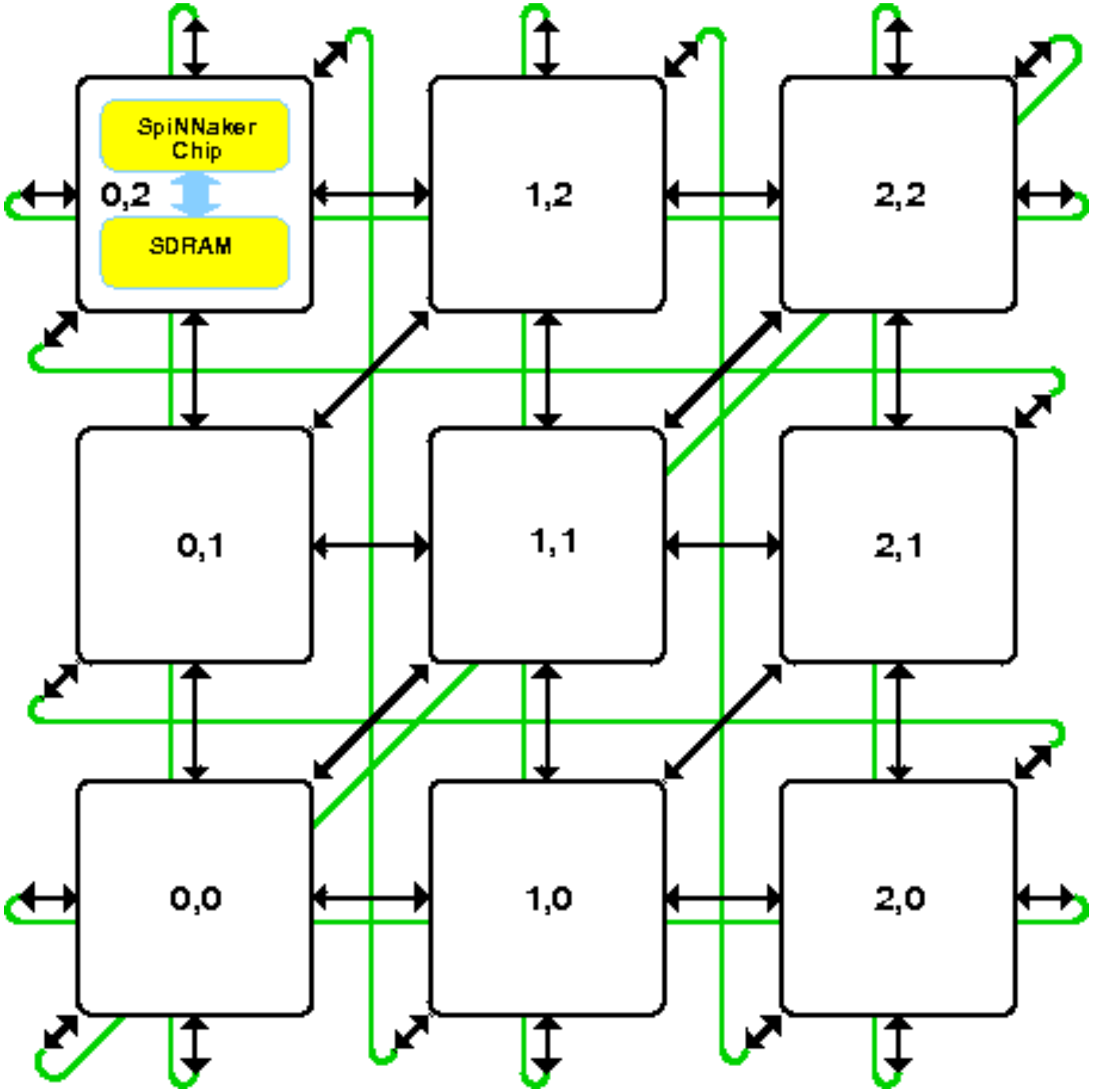
EPSRC

Design principles

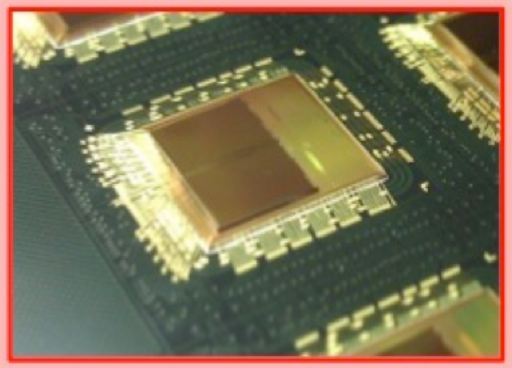


- *Virtualised topology*
  - physical and logical connectivity are decoupled
- *Bounded asynchrony*
  - time models itself
- *Energy frugality*
  - processors are free
  - the real cost of computation is energy

