

# *SpiNNaker*

and the

## Human Brain Project



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European Research Council  
Established by the European Commission



The University of Manchester



The  
University  
Of  
Sheffield.



Human Brain Project

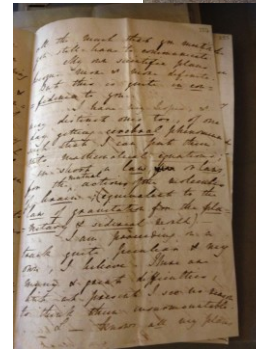


UNIVERSITY OF  
Southampton

# 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
- The Human Brain Project
- Building brains
- The ***SpiNNaker*** project
- The future



# 60 years ago...



VOL. LIX. No. 236.]

[October, 1950

## MIND

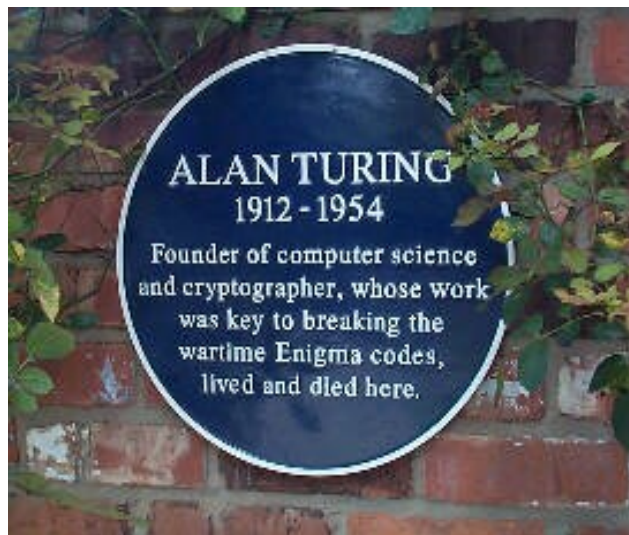
A QUARTERLY REVIEW  
 OF  
 PSYCHOLOGY AND PHILOSOPHY

### 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

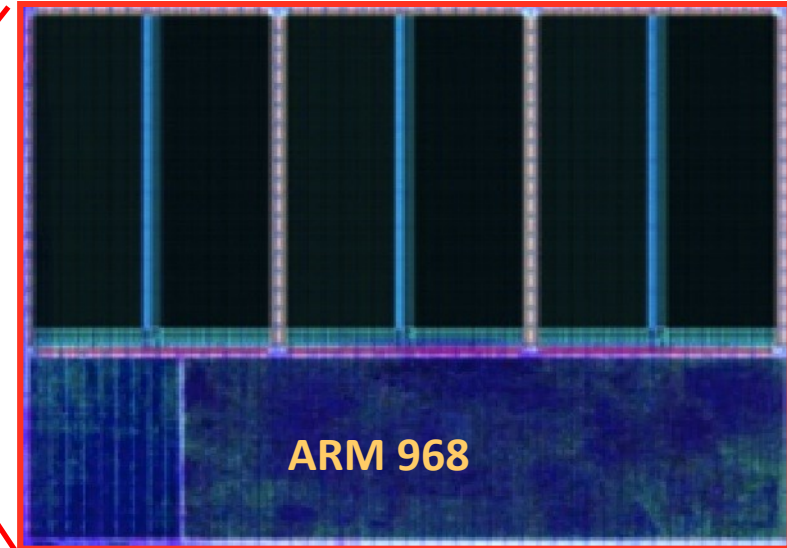
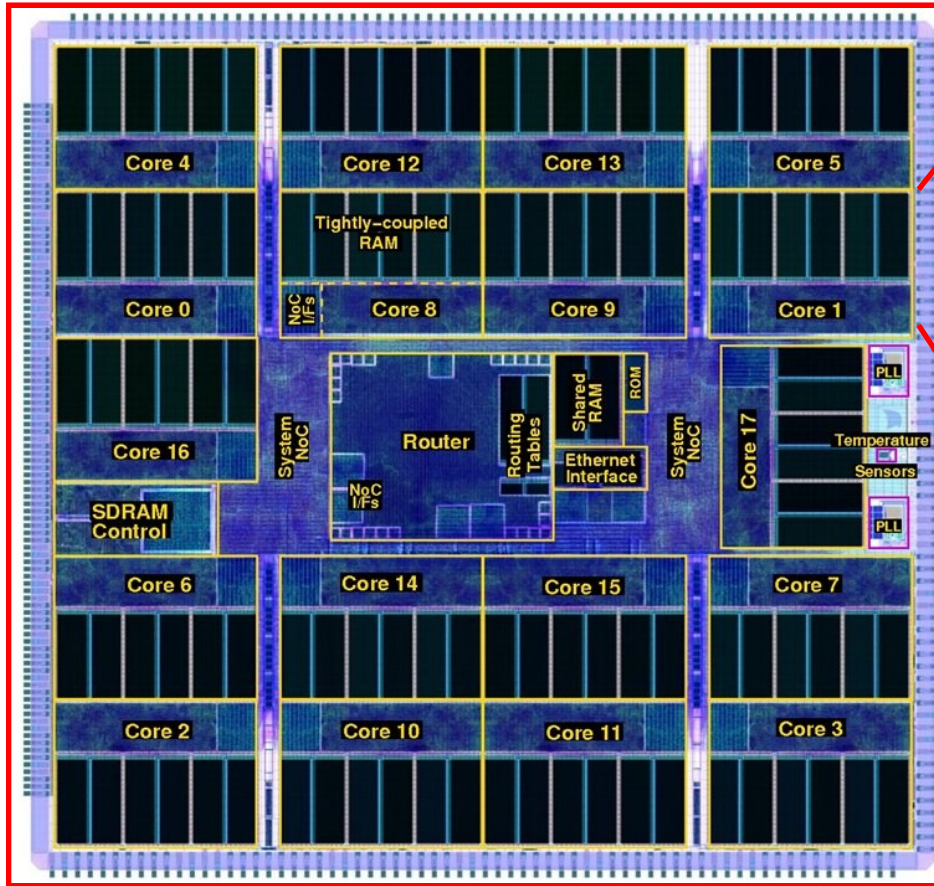


# Manchester Baby (1948)





# *SpiNNaker* 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



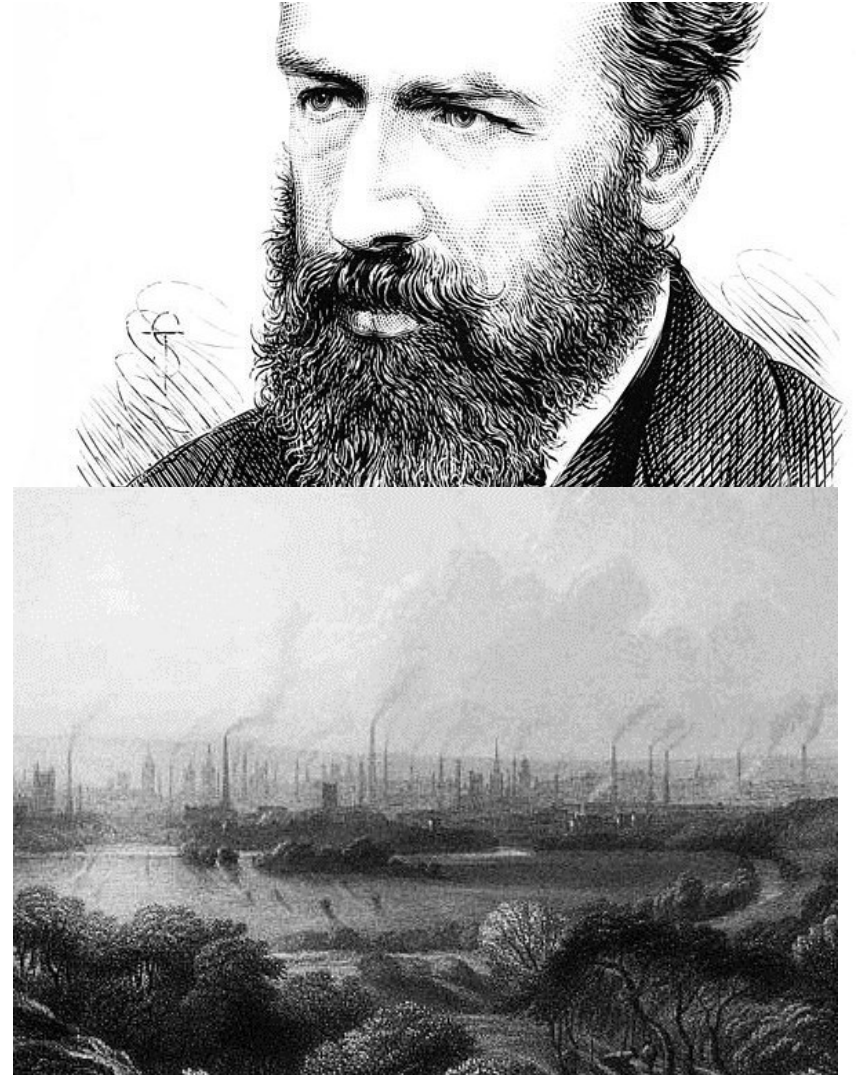
*(James Prescott Joule  
born Salford, 1818)*

