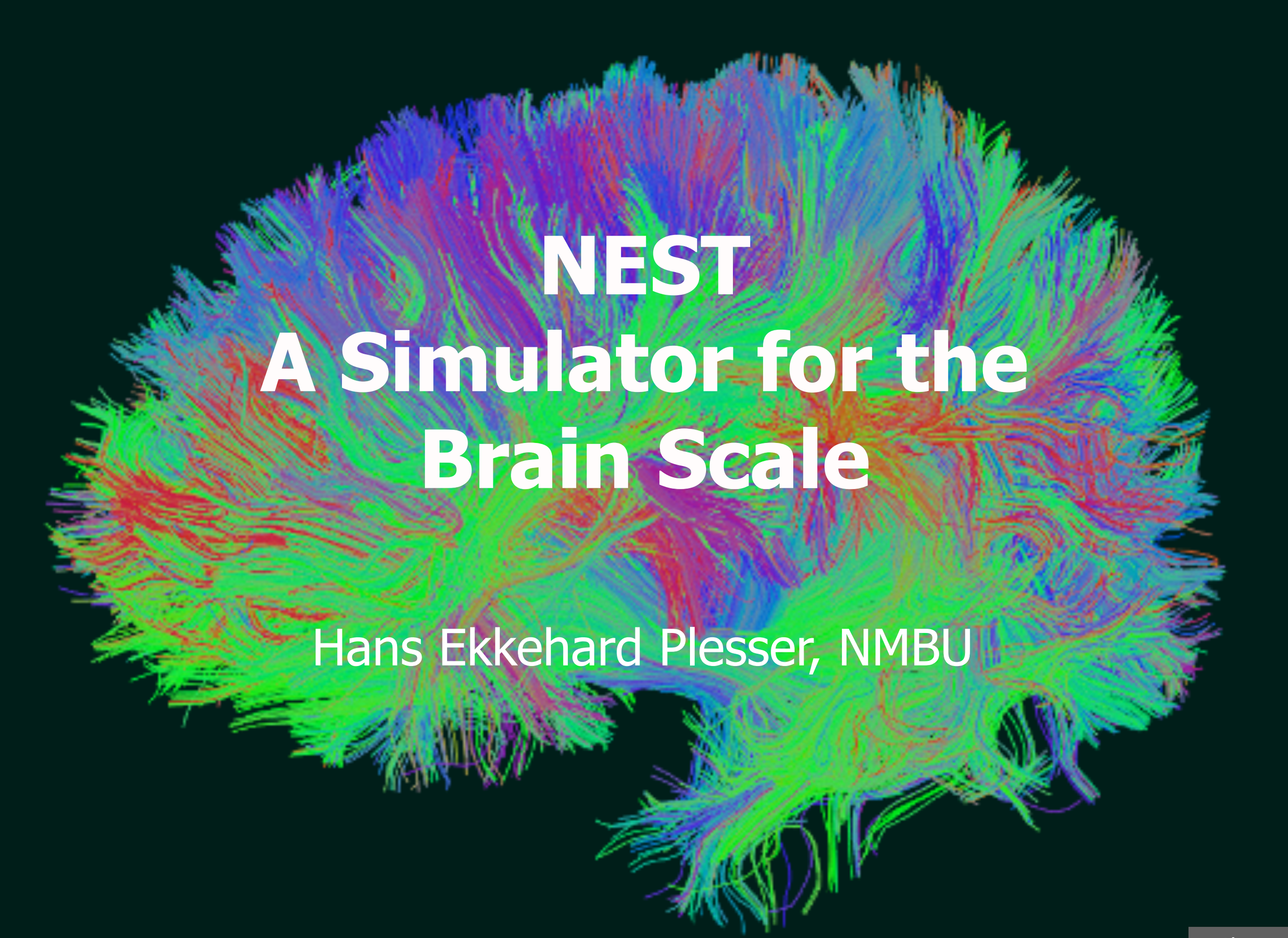
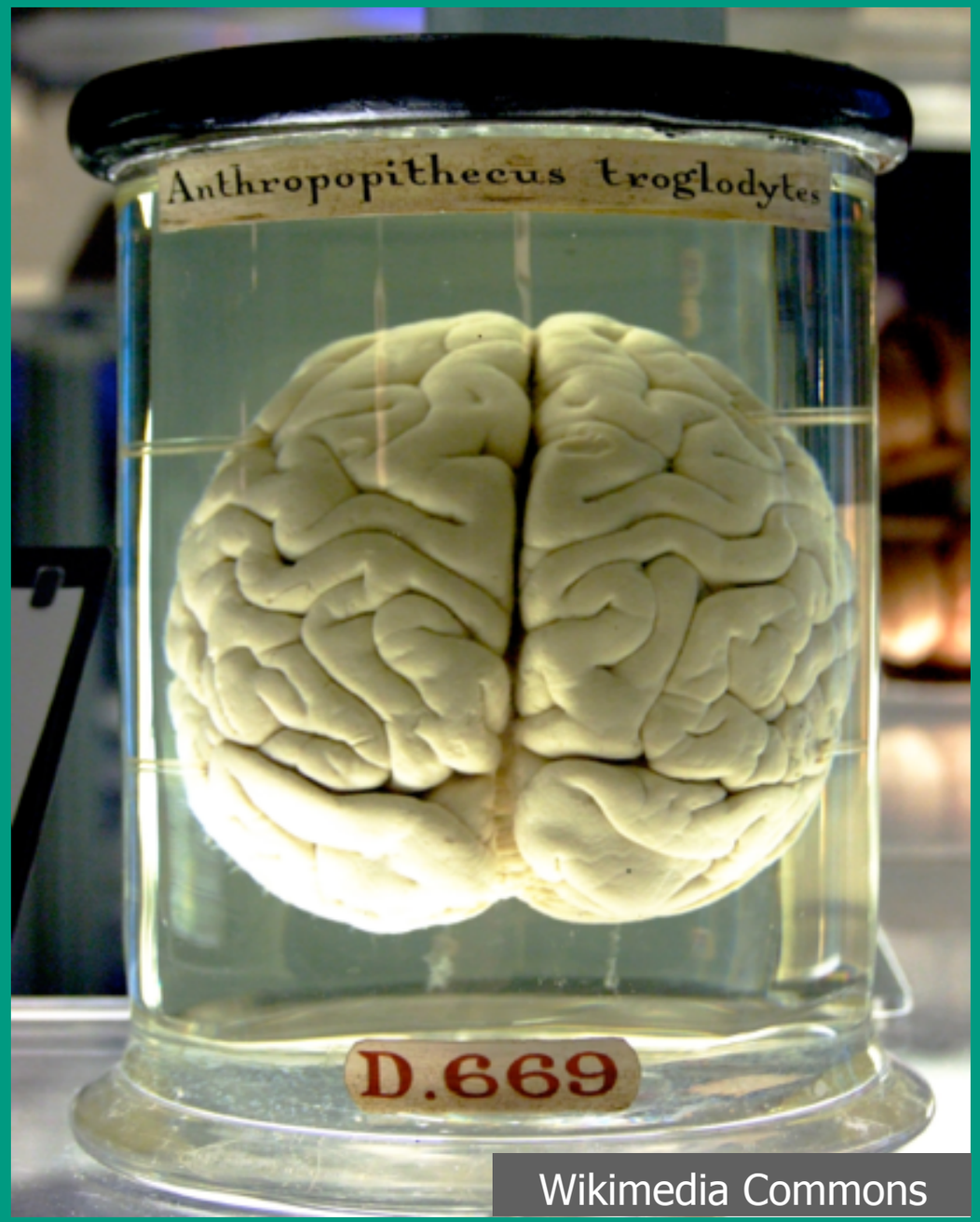


NEST
A Simulator for the Brain Scale

Hans Ekkehard Plesser, NMBU

cmtk.org

What to do we want to simulate?



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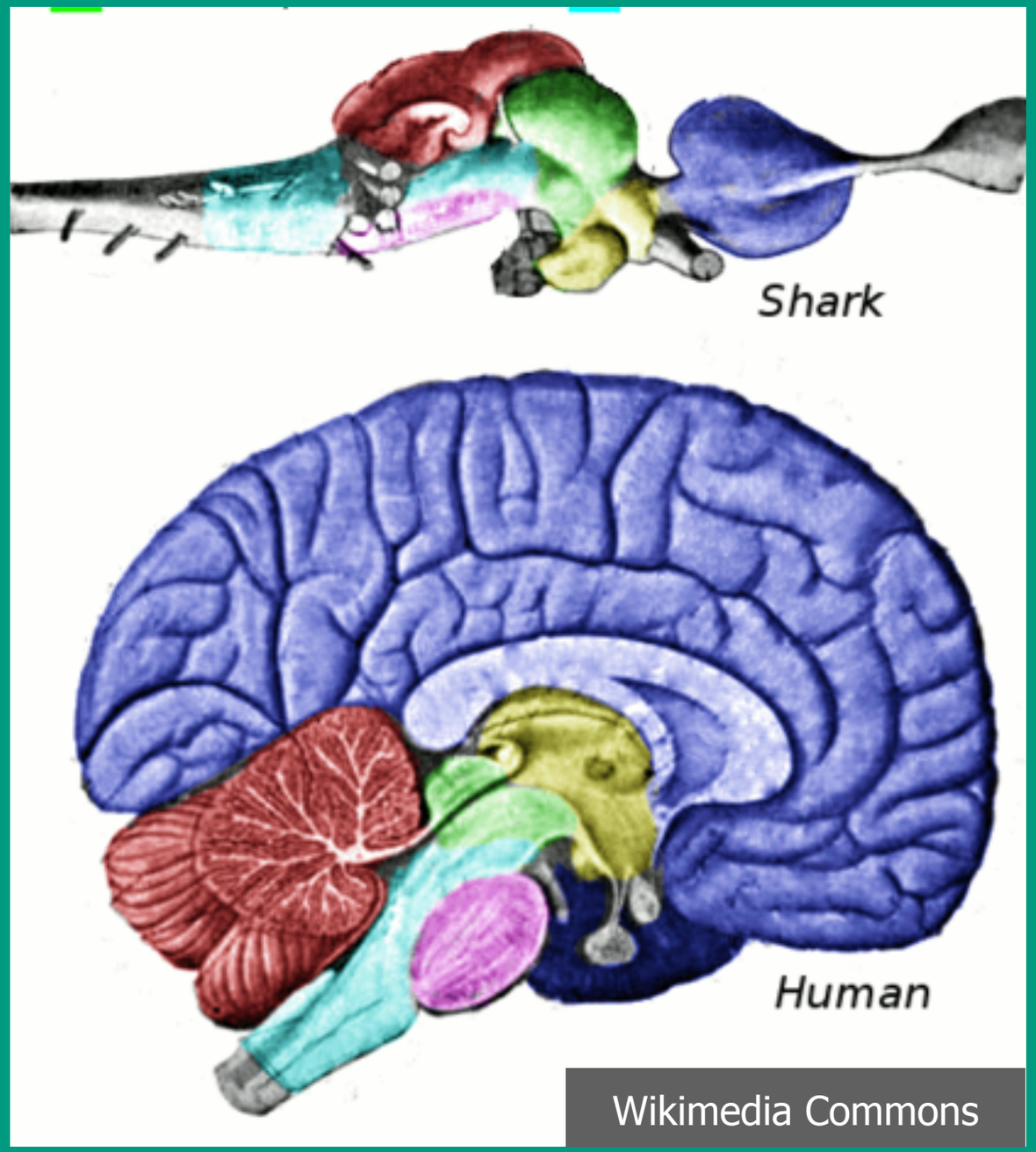