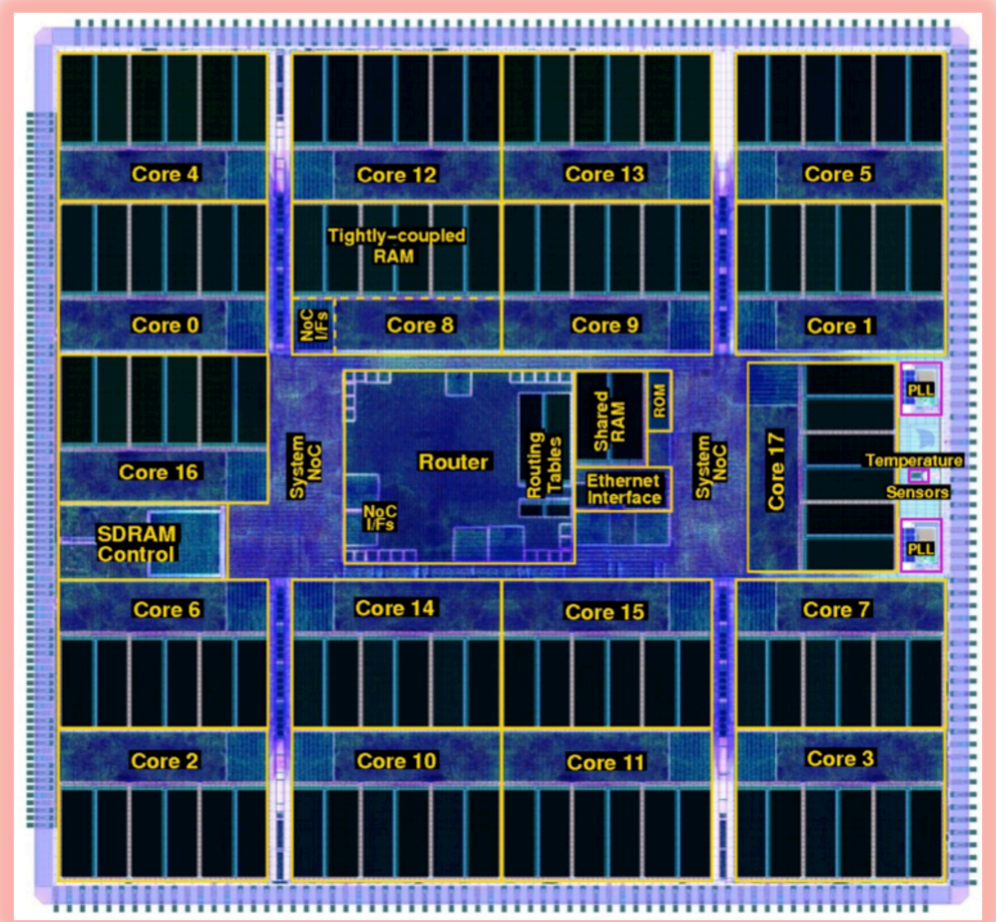
SpiNNaker system



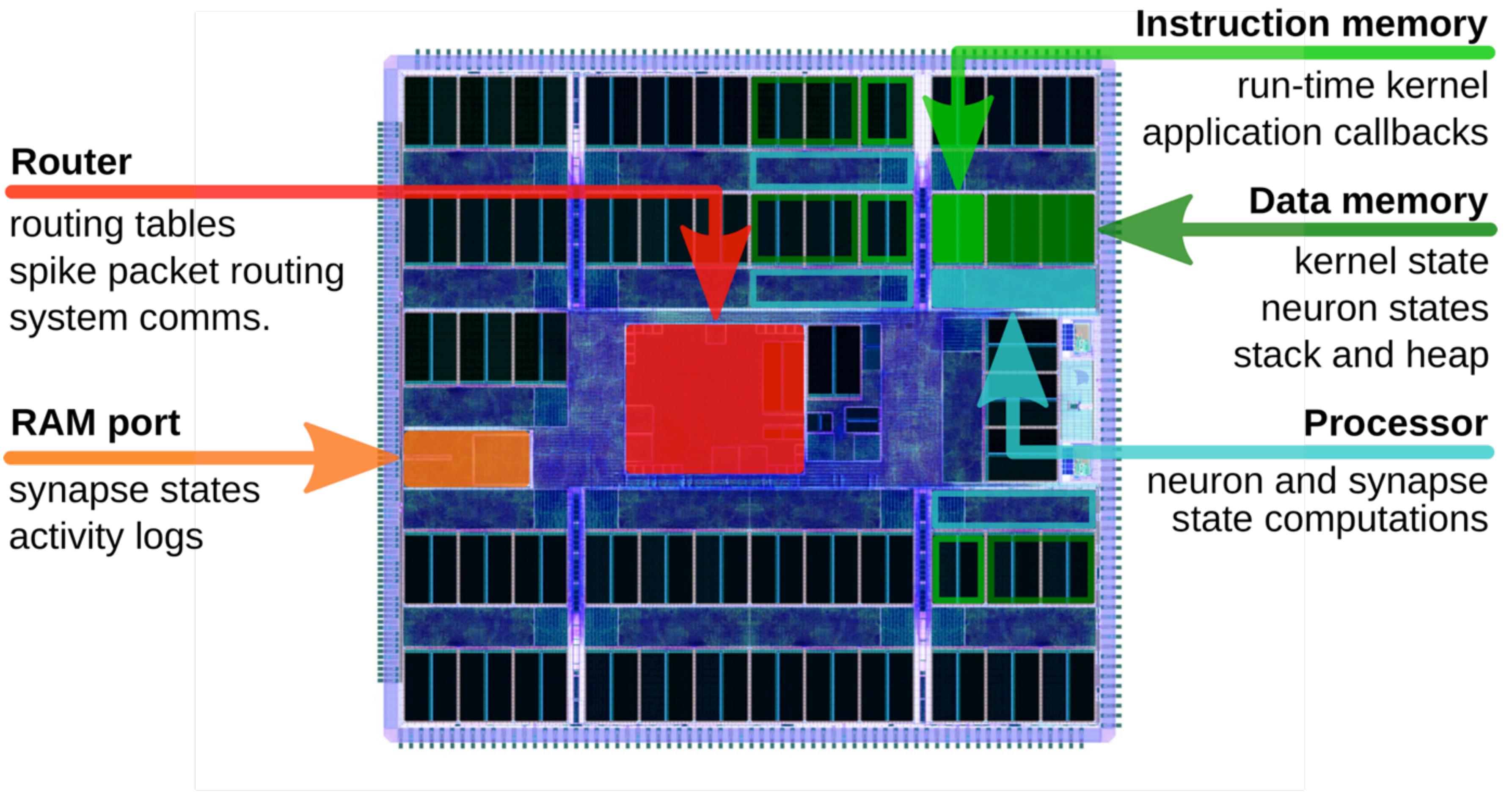
SpiNNaker chip



Multi-chip packaging by UNISEM Europe



Chip resources