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

# 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?

# 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 ( $\sim 100$  Hz)
  - low-speed communication ( $\sim$  metres/sec)
  - adaptivity – tolerant of component failure

# The Human Brain Project



Human Brain Project

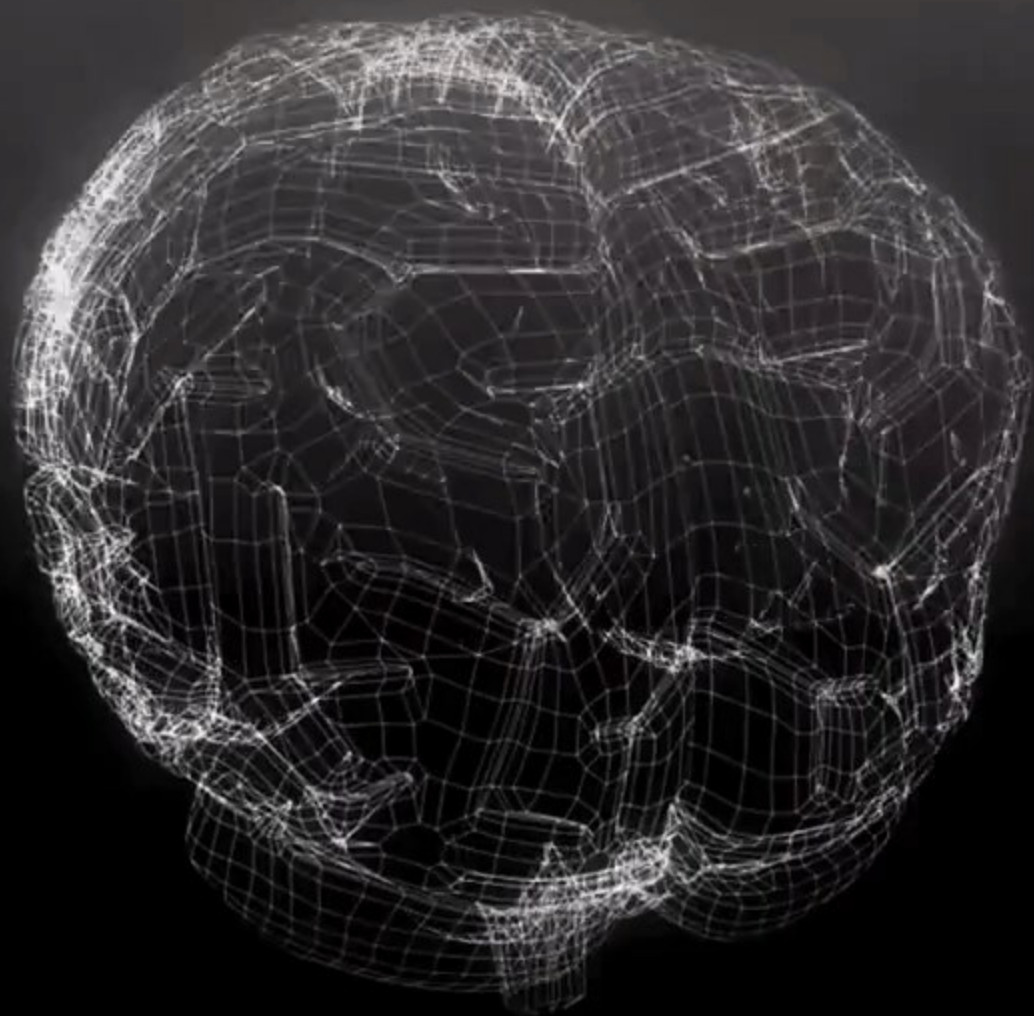
A €1B EU ICT Flagship

Research areas:

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



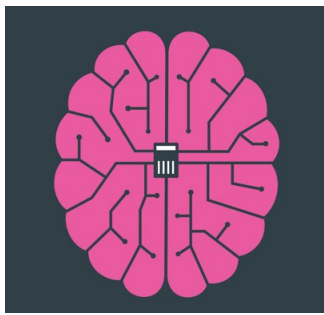




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#### Agricultural Drones

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 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

An alternative design for computer chips that will enhance artificial intelligence.

### Why It Matters

Traditional chips are reaching fundamental performance limits.

### Key Players

+ Qualcomm  
+ IBM  
+ HRL Laboratories  
+ Human Brain Project

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

# Top 10 emerging technologies of 2015

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

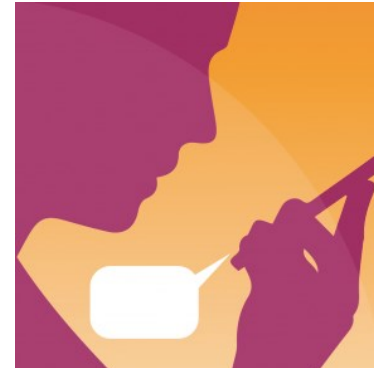
*Computer chips that mimic the human brain*



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.

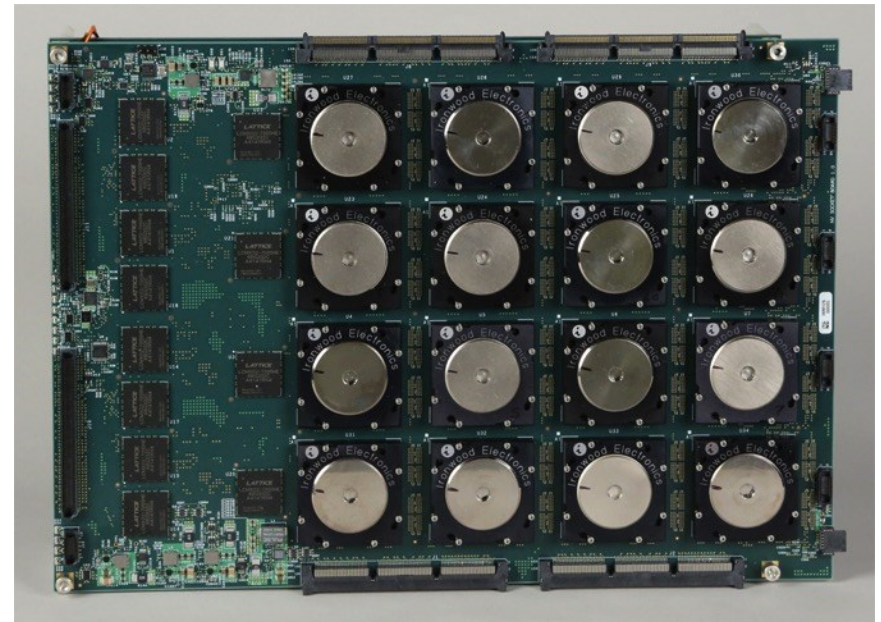
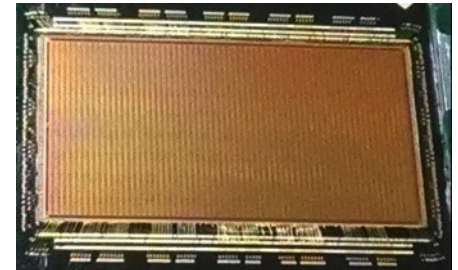
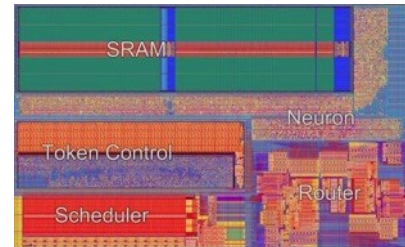
Miniaturization has delivered massive increases in conventional computing power over





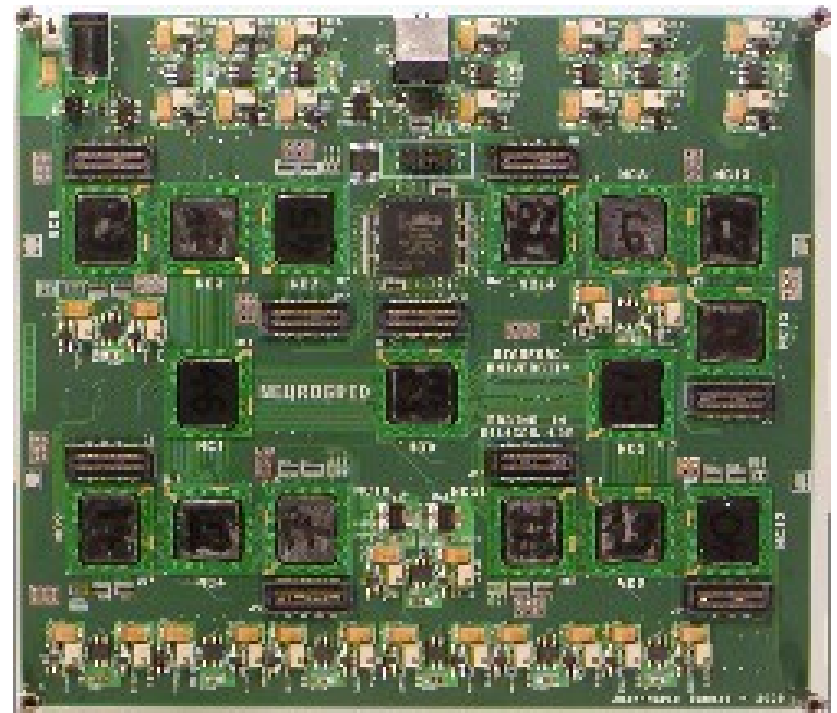
# IBM TrueNorth

- 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.