Wikimedia Commons

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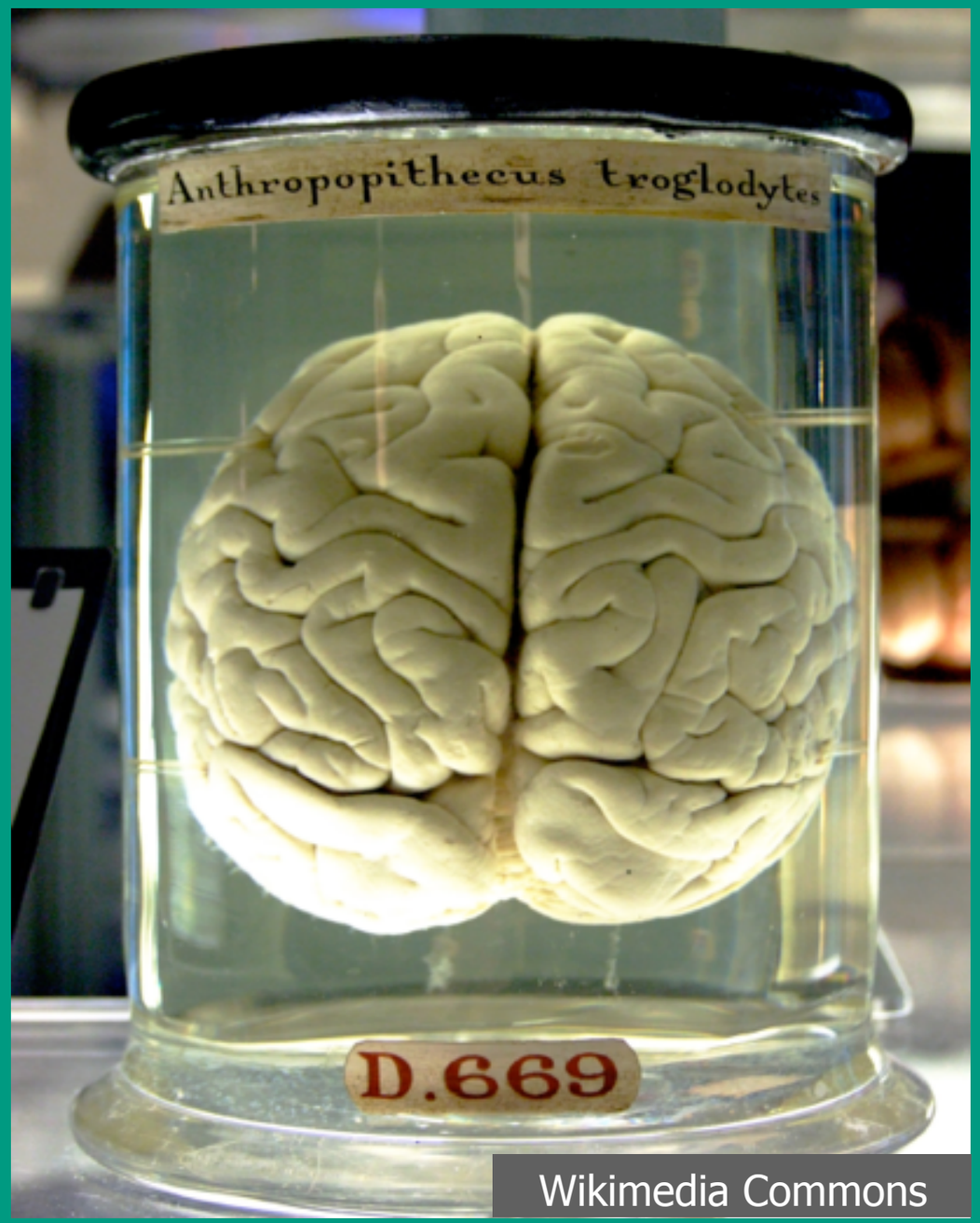

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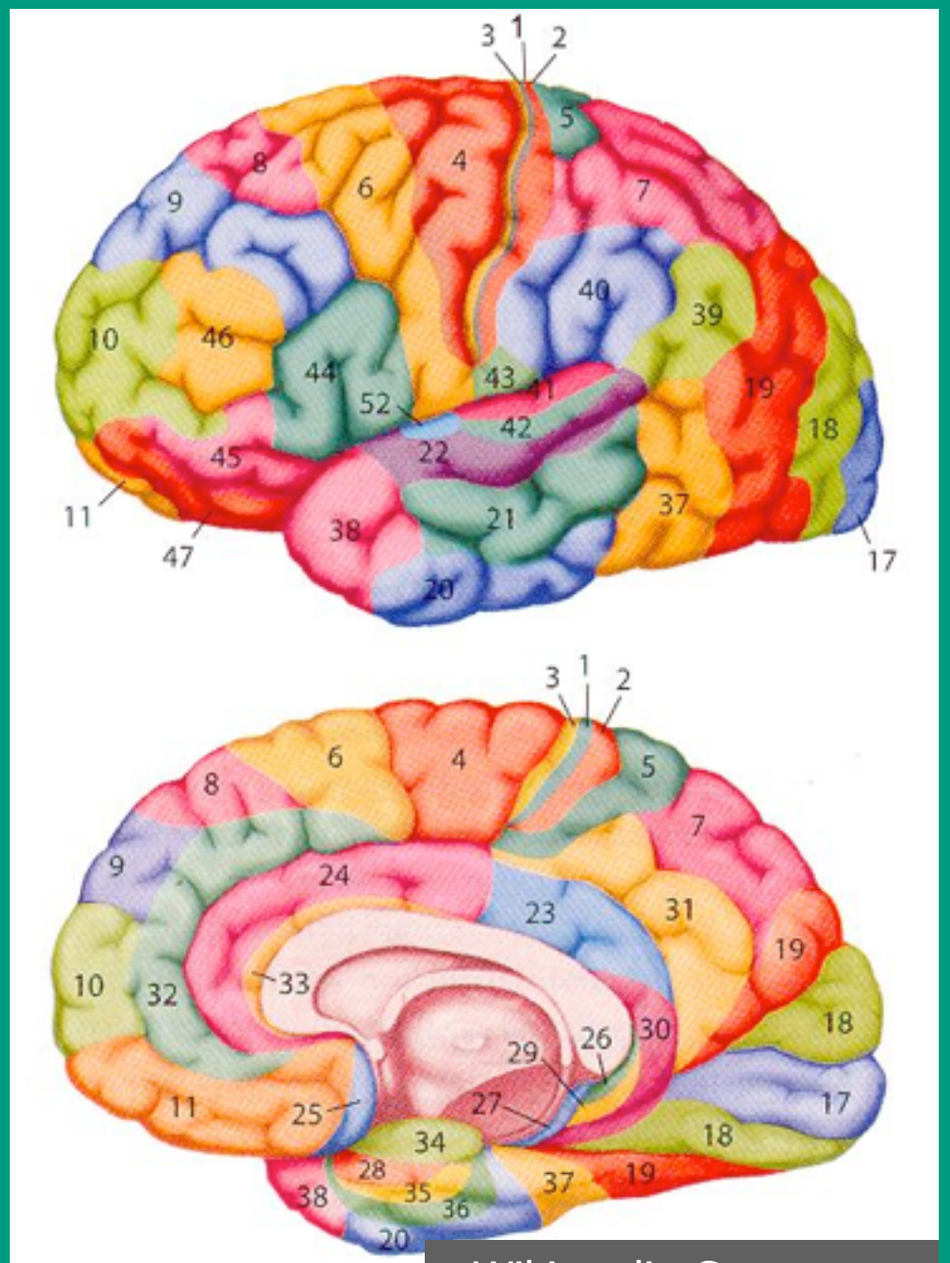

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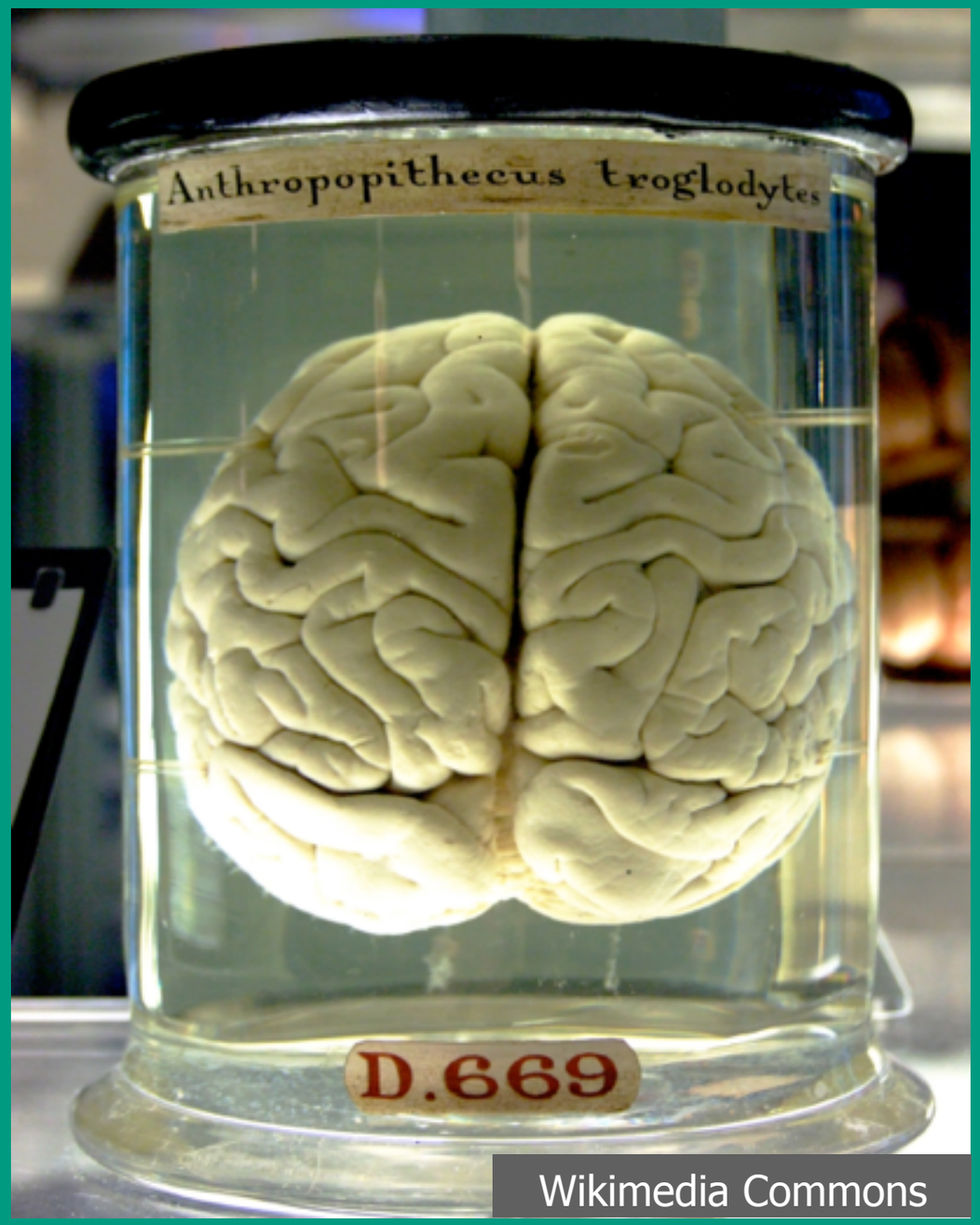