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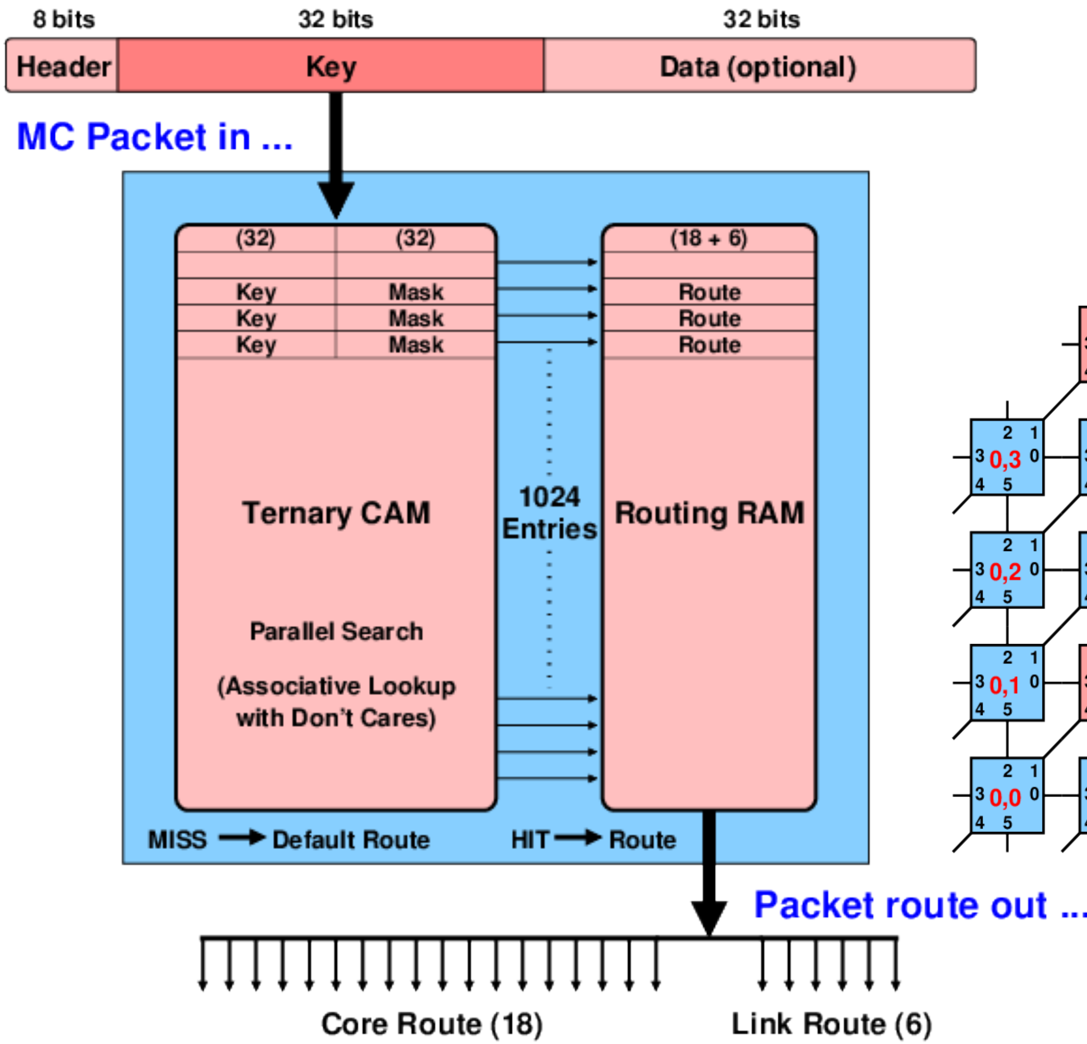
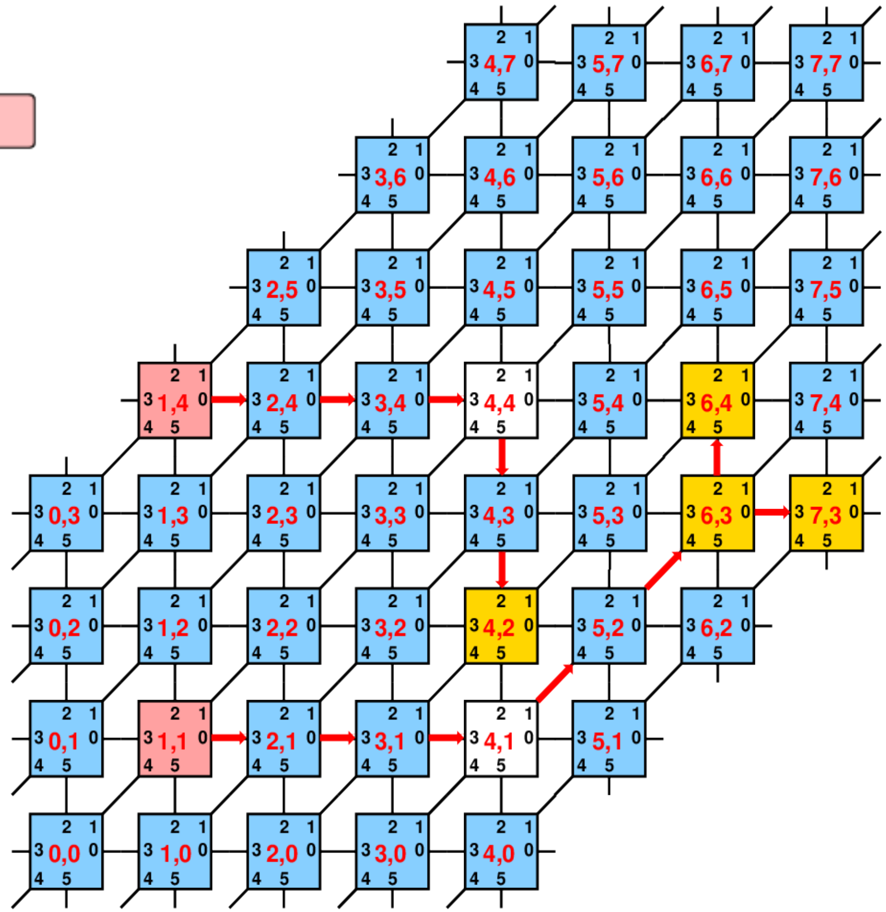
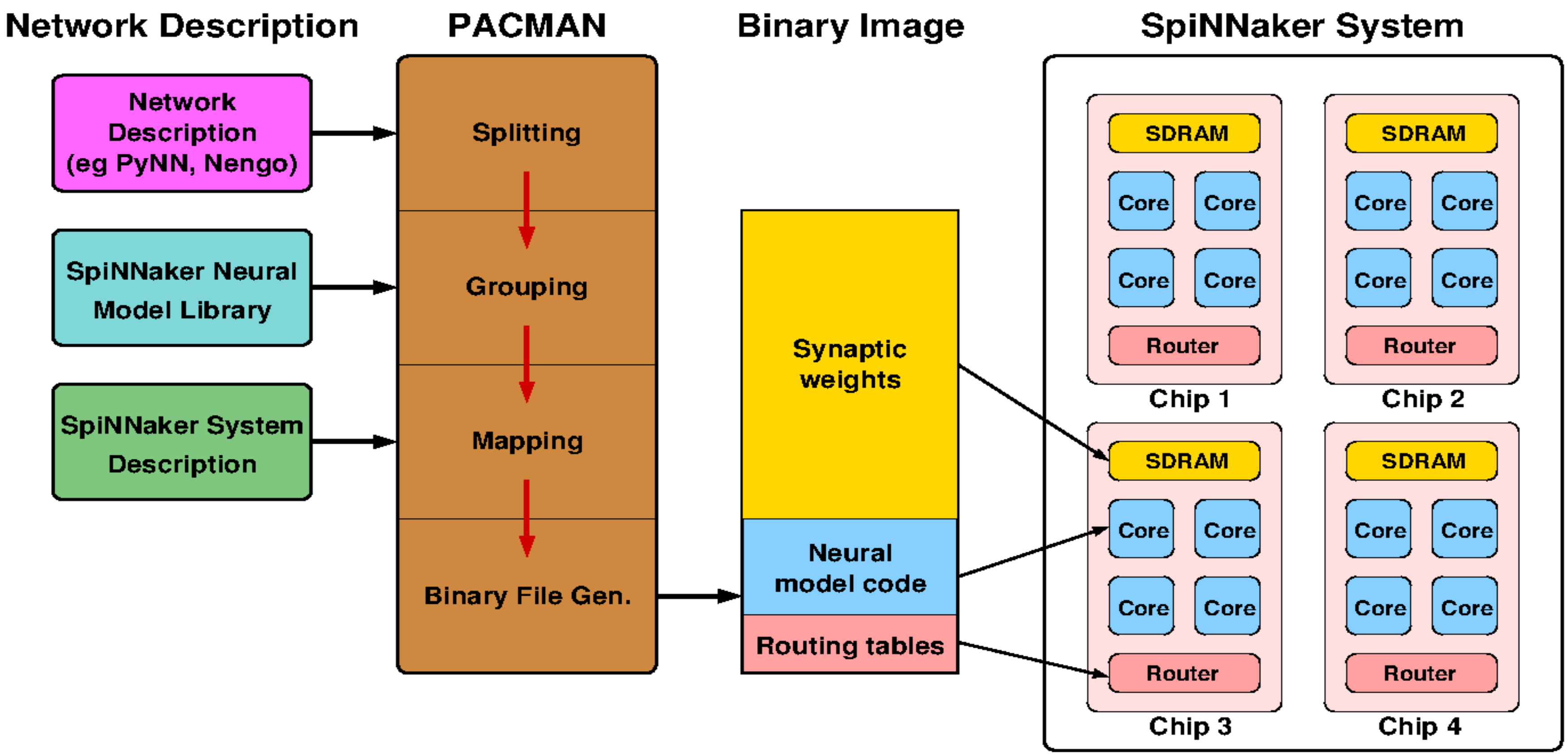
Multicast routing