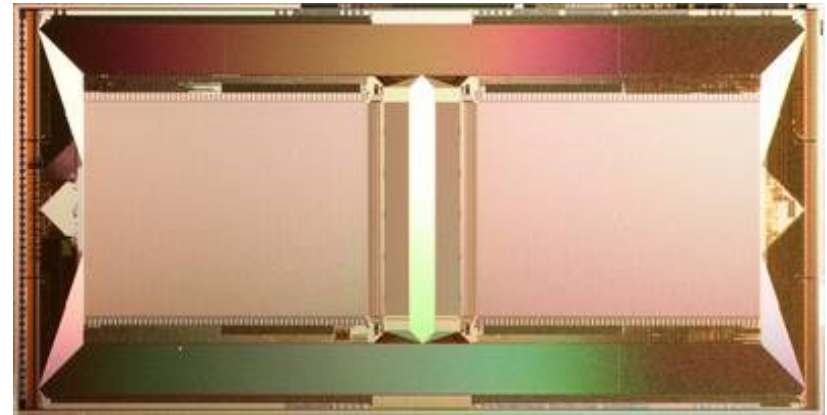
# Stanford Neurogrid

- 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

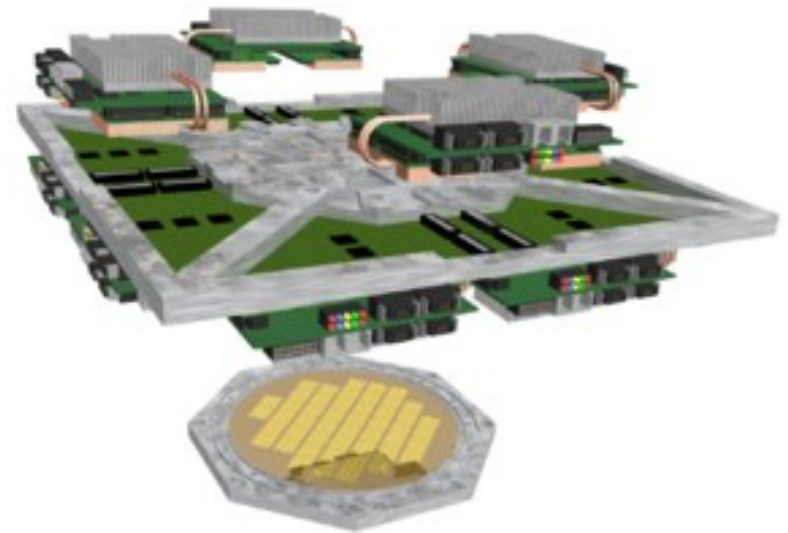


# Heidelberg HiCANN

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

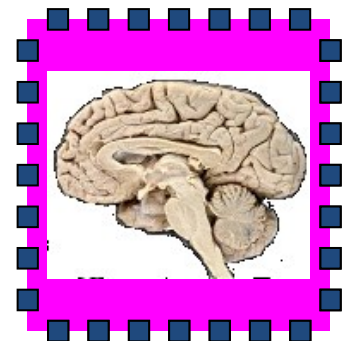


Human Brain Project



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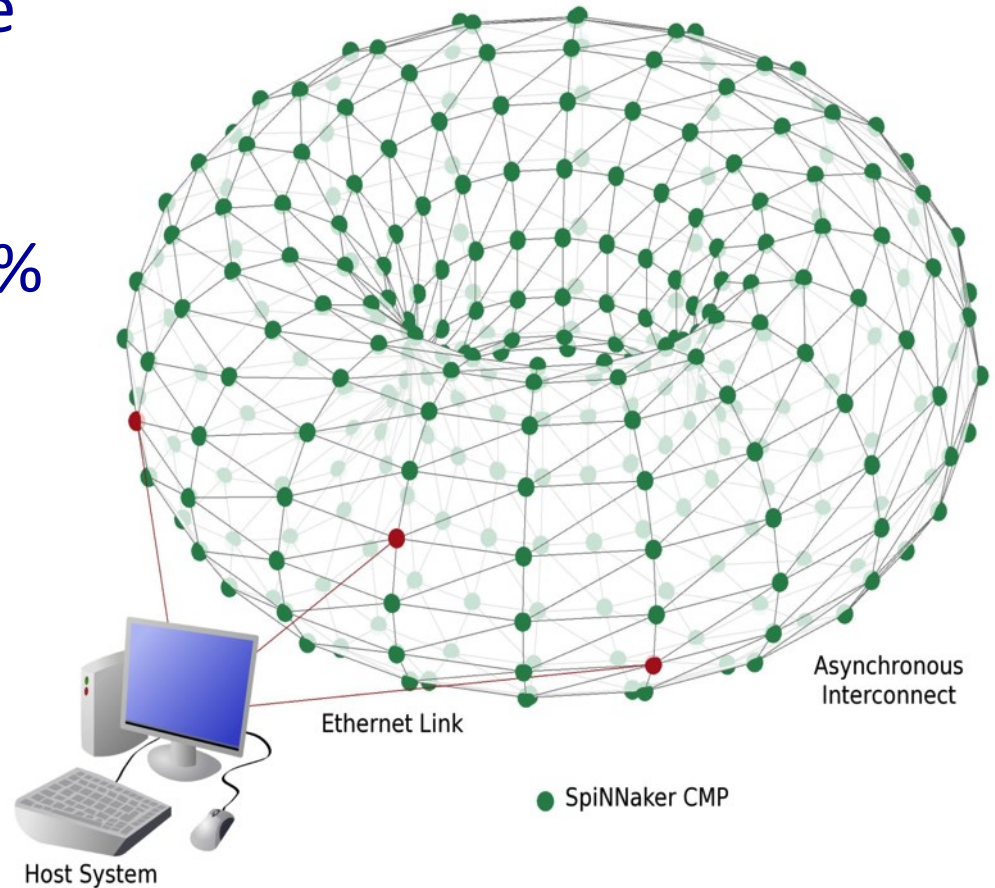


# *SpiNNaker* project

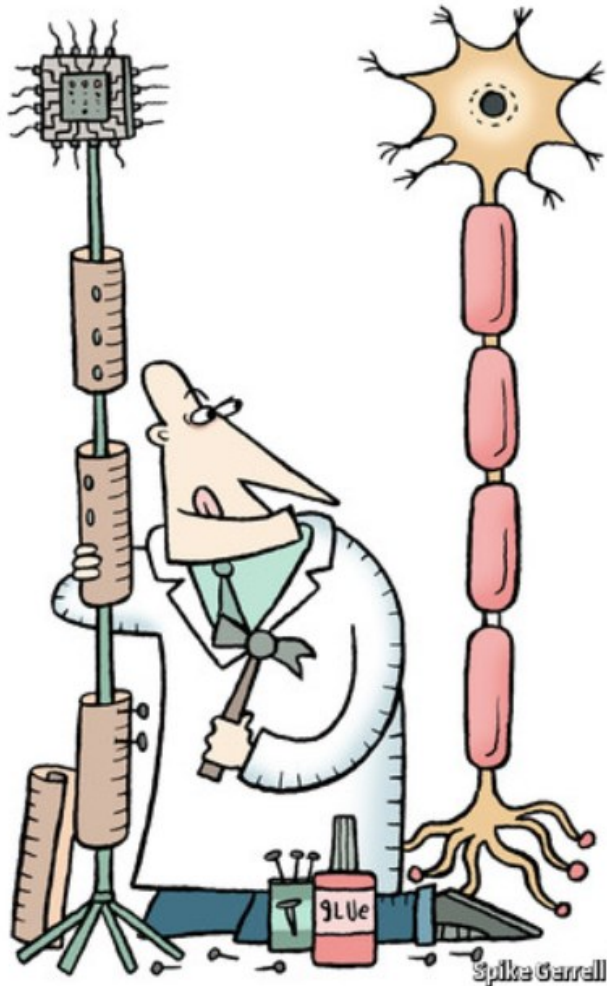
- A million mobile phone processors in one computer
- Able to model about 1% of the human brain...
- ...or 10 mice!