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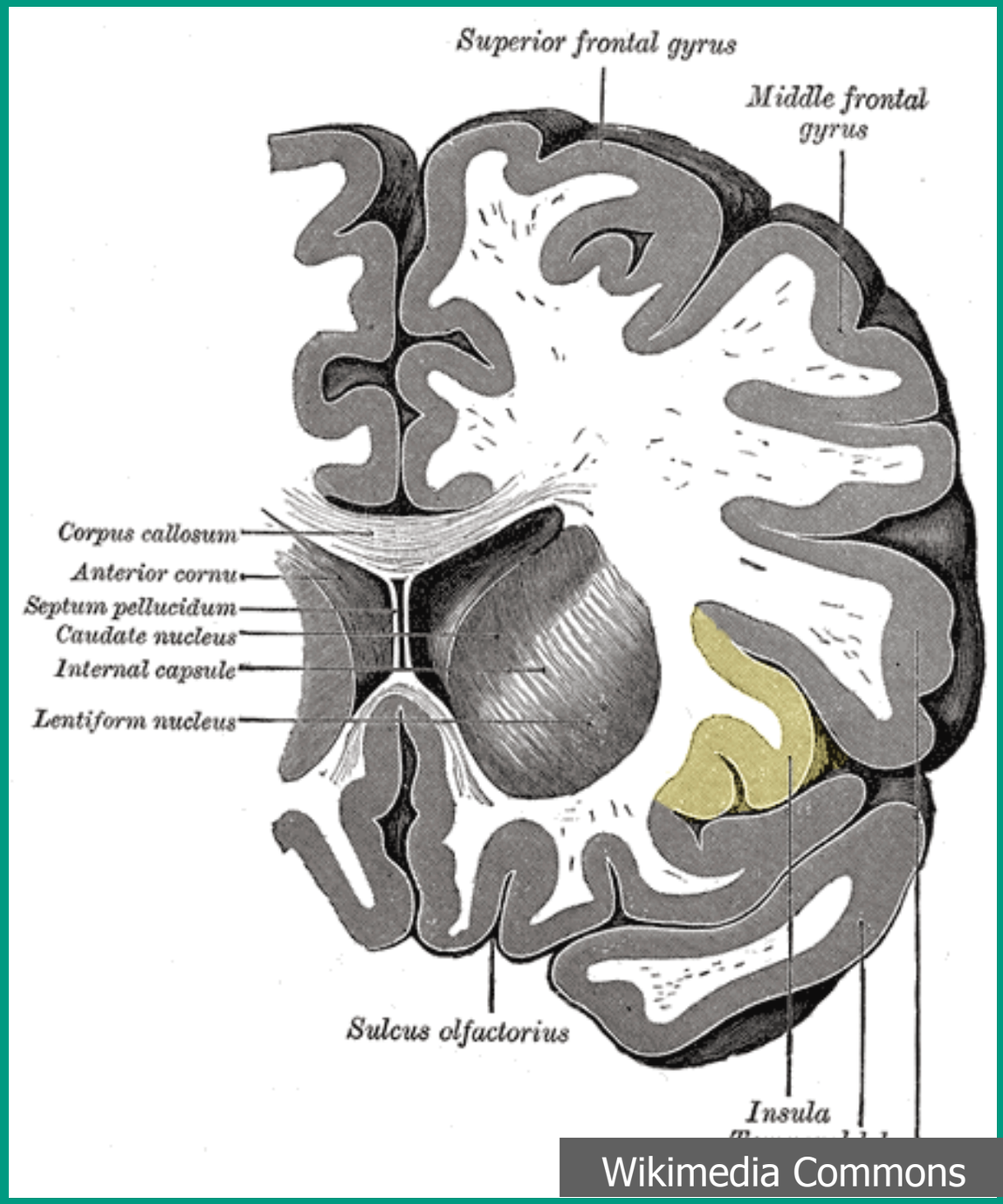

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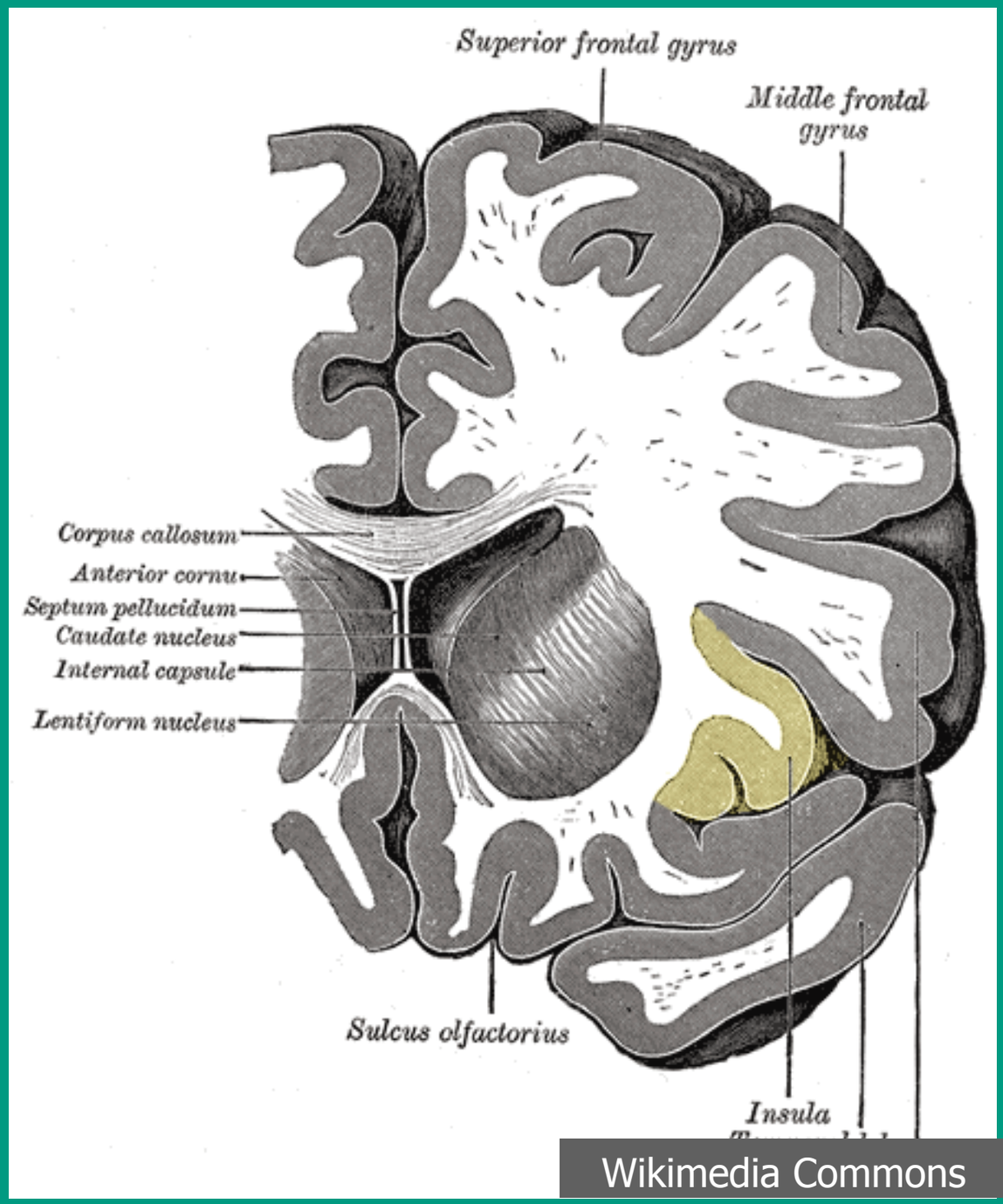

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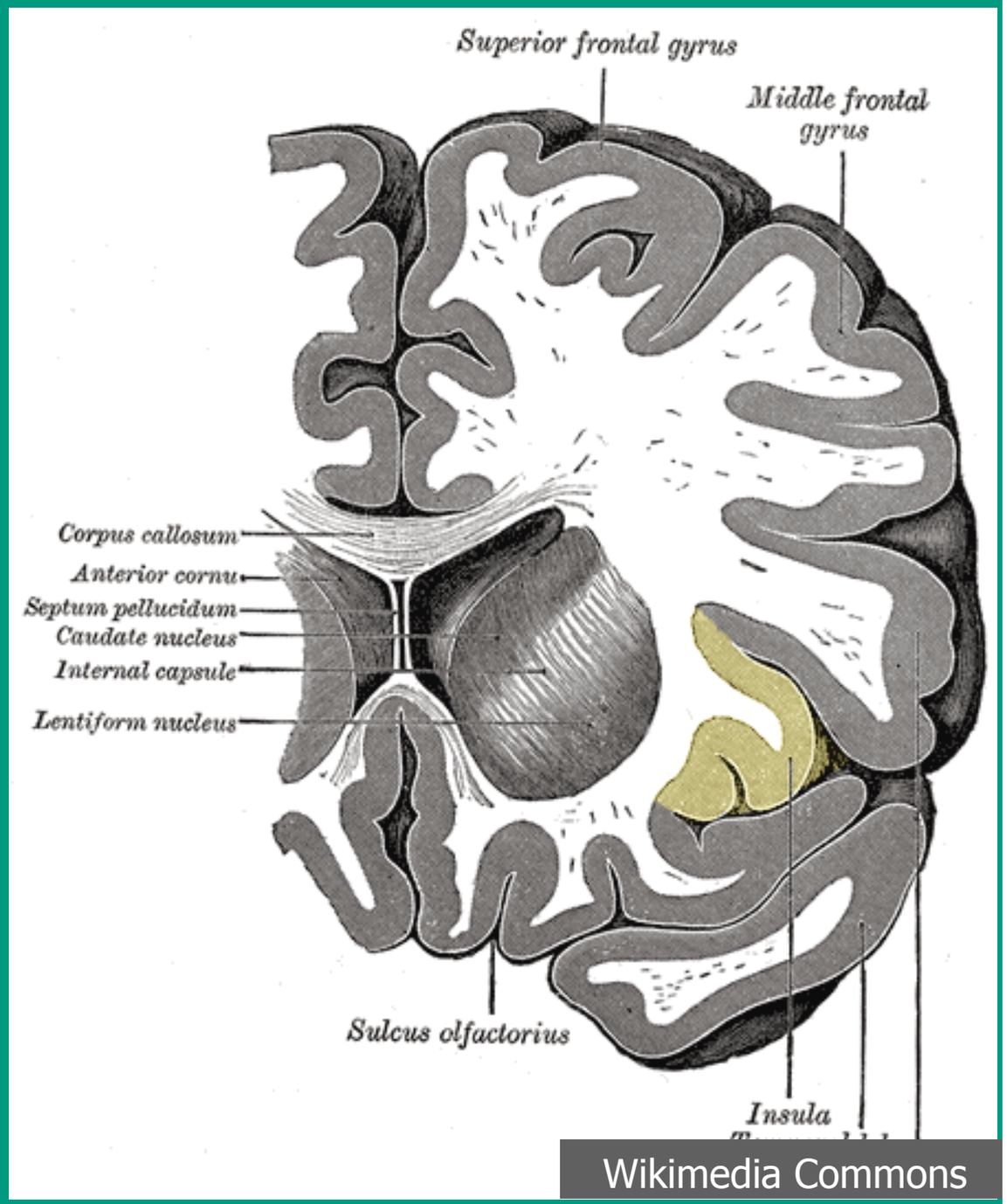