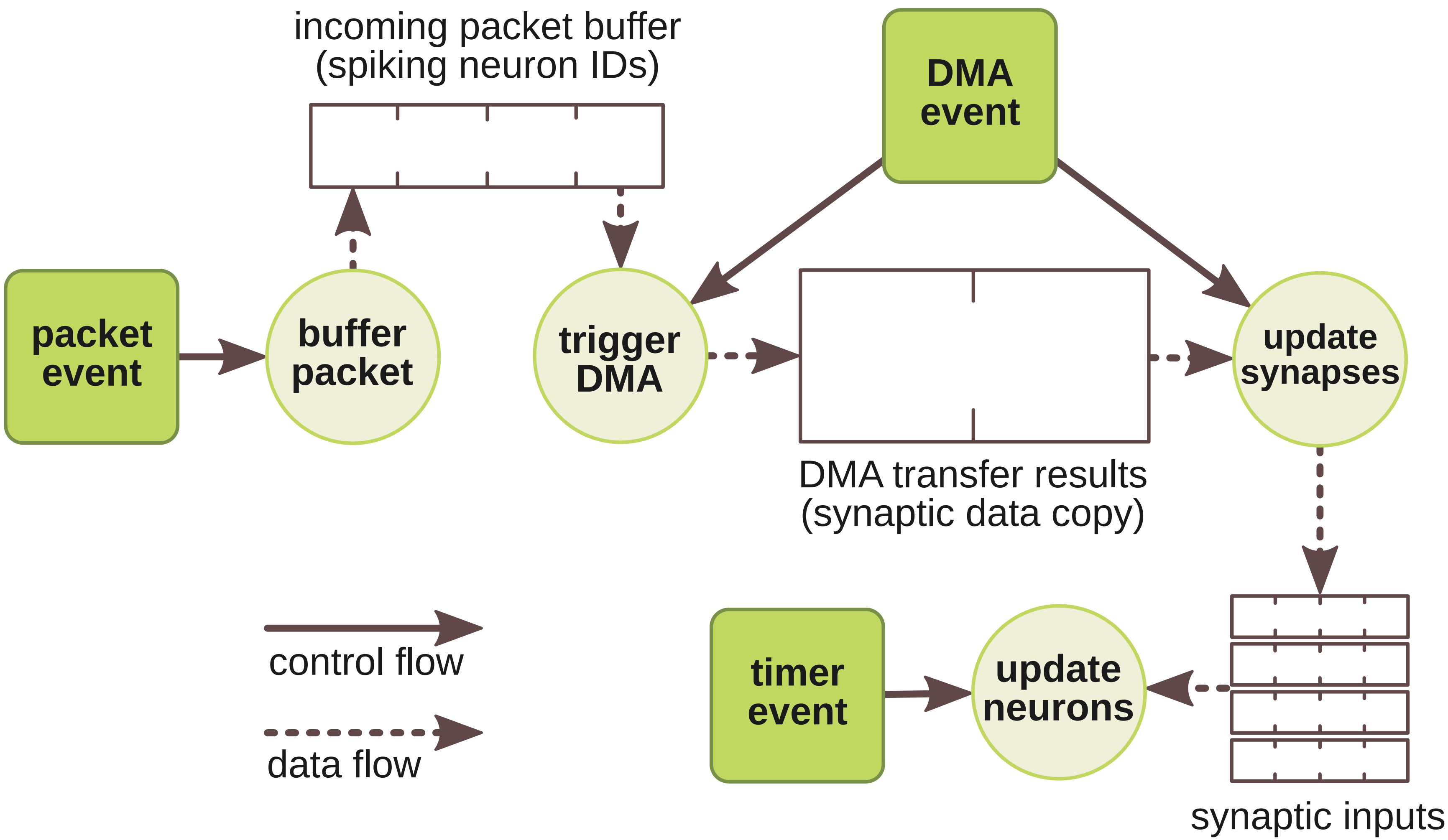




Problem mapping



Event-driven software



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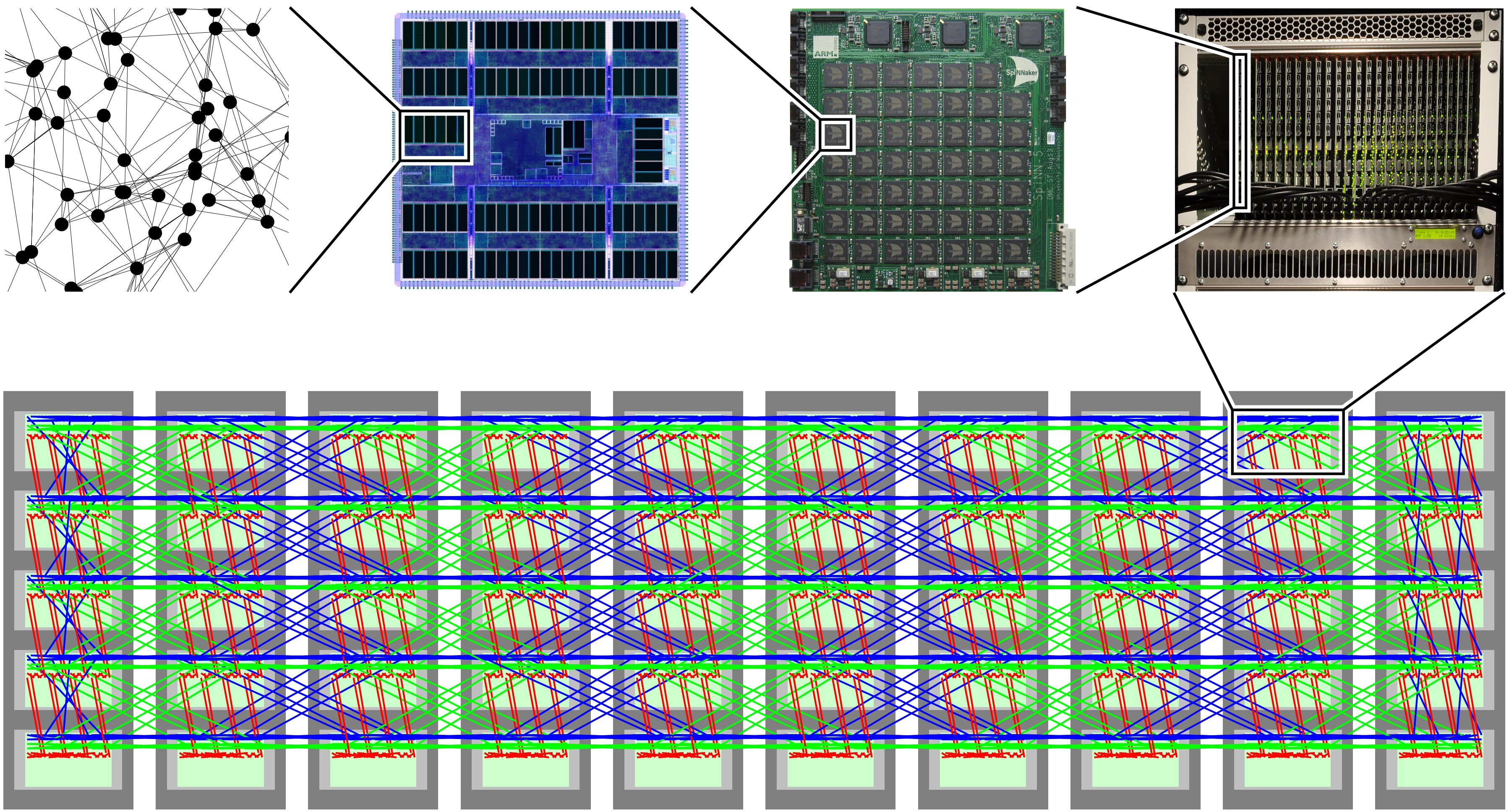
Scaling to a billion neurons

1,000 neurons per core.

18 cores per chip.

48 chips per board.

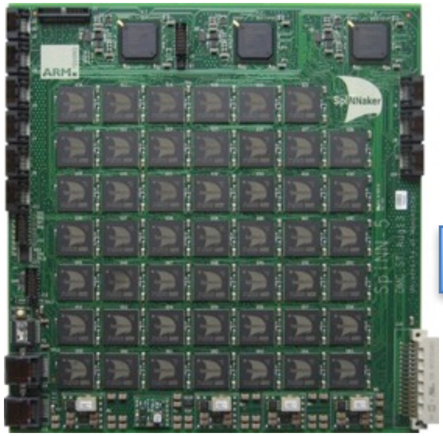
24 boards per rack.



5 racks per cabinet, 10 cabinets.

SpiNNaker machines

103

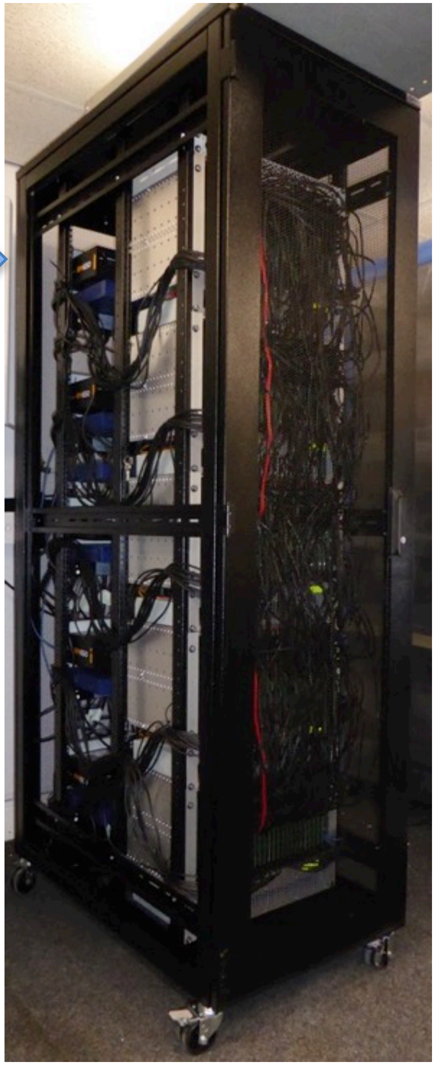


864 cores
- drosophila scale

104

20,000 cores
– frog scale

105



100,000 cores
– mouse scale

102

72 cores
- pond snail scale

SpiNNaker machines

10^6

- HBP platform
  - 500,000 cores
  - 6 cabinets
    (including server)
- Launch
  - 22 March 2016

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Sudoku on *SpiNNaker*

6	8	1	9	6	2	4	8	1
5	3	4	7	6	8	2	9	8
5	8	9	4	8	5	5	1	3