**EPSRC**

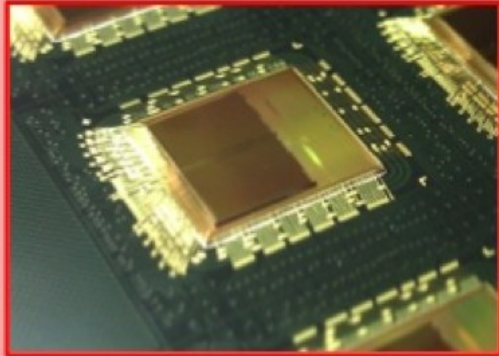


# Design principles

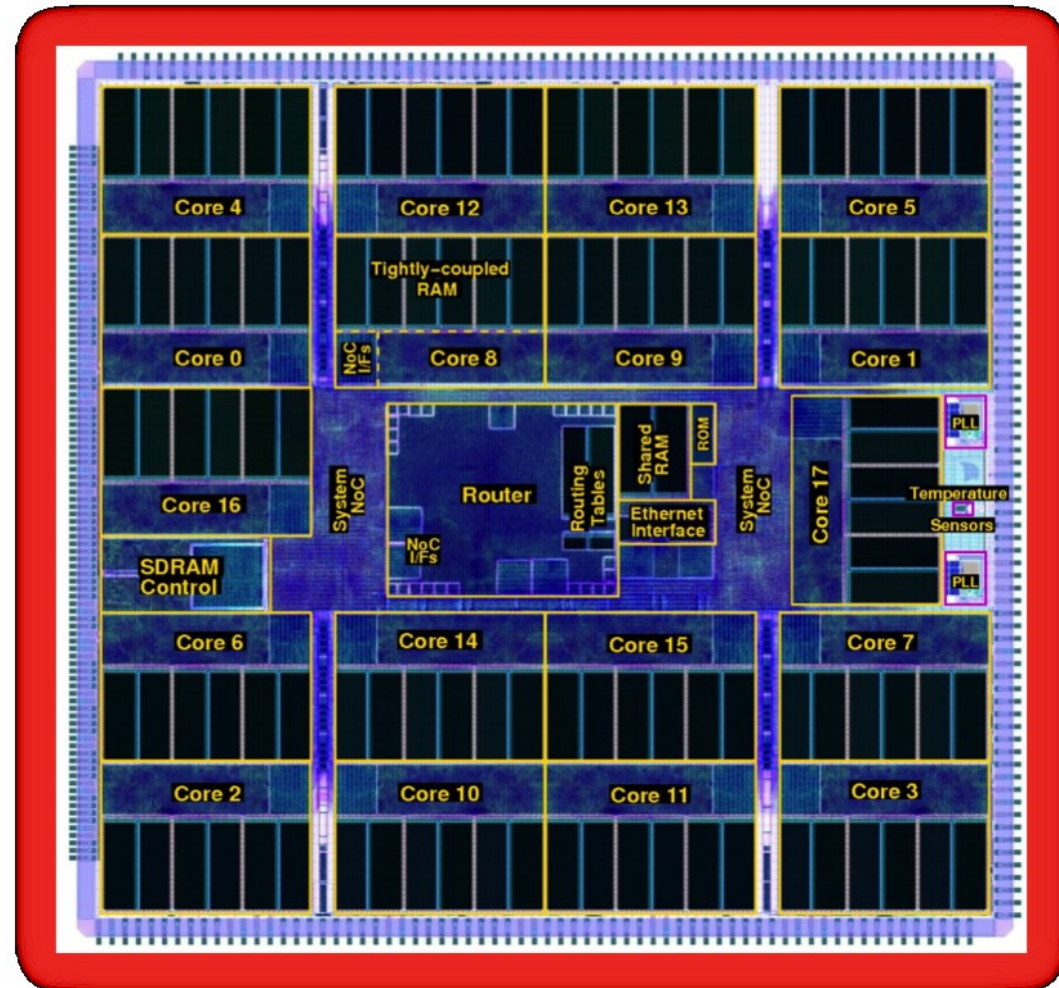


- *Virtualised topology*
  - physical and logical connectivity are decoupled
- *Bounded asynchrony*
  - time models itself
- *Energy frugality*
  - processors are free
  - the real cost of computation is energy