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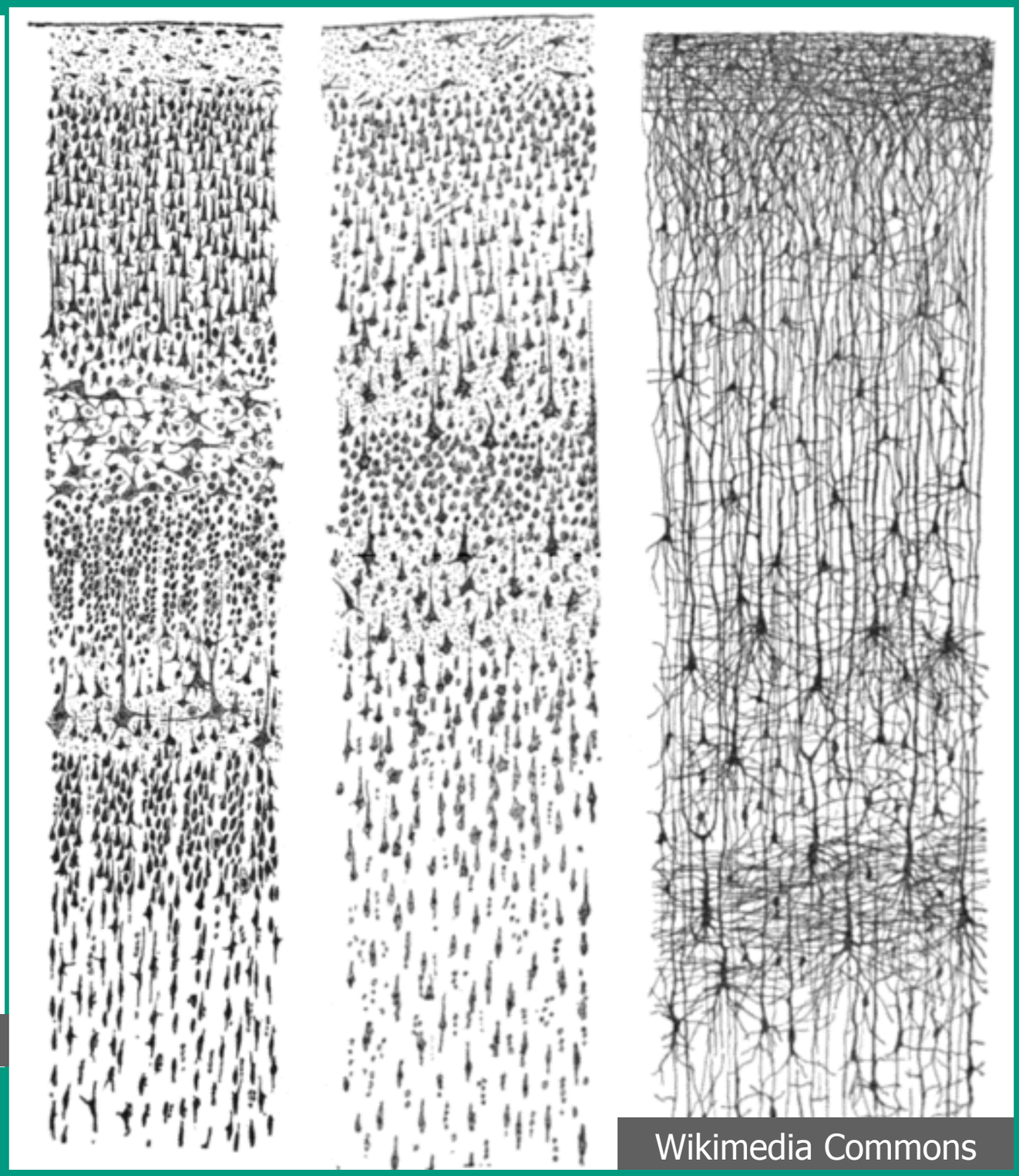

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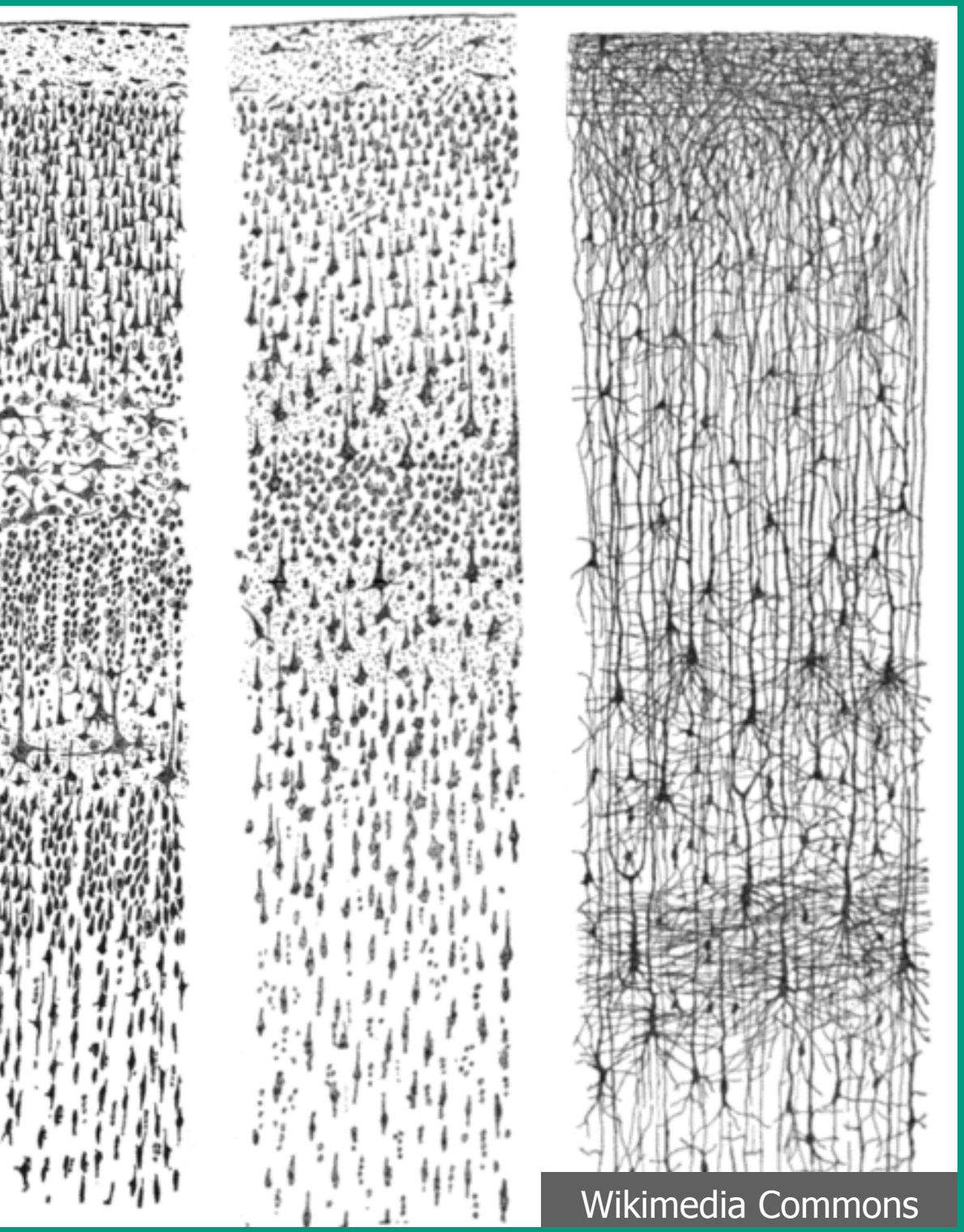