3	2	5	6	7	4	1	7	8
3	1	5	2	9	9	6	2	7
8	9	6	2	8	1	1	3	9
1	6	2	8	9	7	8	5	4
9	5	8	8	3	7	2	1	2
1	5	8	1	2	7	9	3	9

S. Habenschuss, Z. Jonke, and W. Maass, "Stochastic computations in cortical microcircuit models", PLOS Computational Biology, 9(11):e1003311, 2013.

Sudoku rules

square

row

5	8	6	1	2	4	9	7	3
2	3	4	7	5	9	8	6	1
1	7	9	6	8	3	4	2	5
7	4	8	2	9	5	3	1	6
9	5	2	3	1	6	7	4	8
6	1	3	4	7	8	5	9	2
3	2	5	9	6	7	1	8	4
8	9	1	5	4	2	6	3	7
4	6	7	8	3	1	2	5	9

column

Sudoku PyNN network

- 1 population per cell
  - 25 IF_curr_exp neurons x 9 digits = 225 total
  - +1 SpikeSourcePoisson neuron per cell neuron
  - total: 81 x 225 x 2 = 36,400 neurons
- Initial values applied to some cells (~28)
  - 30 SpikeSourcePoisson neurons
  - 30 x 25 random excitatory connections to relevant sub-population
    - 30 x 25 x 28 = 21,000 synapses