# *SpiNNaker chip*

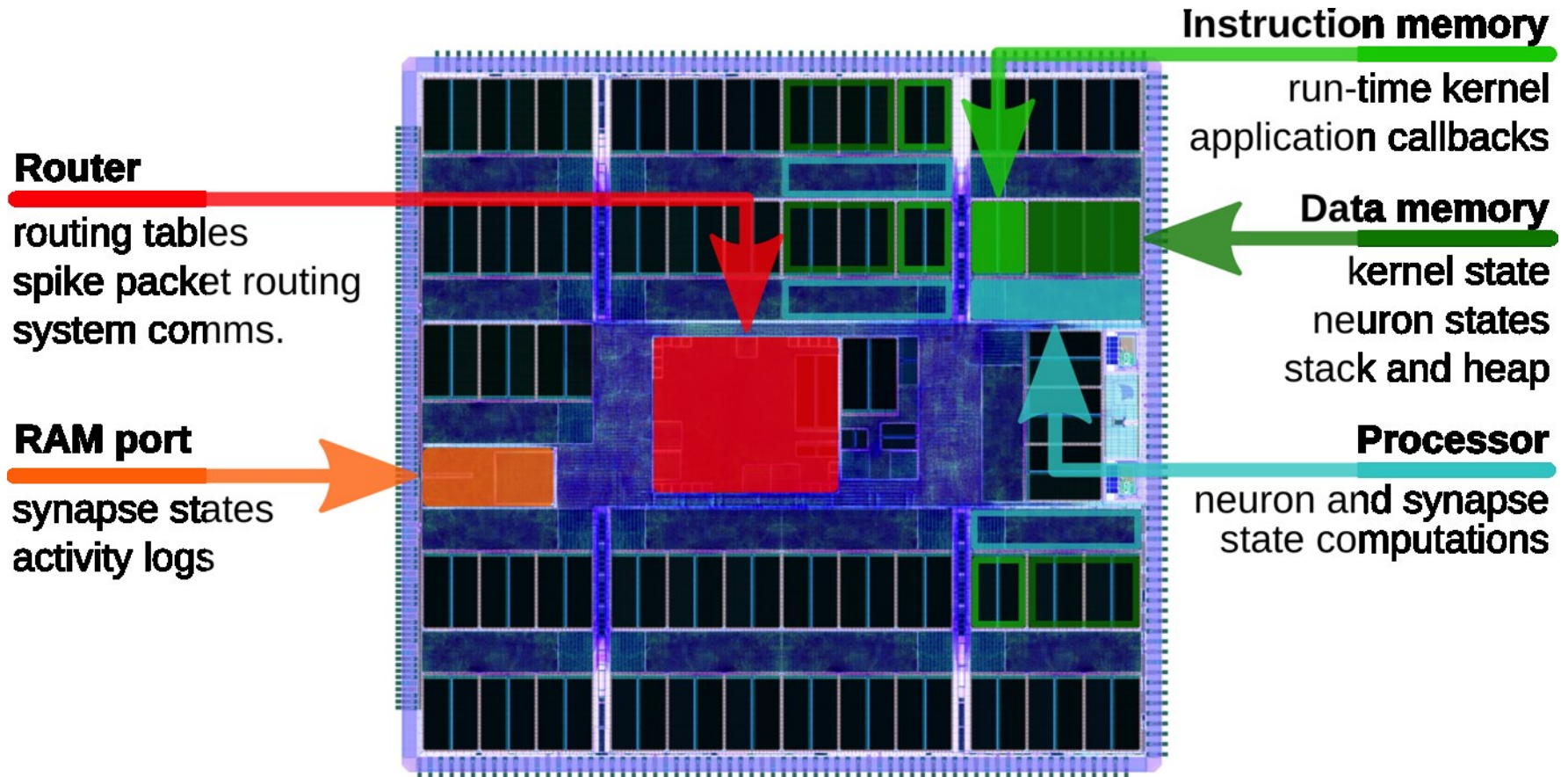


Multi-chip  
 packaging by  
 UNISEM Europe



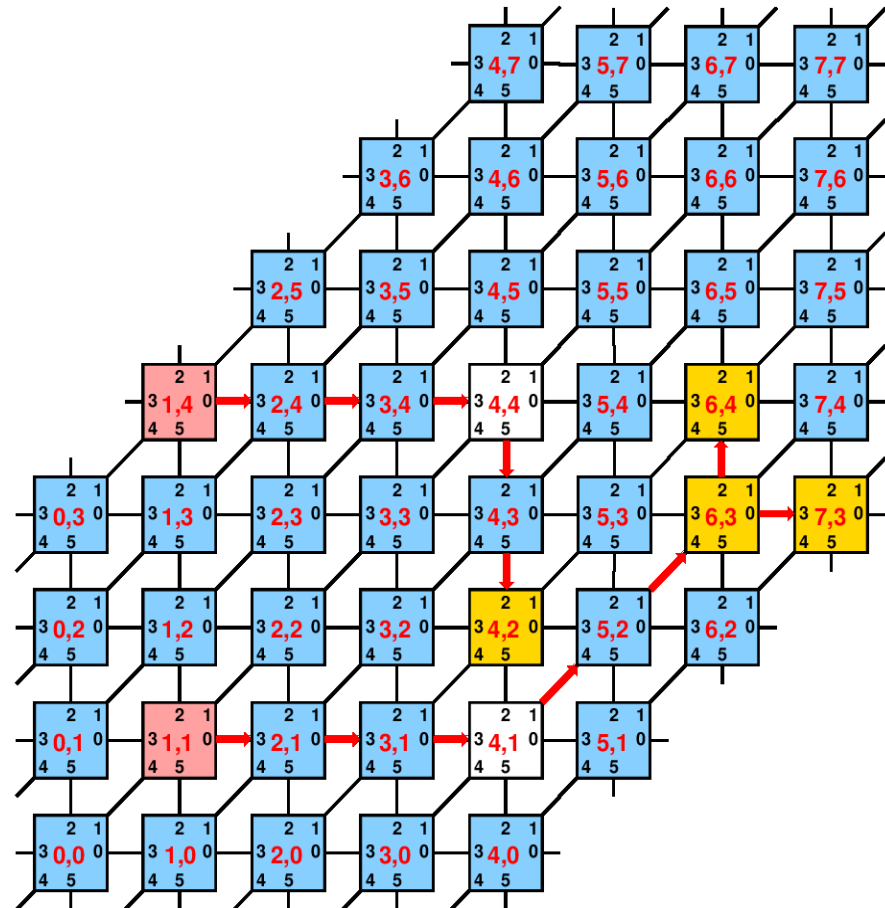
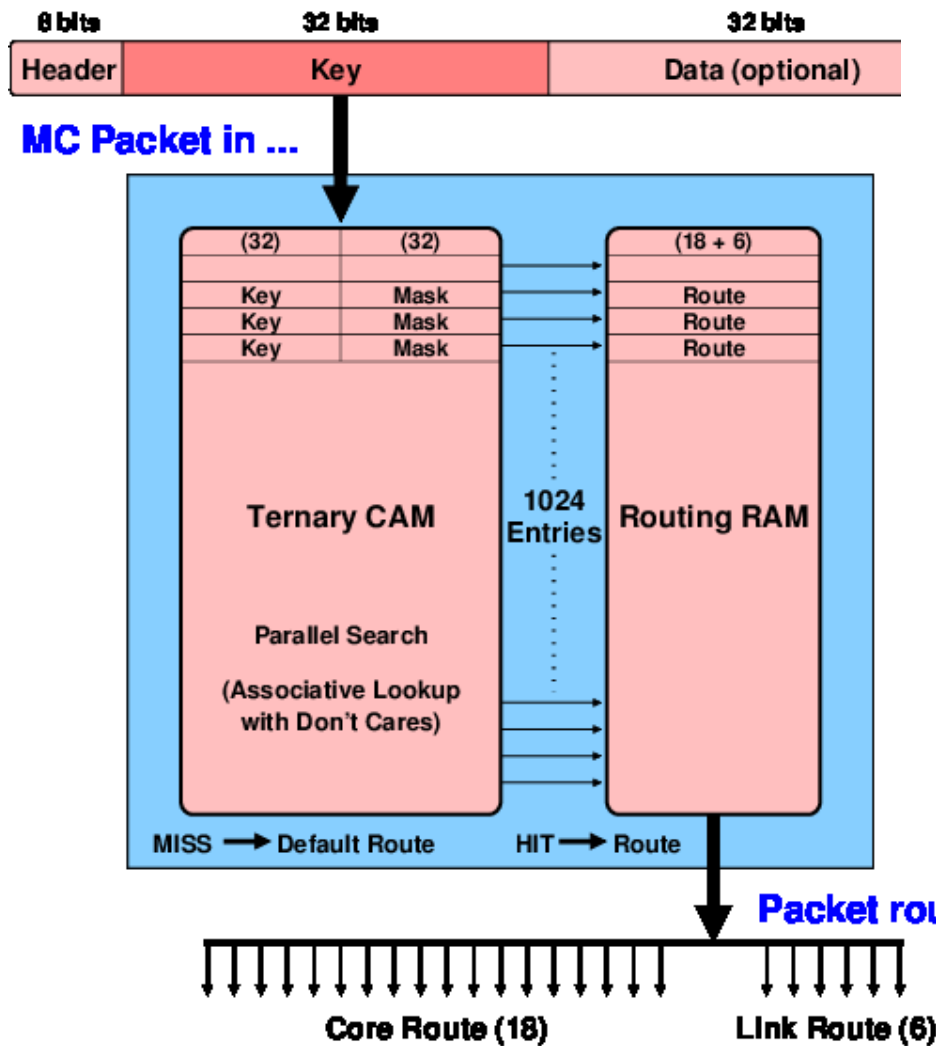