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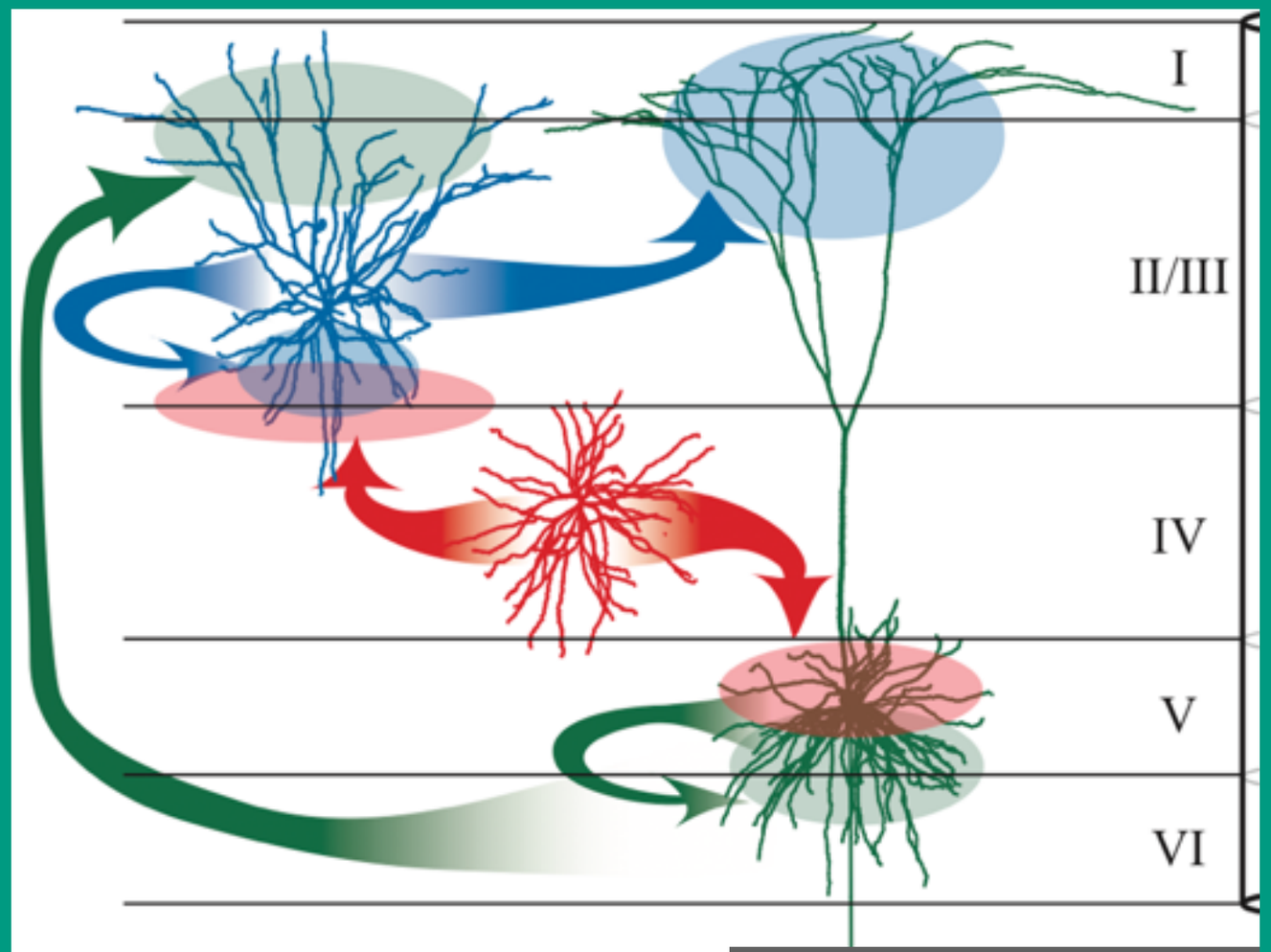
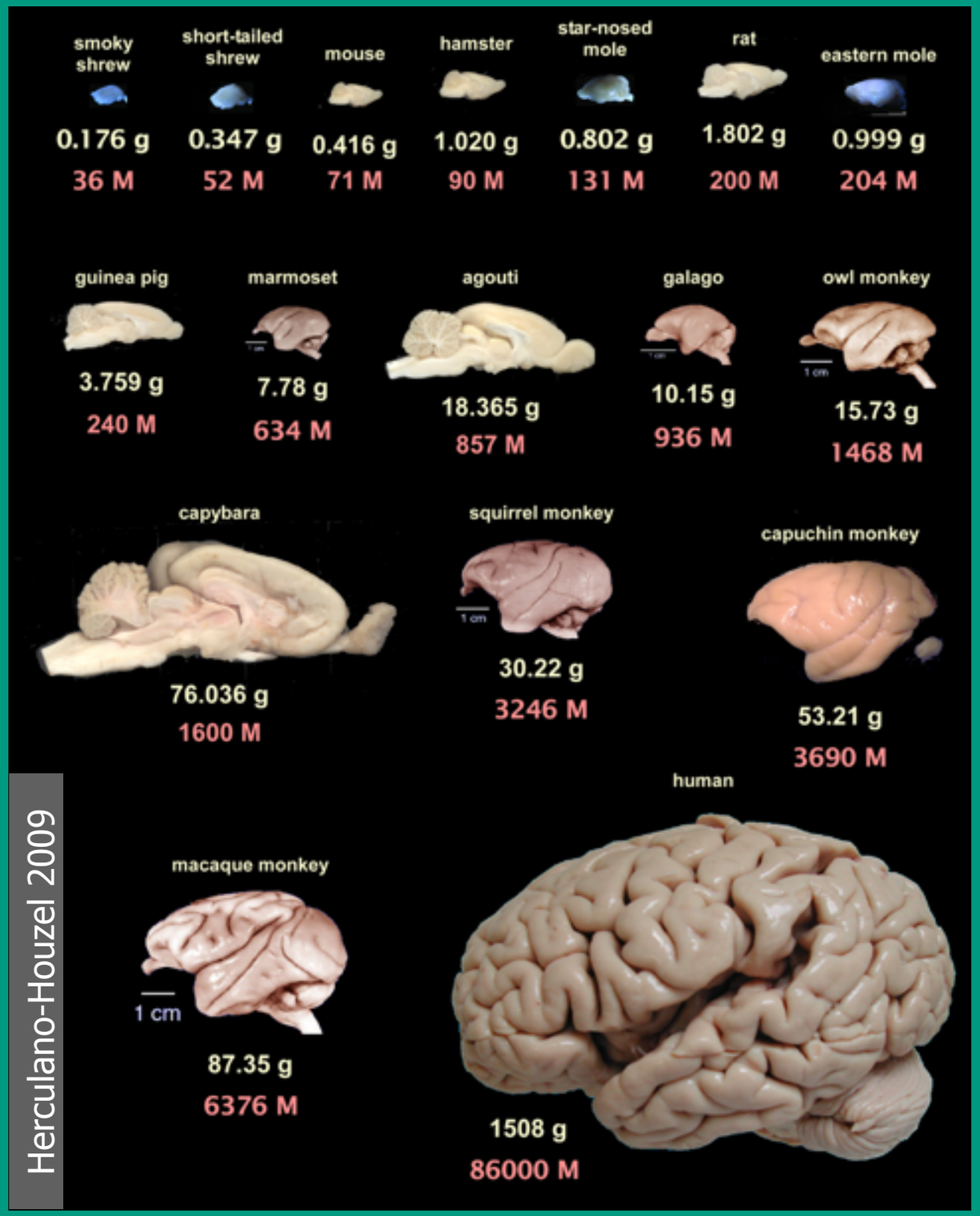


Plesser & Pettersen 2008

Some numbers

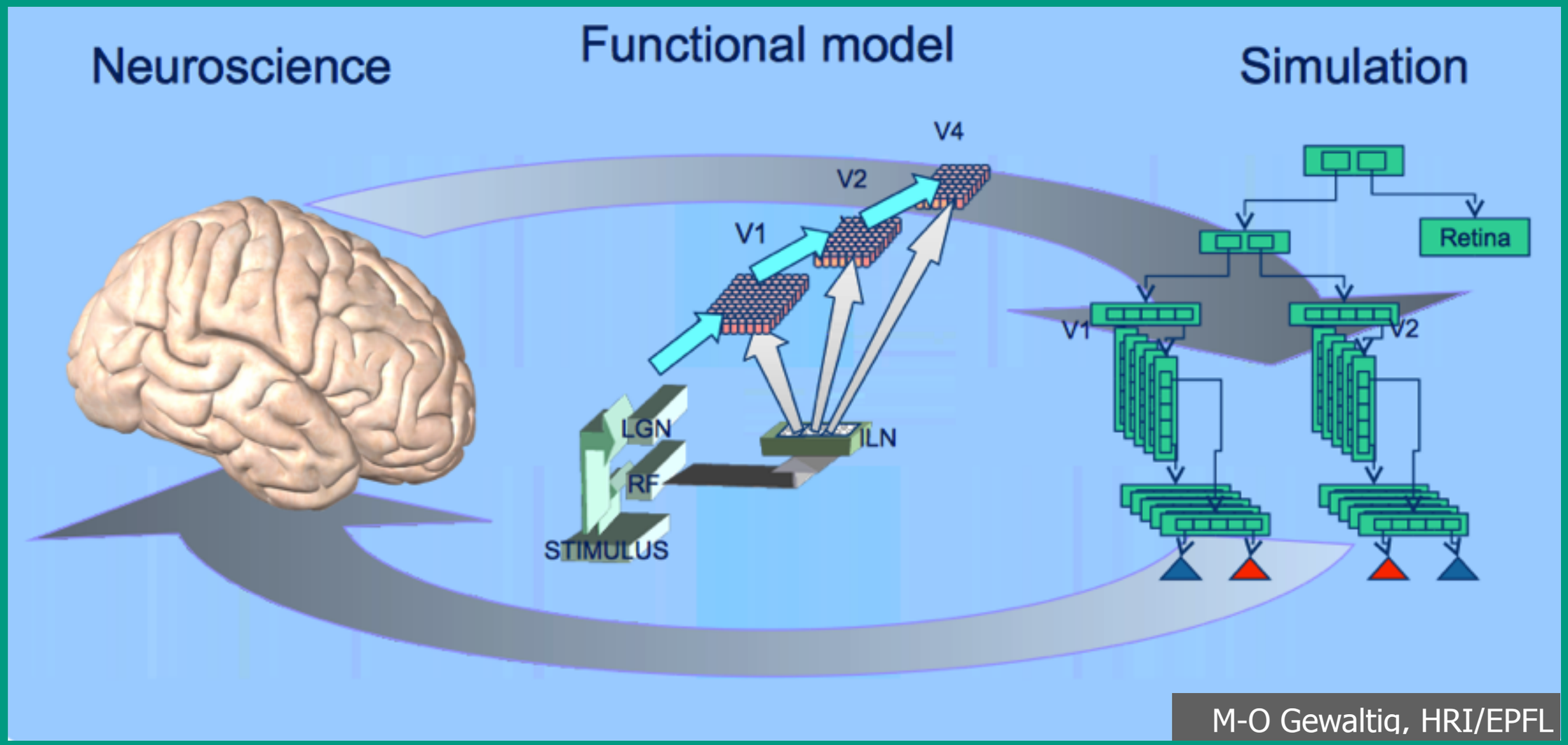
Human brain	
Total neurons	$1x10^{11}$
Cortex neurons	$2x10^{10}$
Total Synapses	$1x10^{15}$

Wikipedia



Herculano-Houzel 2009

Functional Network Modeling

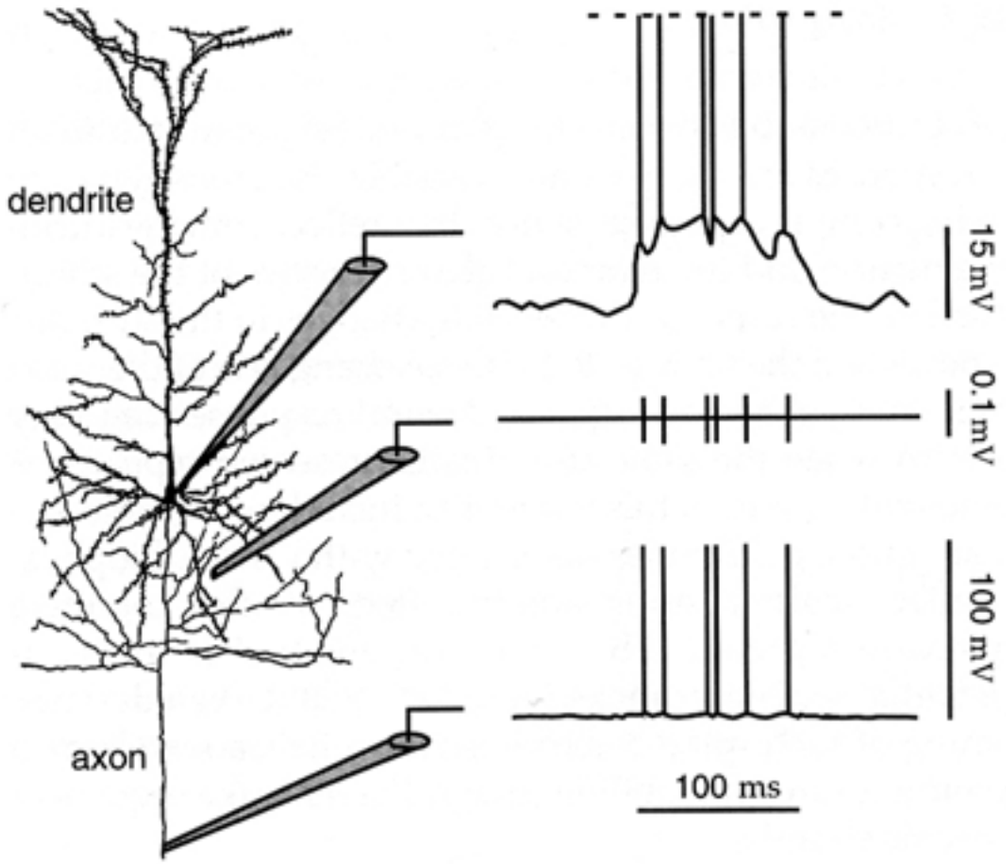


The goal of neural modeling is to relate, in nervous systems, function to structure on the basis of operation.