Sudoku PyNN network

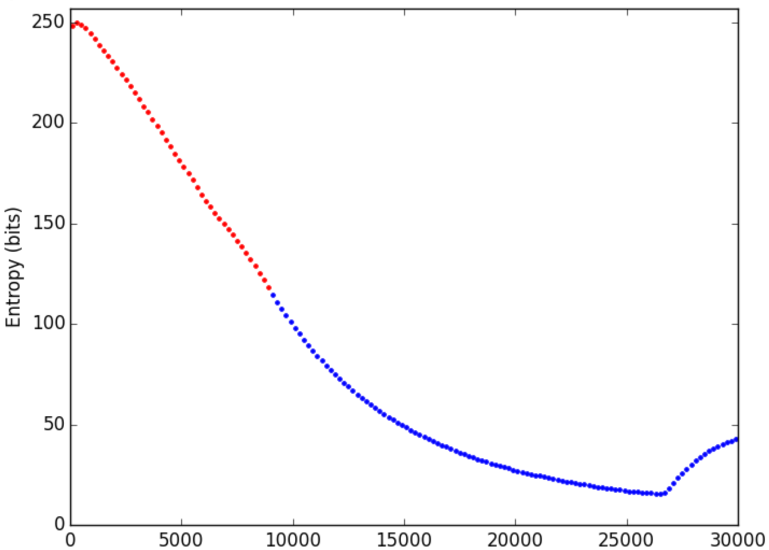
- Inhibitory constraints:
  - from each digit to all other digits within cell
    - uniform random weight distribution
    - 9 x 25 x 25 x 8 x 81 = 3,645,000 synapses
  - from each digit to the same digit in the same row, column and square
    - uniform random weight distribution
    - 9 x 25 x 25 x 20 x 81 = 9,112,500 synapses
- Total 165 lines Python

Network entropy measure

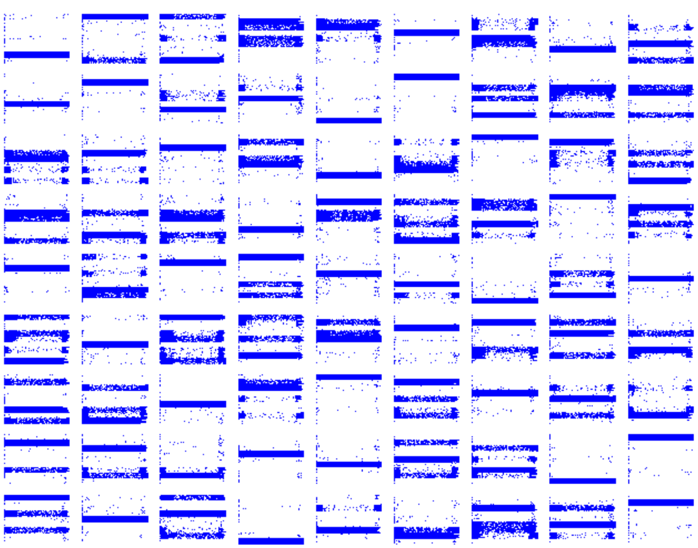
- analyze spike file (~145 lines Python)
- estimate p(N) by counting spikes
  - in a time window
  - normalize across cell
  - use cumulative value with small decay
- choose digit with highest p(N)
- H = sum [-p log2 p] over all digits & cells
- Max H: 81 x 9 x [-p log2 p] where p = 1/9

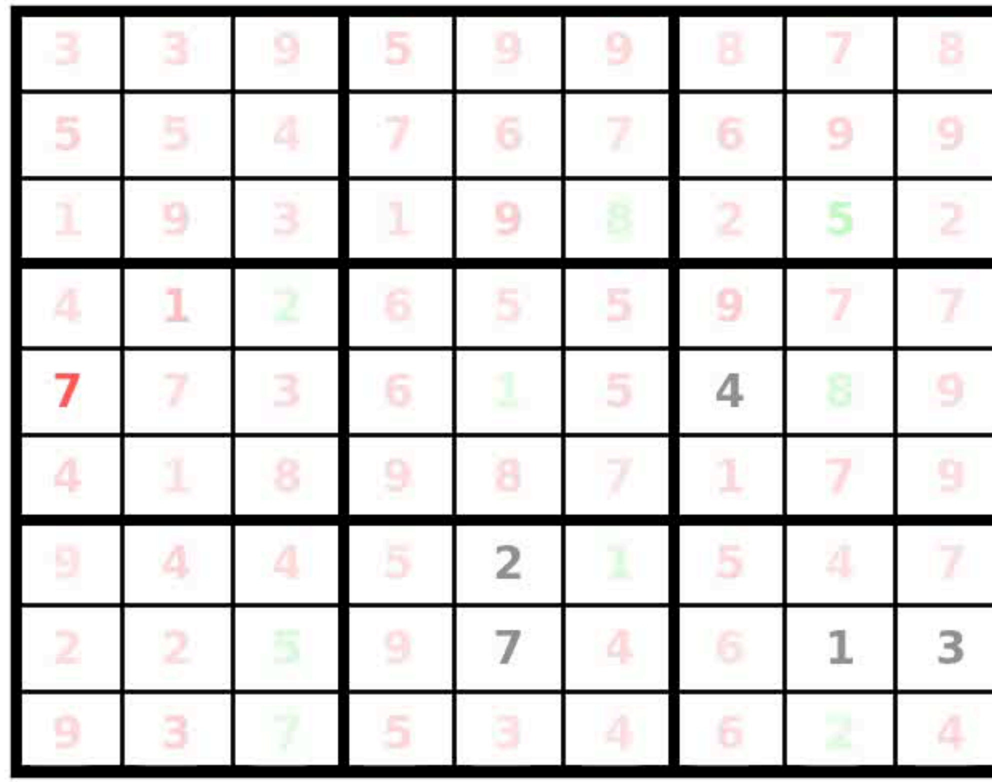
  = 256.8

Solve: w_n = 1.6



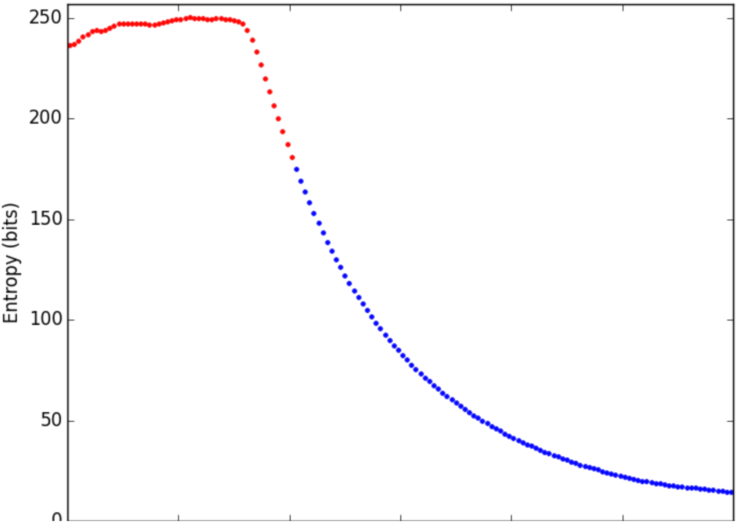
Entropy (bits)
250
200
150
100
50
0
0
5000
10000
15000
20000
25000
30000