# Chip resources

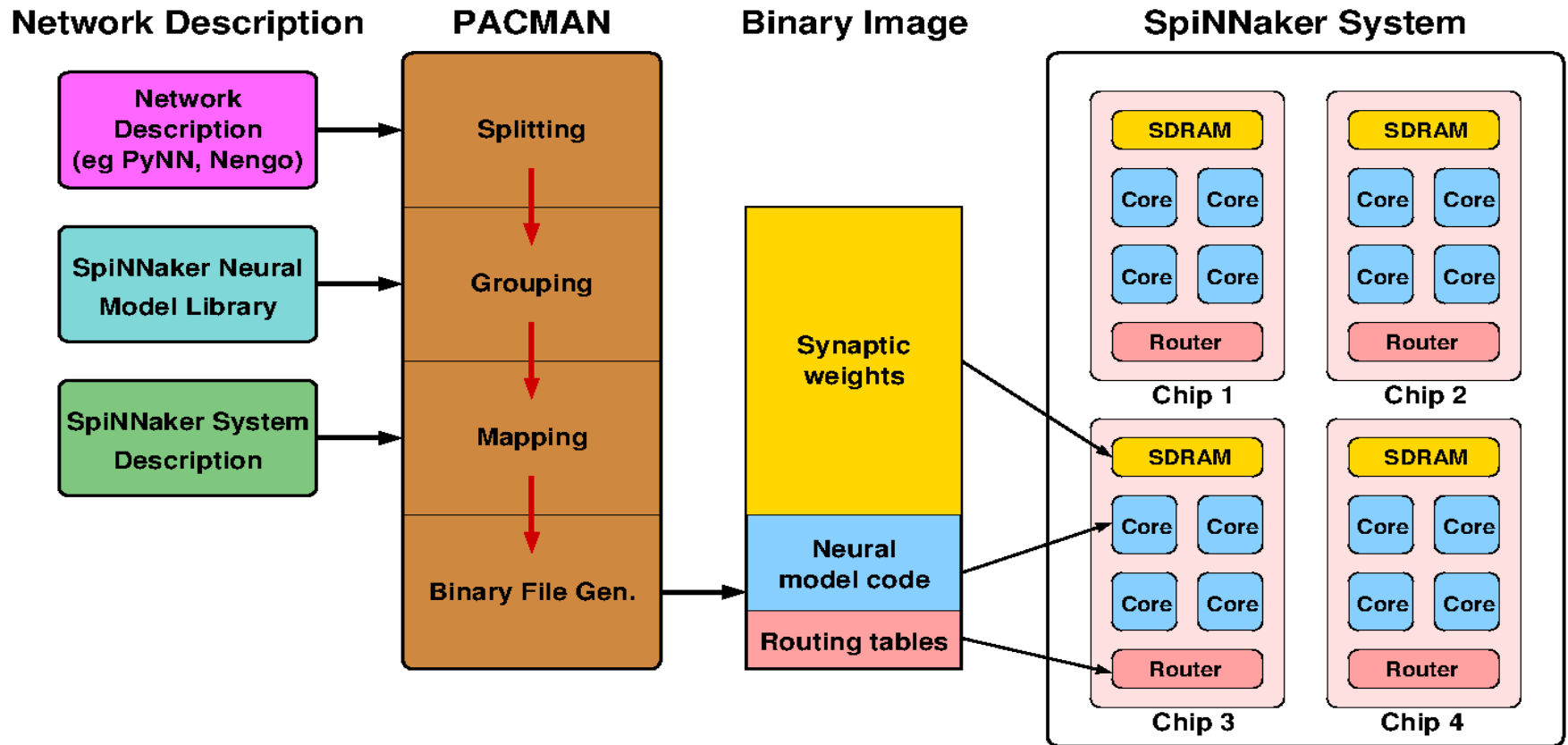




# Multicast routing



# Problem mapping



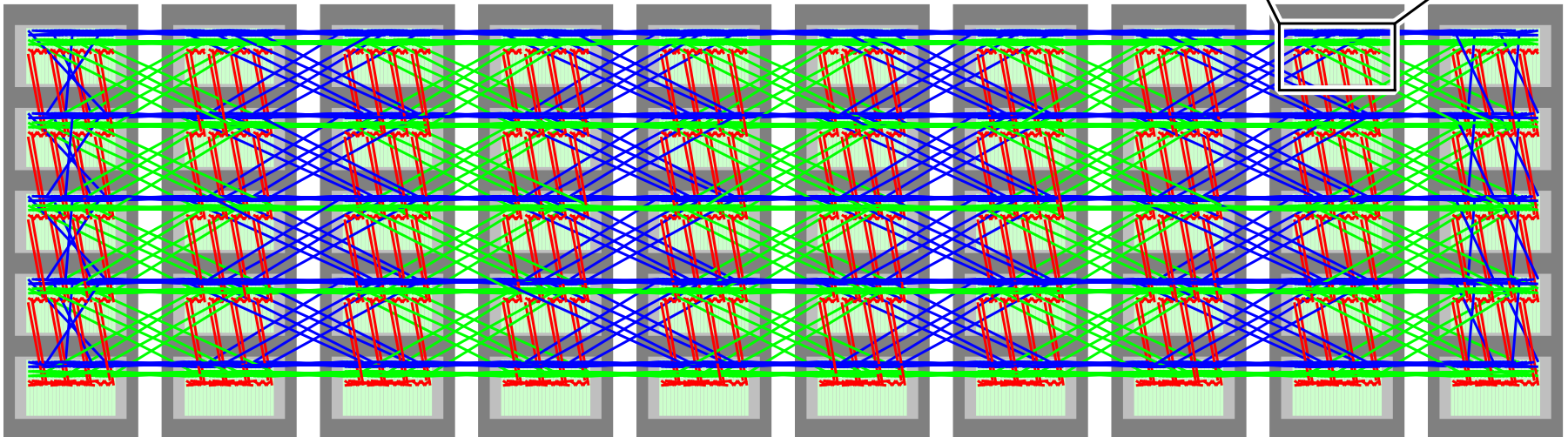
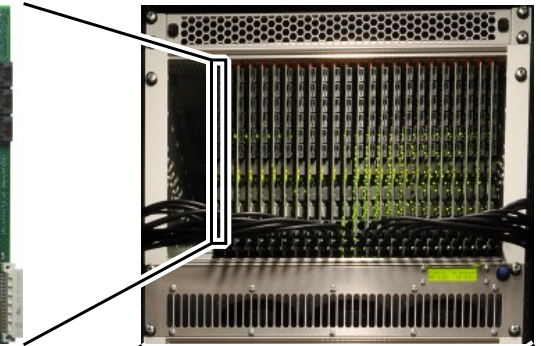
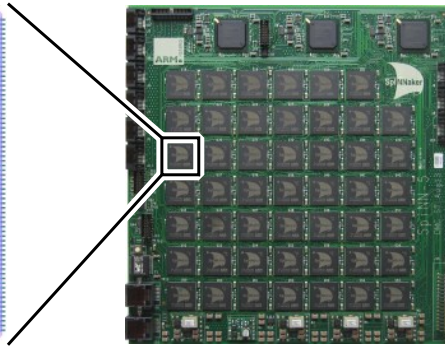
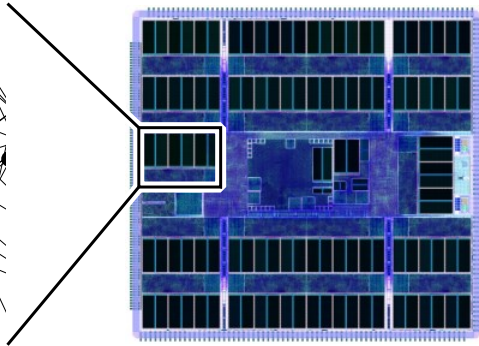
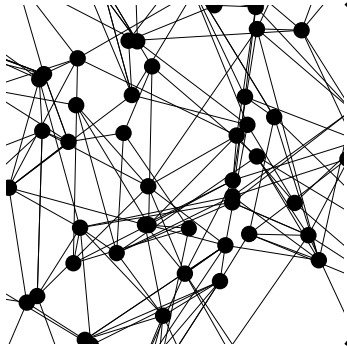
# Scaling to a billion neurons

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



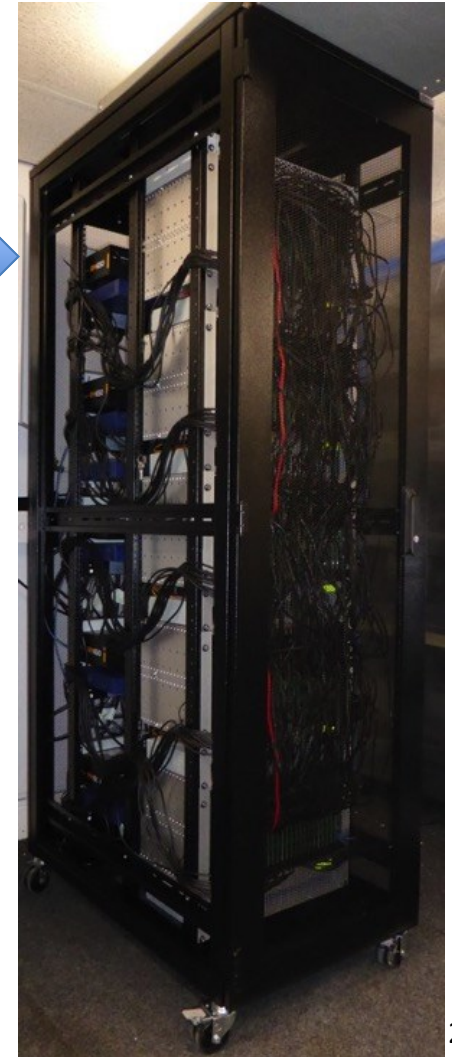
104



20,000 cores  
 – frog scale



105



100,000 cores  
 – mouse scale

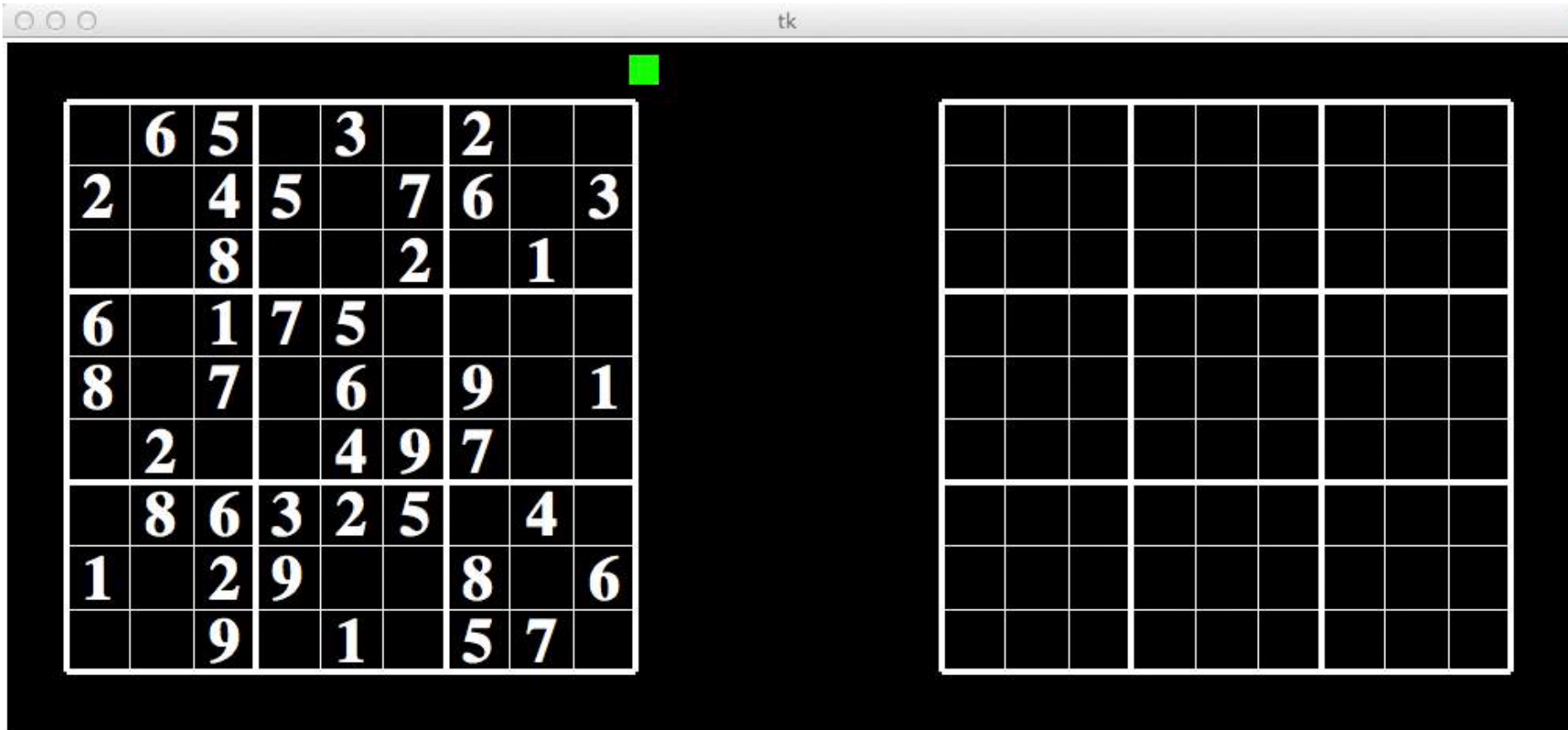
102



72 cores  
 – pond snail scale



# Sudoku on *SpiNNaker*



SpiNNaker model developed by Evie Andrew, based on:  
*S. Habenschuss, Z. Jonke, and W. Maass, "Stochastic computations in cortical microcircuit models", PLOS Computational Biology, 9(11):e1003311, 2013.*