MacGregor & Lewis, 1977

Keeping it simple: point neurons

Complexity of the neuron



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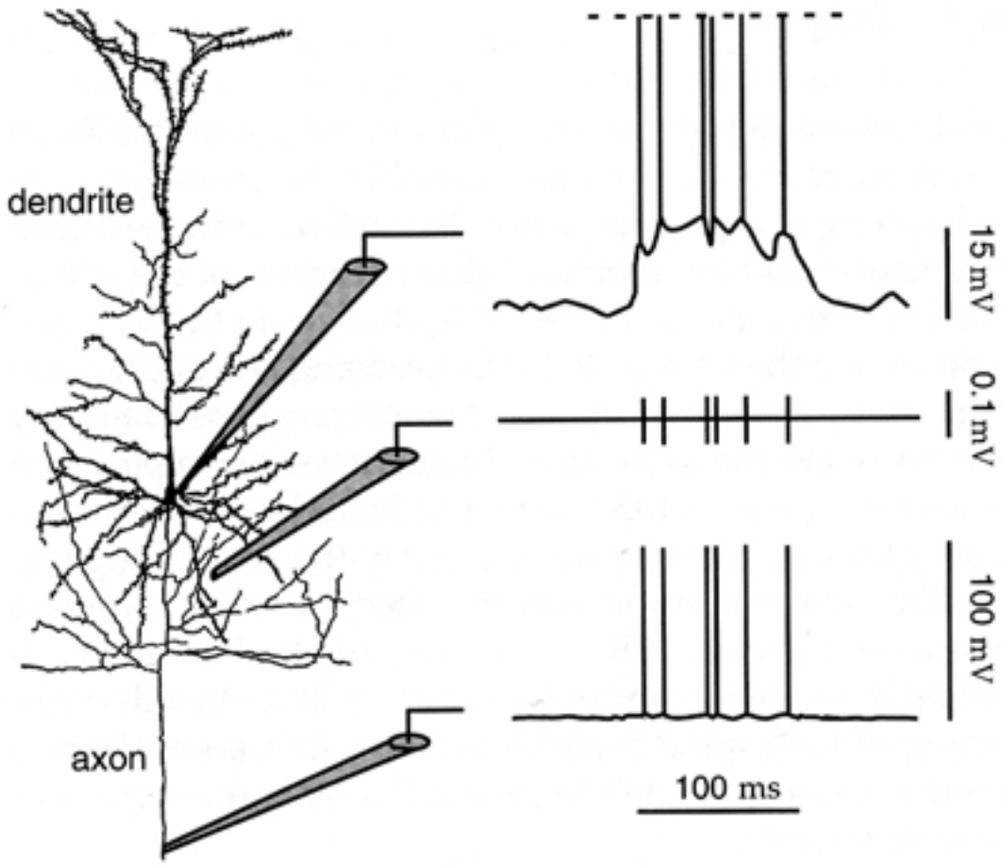
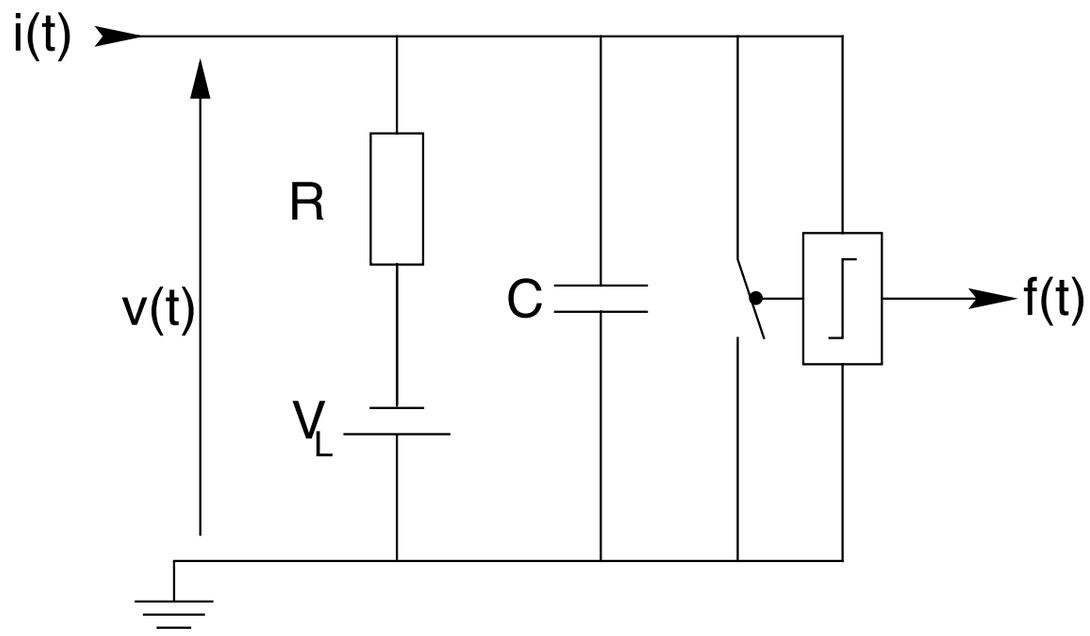
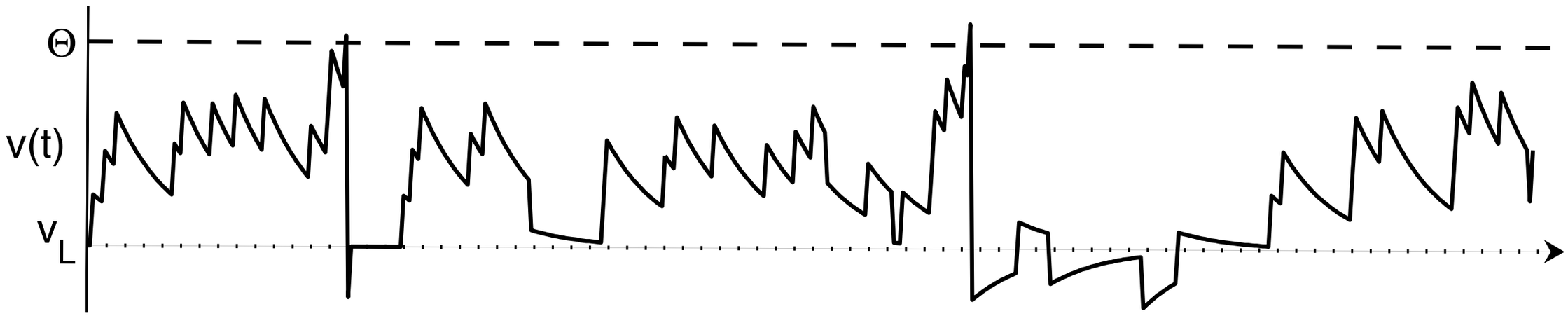


... abstracted as simple RC-circuit

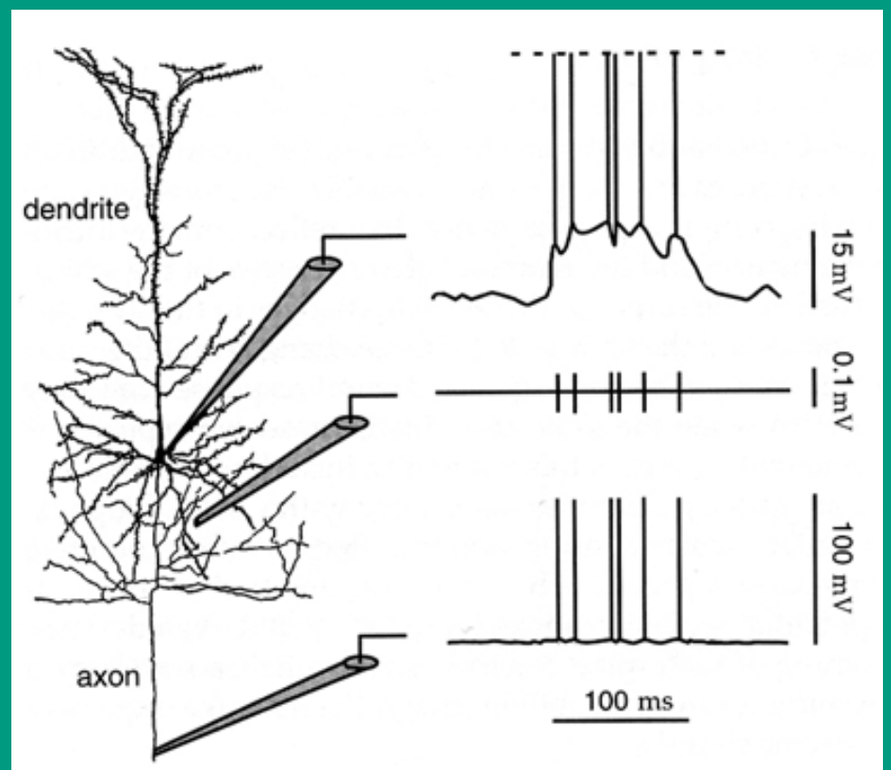


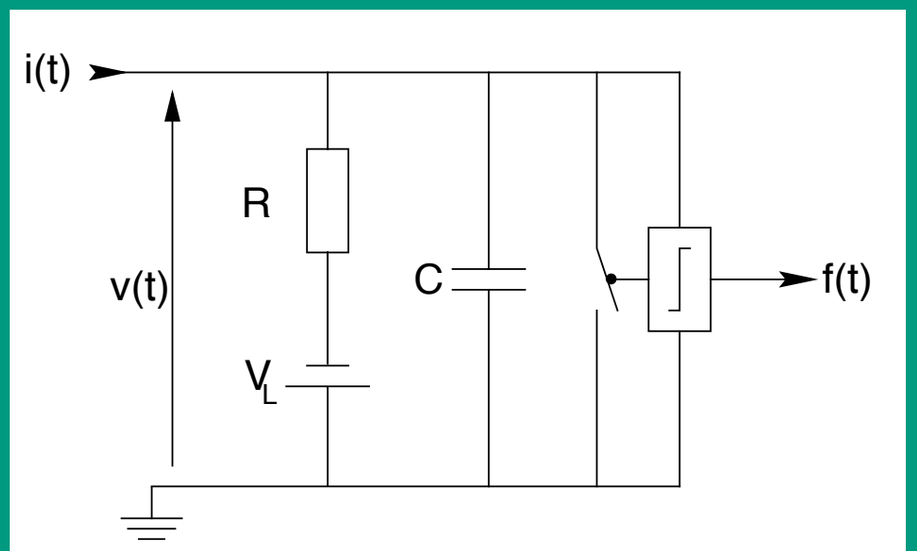
$$C\dot{V} = -\frac{(V - V_L)}{R} + i(t)$$