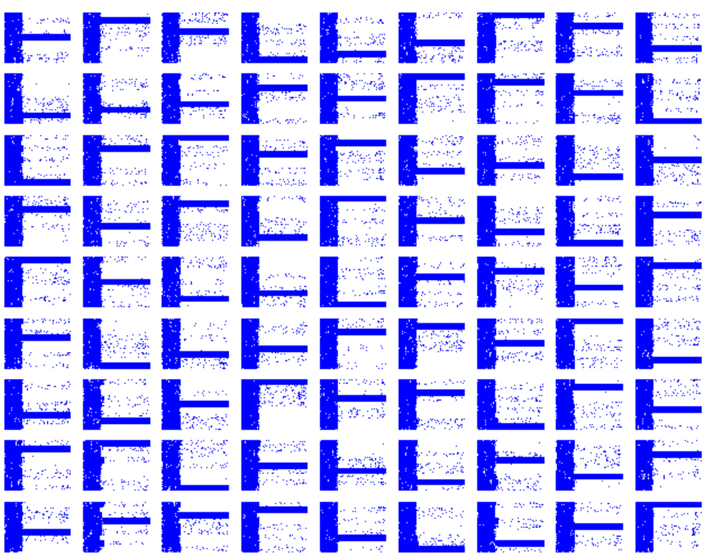




3 3 9 5 9 9 8 7 8
5 5 4 7 6 7 6 9 9
1 9 3 1 9 8 2 5 2
4 1 2 6 5 5 9 7 7
7 7 3 6 1 5 4 8 9
4 1 8 9 8 7 1 7 9
9 4 4 5 2 1 5 4 7
2 2 5 9 7 4 6 1 3
9 3 7 5 3 4 6 2 4

Dream: w_n = 1.0





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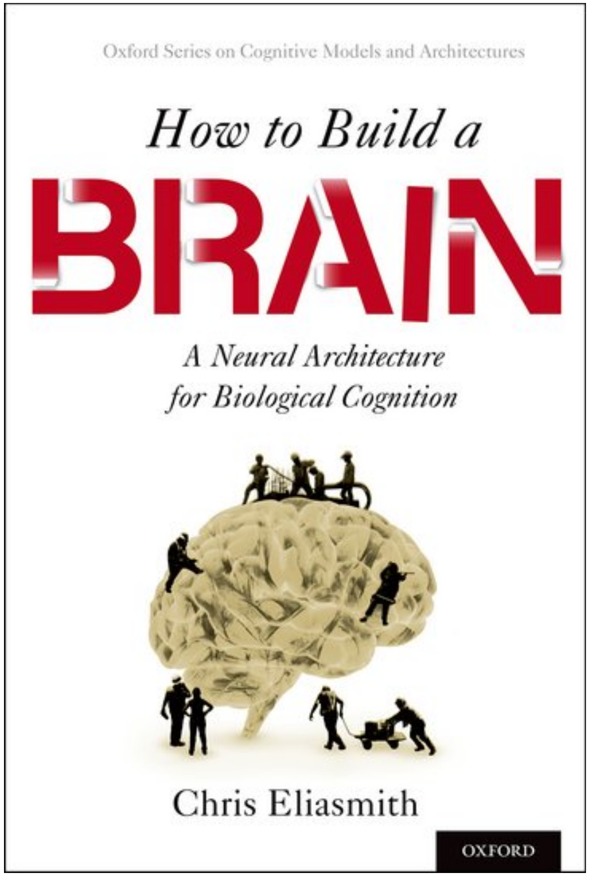
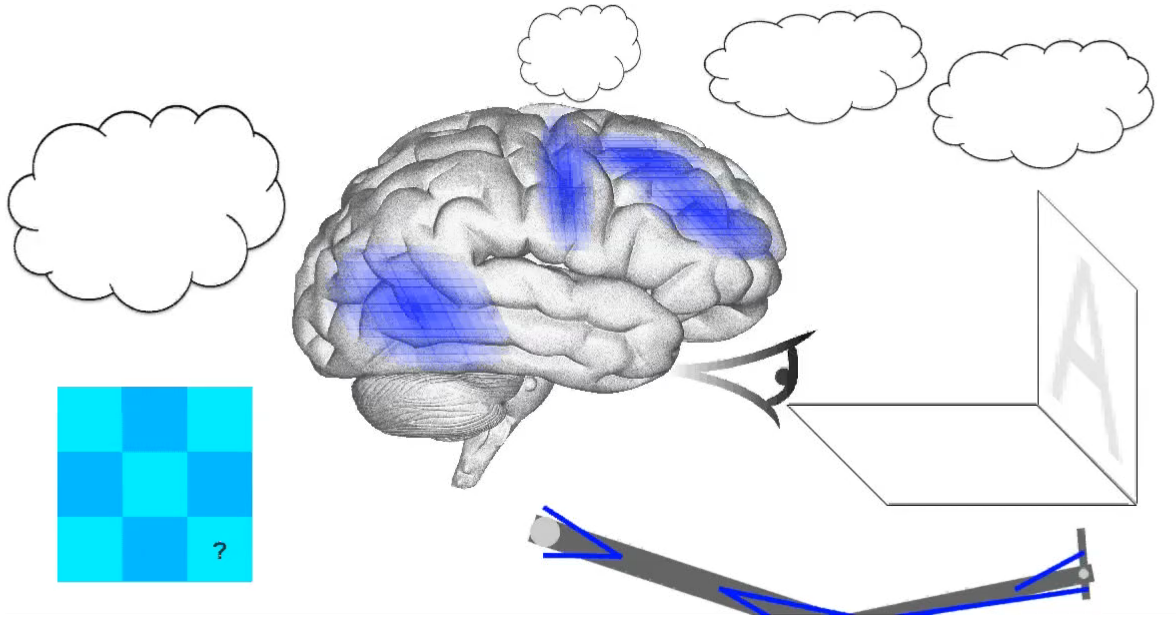
Spaun





Cluster machine:

- 2.5 hours/sec

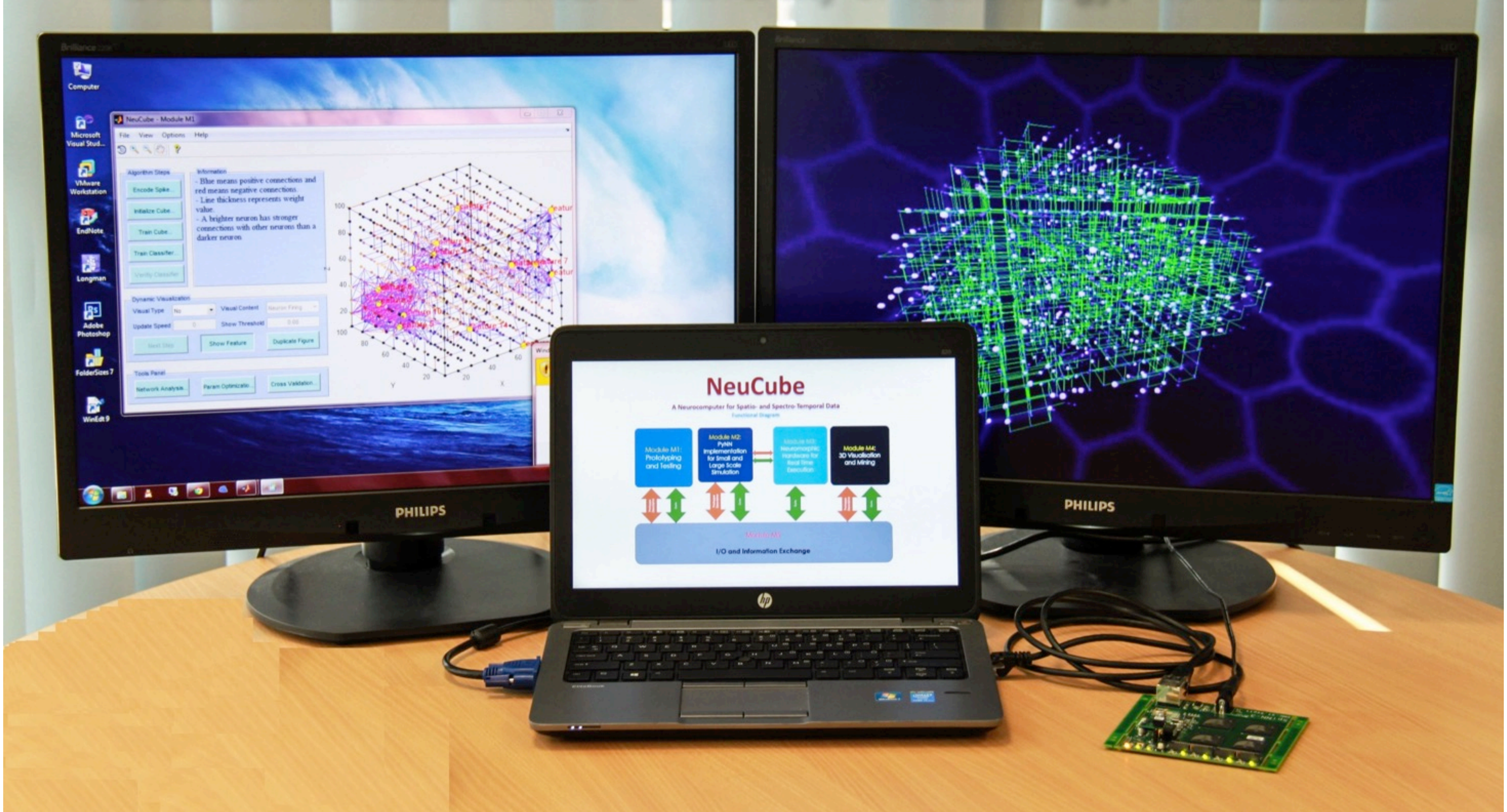
SpiNNaker:

- 12,000 ARMs
- 15x 48-node PCBs
- real-time - soon!

Chris Eliasmith et al, Science vol. 338, 30 Nov 2012

SpiNNaker port by Andrew Mundy

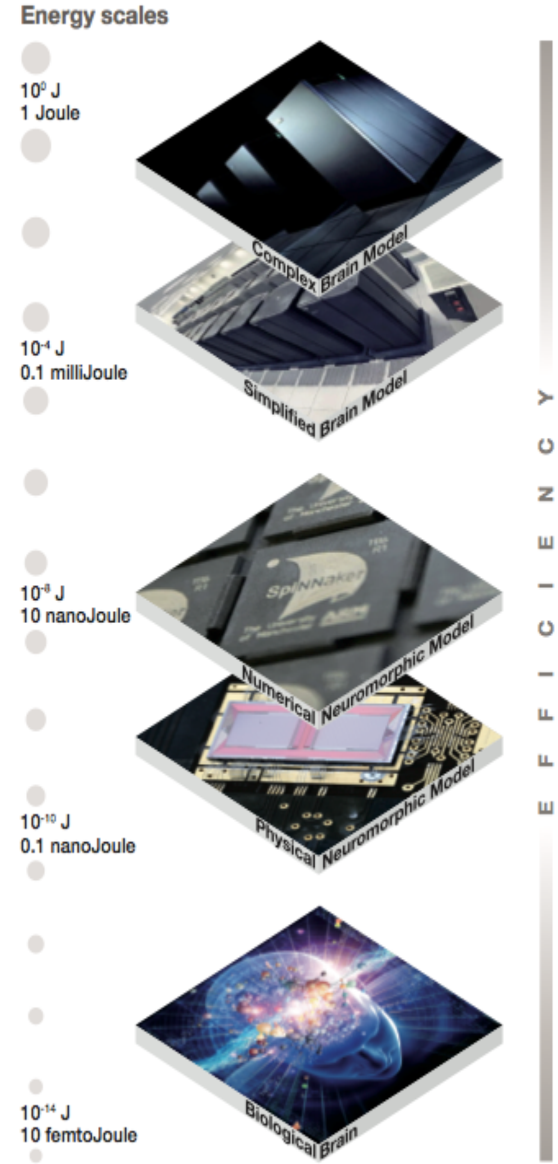
External SpiNNaker user example: Knowledge Engineering & Discovery Research Institute, Auckland University of Technology, New Zealand



NeuCube: Spiking Neural Network Development System for Spatio/Spectro Temporal Data

Conclusions

- *SpiNNaker:*
  - has been 15 years in conception…
  - …and 8 years in construction,
  - and is now ready for action!
- ~70 boards with groups around the world
- 20,000 and 100,000 core machines built
  - 1M core machine to follow soon
  - large models: Spaun, …?
- HBP is supporting s/w development
  - leading to open access



Credits

Evie Andrew
Patrick Camilleri
Dave Clark
Simon Davidson
Sergio Davies
Francesco Galluppi
Garibaldi Pineda Garcia
Jim Garside
Martin Grymel
Yebin Shi
Alan Stokes
Evangelos Stromatias

Jonathan Heathcote
Michael Hopkins
Mukaram Khan
Jamie Knight
Dave Lester
Gengting Liu
Qian Liu
Xin-Jin Liu
Joanna Moy
Steve Temple
Andrew Webb
Viv Woods

Andrew Mundy
Javier Navaridas
Eustace Painkras
Cameron Patterson
Luis Plana
Alex Rast
Dominic Richards
Andrew Rowley
Tom Sharp
Jian Wu
Shufan Yang
…