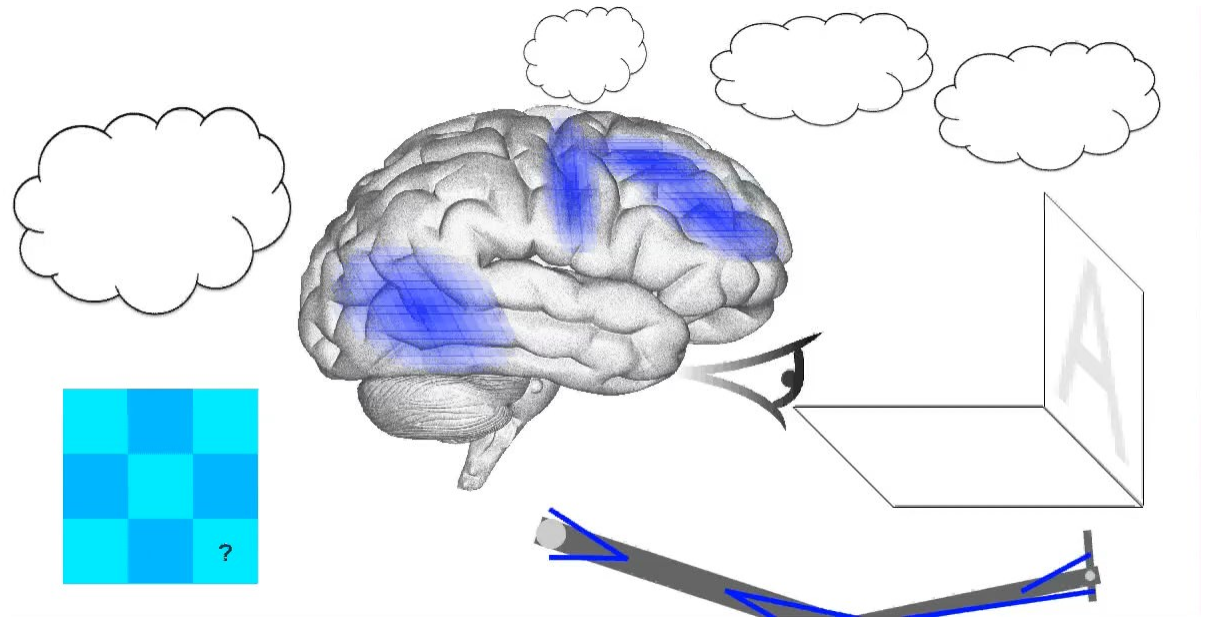
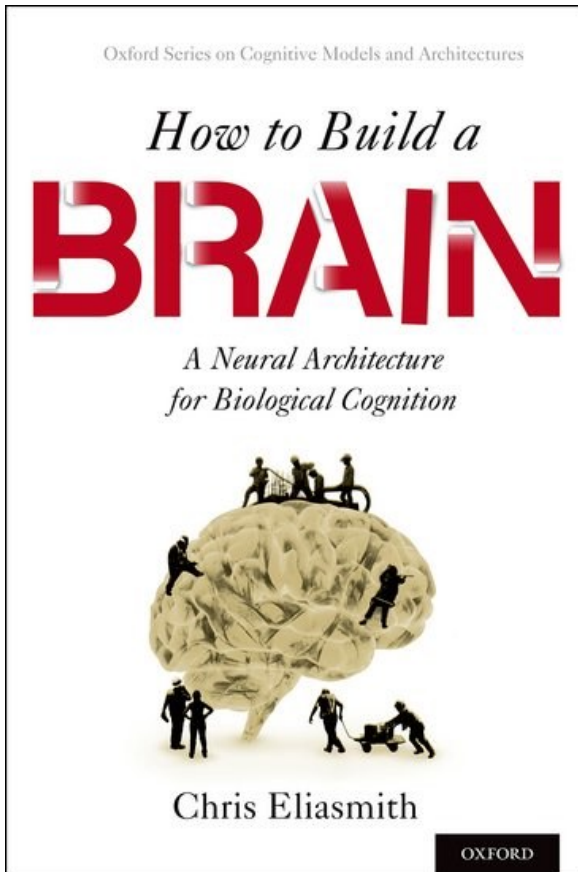


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# Spaun



Cluster machine:

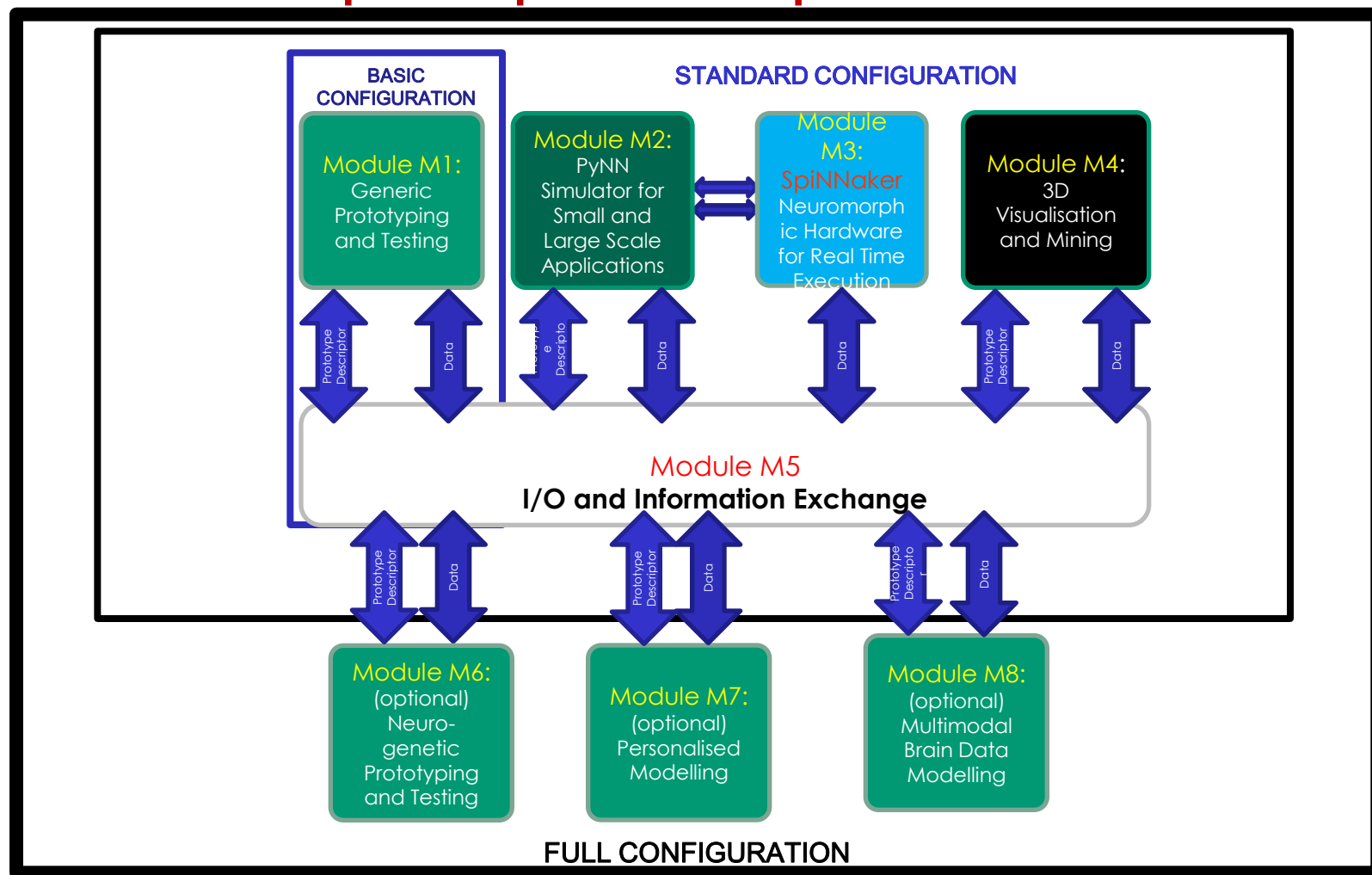
- 2.5 hours/sec

SpiNNaker:

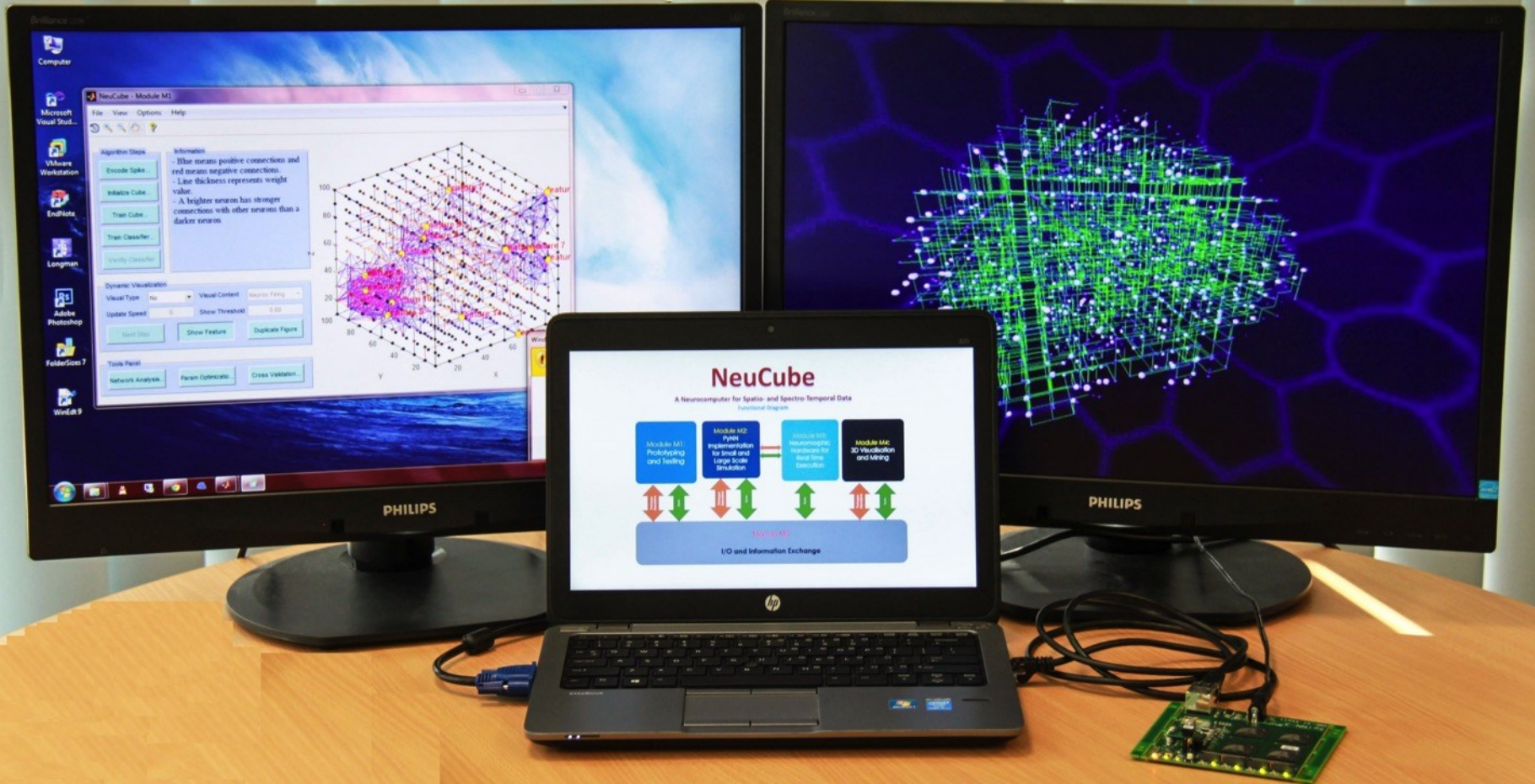
- 25,000 ARMAs
- 30x 48-node PCBs
- real-time - soon!

*Chris Eliasmith et al, Science vol. 338, 30 Nov 2012*  
 SpiNNaker port by Andrew Mundy

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



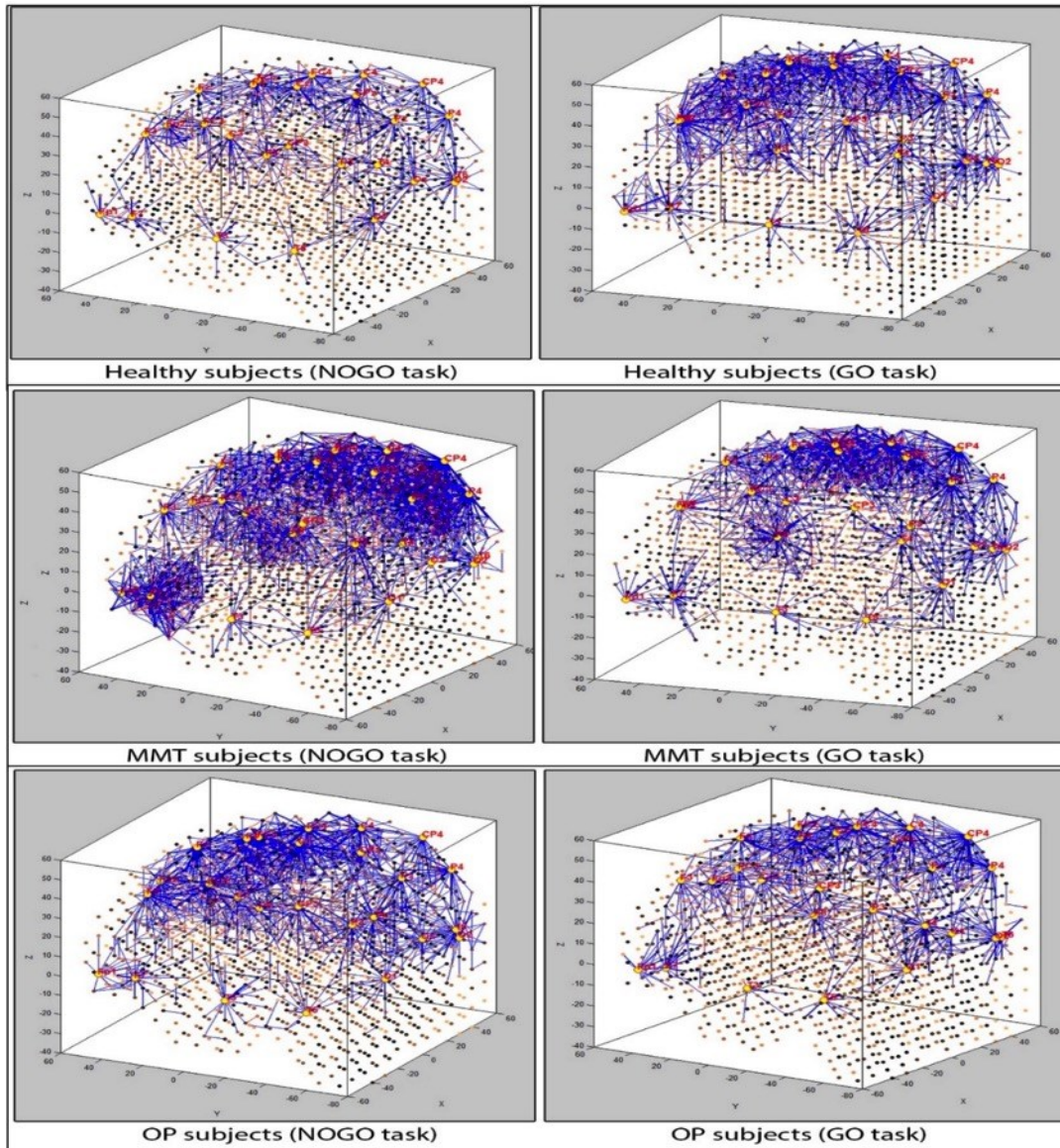
(some modules are available from: [www.kedri.aut.ac.nz](http://www.kedri.aut.ac.nz) -> NeuCube\_)





# Understanding and predicting addicts' response to treatment

E. Capecchi, N. Kasabov, G.Wang, Analysis of connectivity in a NeuCube spiking neural network trained on EEG data for the understanding and prediction of functional changes in the brain: A case study on opiate dependence treatment, Neural Networks, (2015), <http://dx.doi.org/10.1016/j.neunet.2015.03.009>.



Tracing and interpreting dynamic brain activities in the GO/NOGO task performed by three subject groups:

- healthy subjects CO);
- addicts on Methadone treatment (MMT);
- addicts on opiates (OP), i.e. no treatment



# Conclusions

- *SpiNNaker*:
  - has been 15 years in conception...
  - ...and 8 years in construction,
  - and is now ready for action!
- ~40 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
- What can we do with a billion neurons for...
  - Big Data?
  - Machine Learning?



Human Brain Project

Energy scales