Network Modeling 101

- Simple nodes, “The music is in the edges”
- Analog signal integration in nodes





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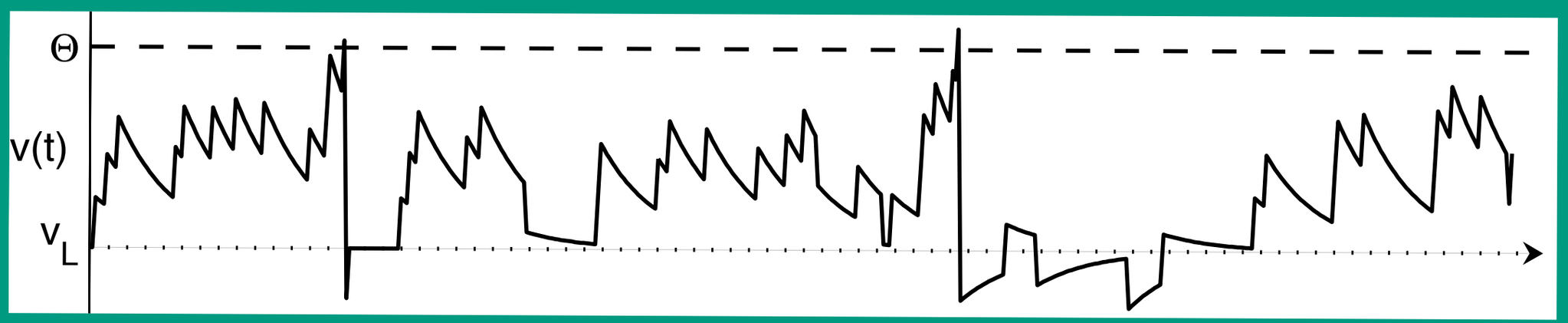

Network Modeling 101

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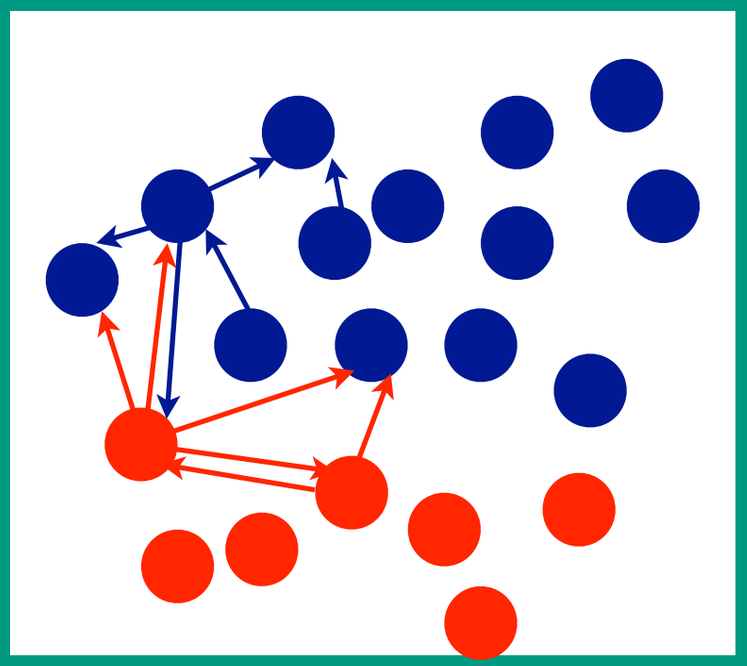
- Pulse-based signaling between nodes (*spikes,* approx 10 per sec per node)
- Fan-in/out: $O(10^4)$, essentially random
- $O(10^5)$– $O(10^{11})$ nodes, $O(10^9)$– $O(10^{15})$ edges



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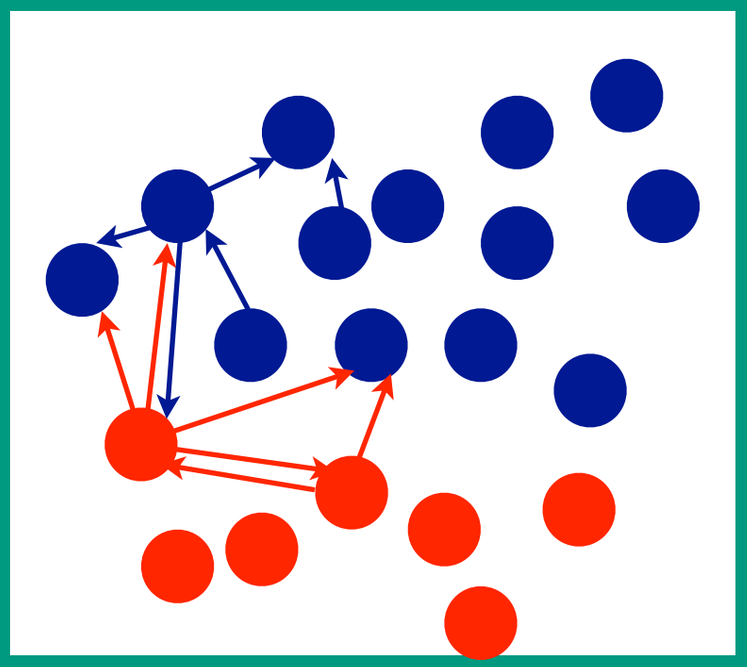
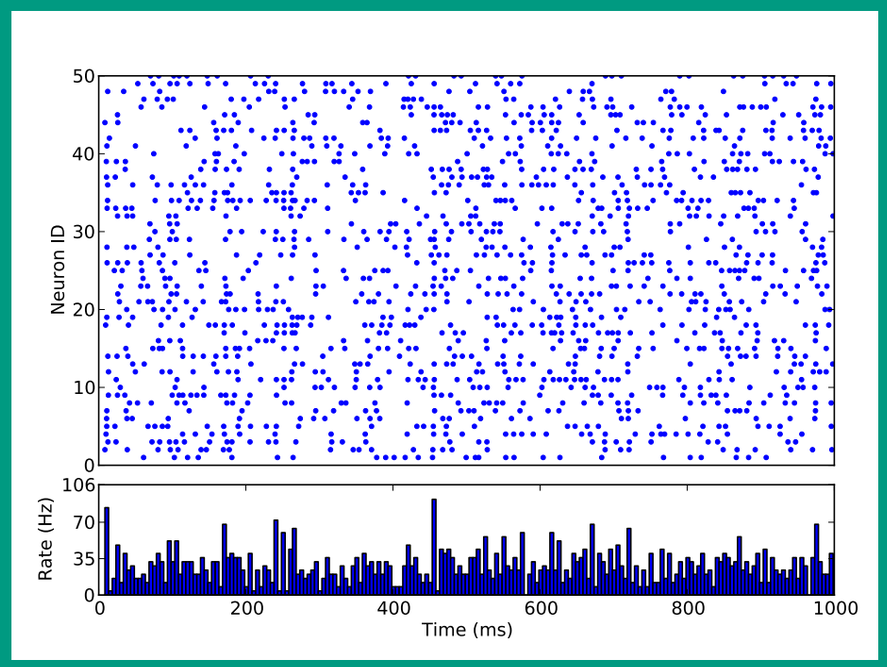
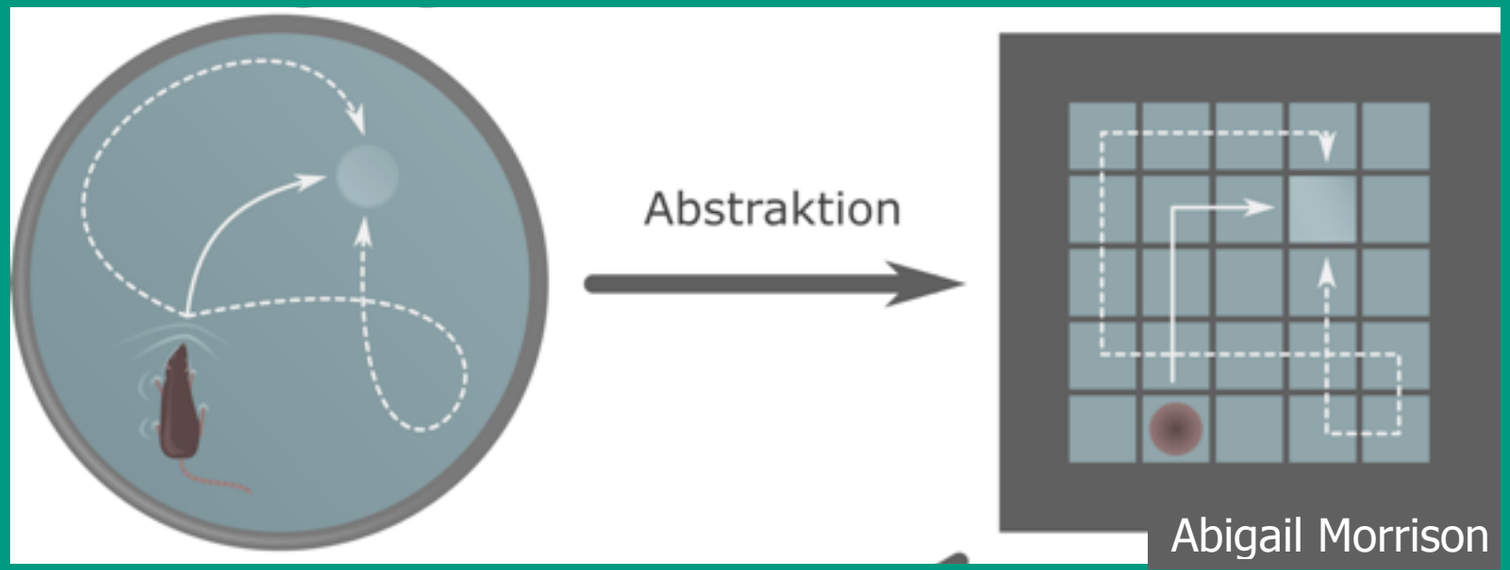
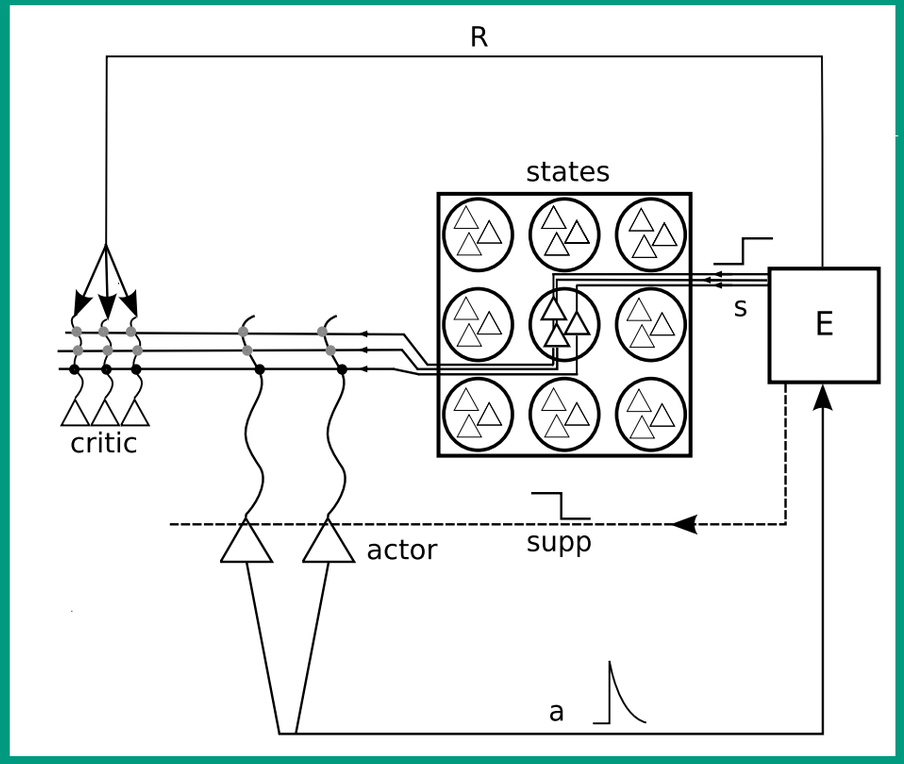
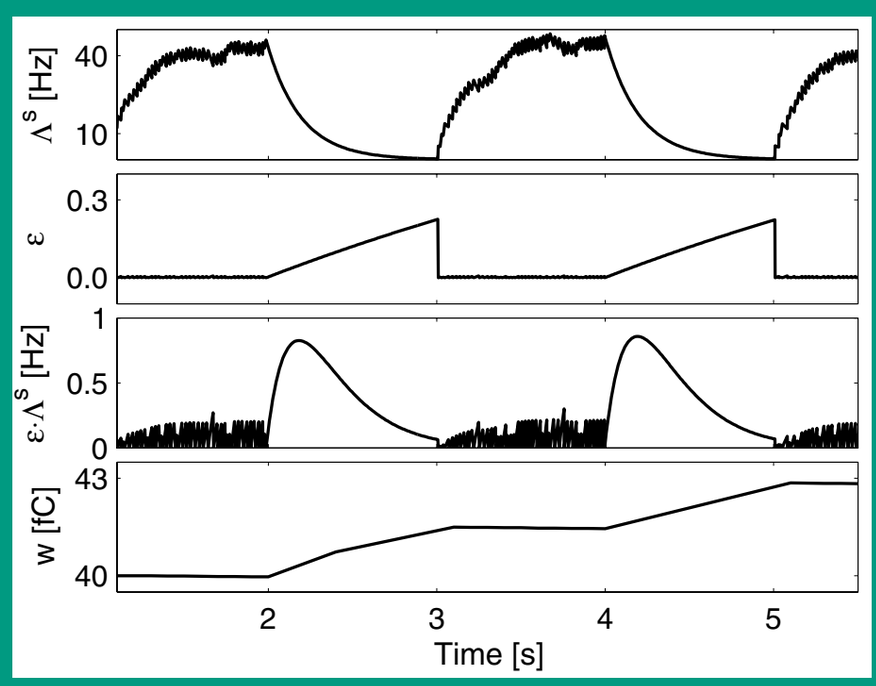




How do rats learn?



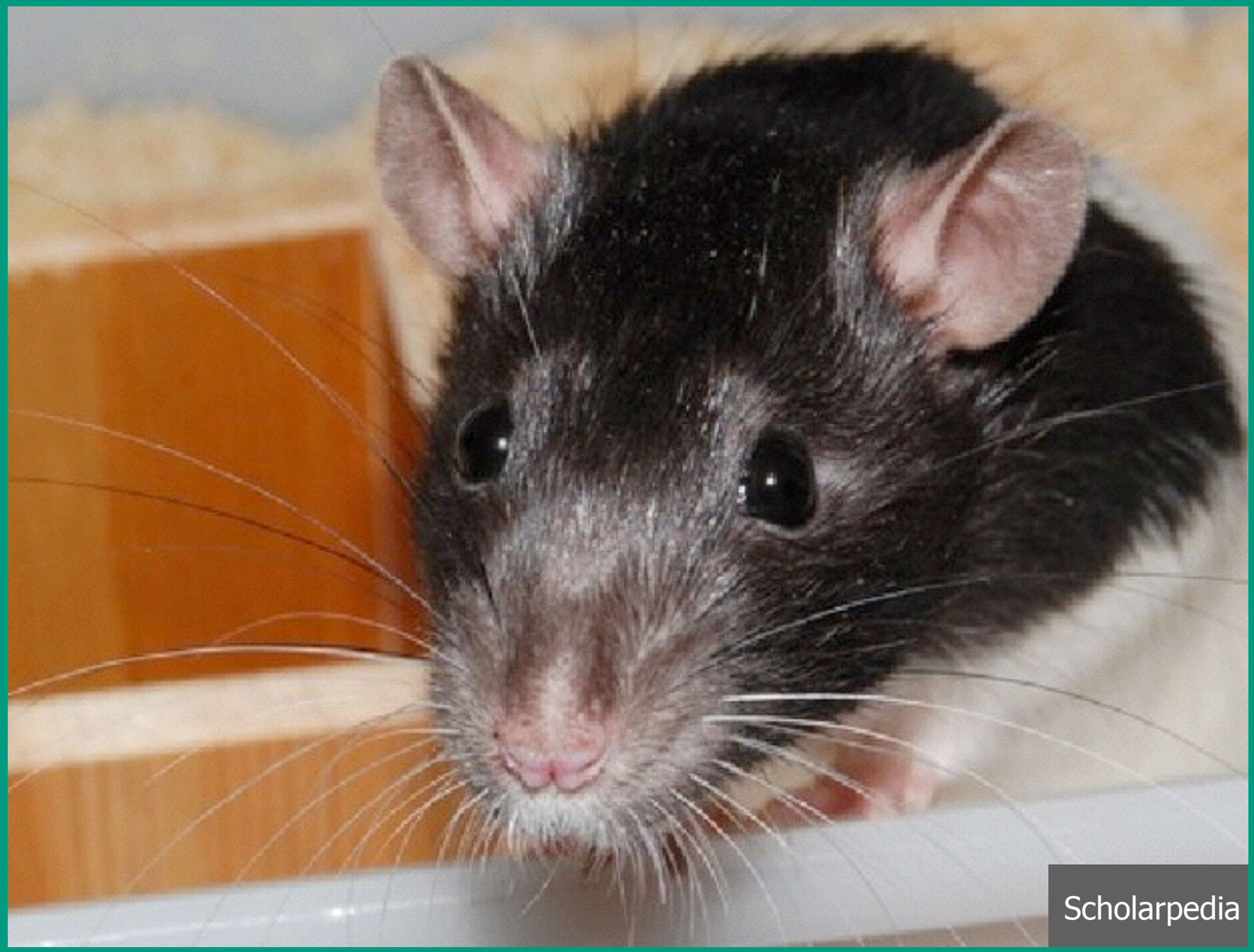




W Potjans et al, Neural Computing 2009
W Potjans et al, Front Neuroinform 2010

nest::
simulated()

How do connections change?



Phoka et al, J Comput Neurosci 2012

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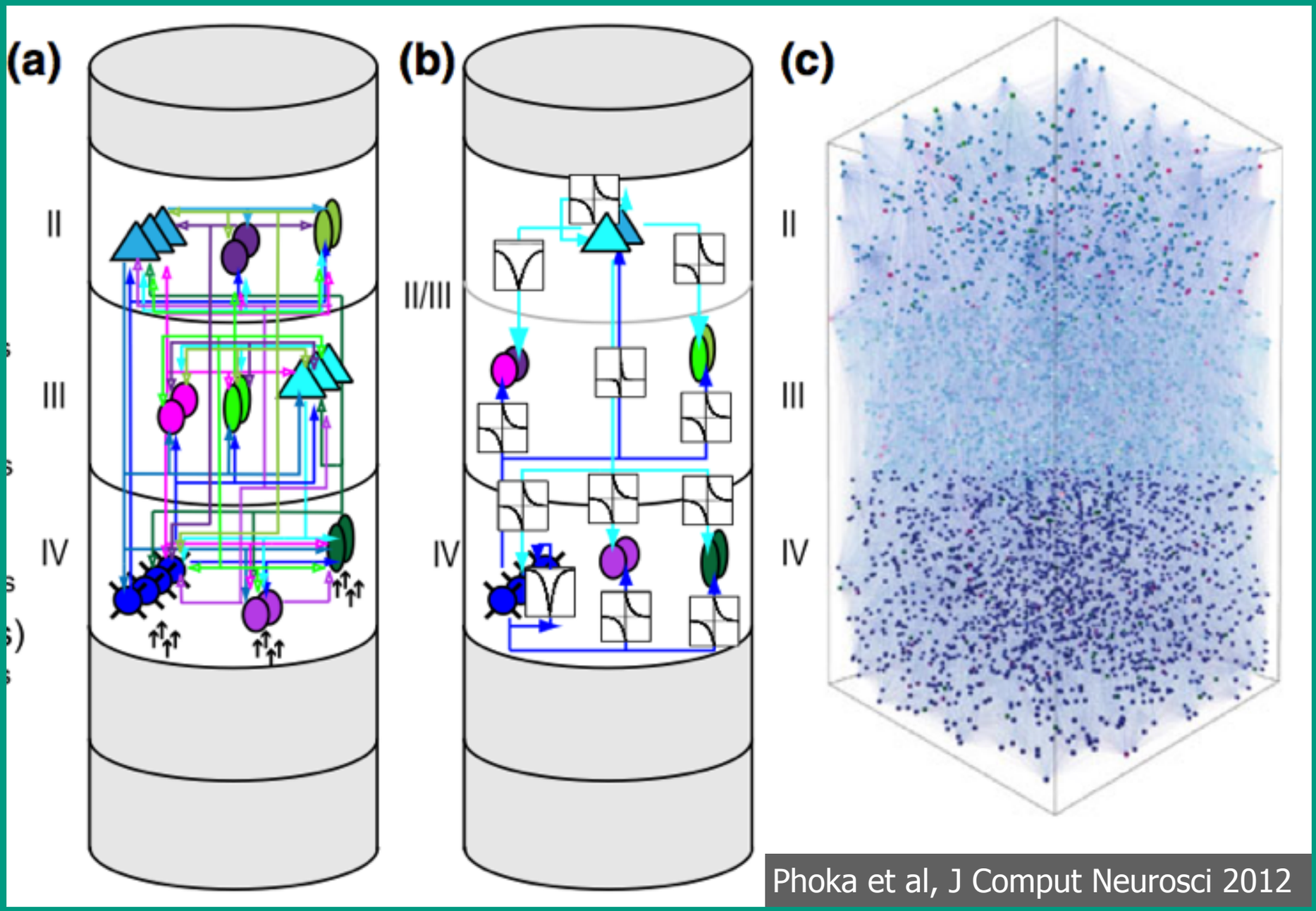

Phoka et al, J Comput Neurosci 2012

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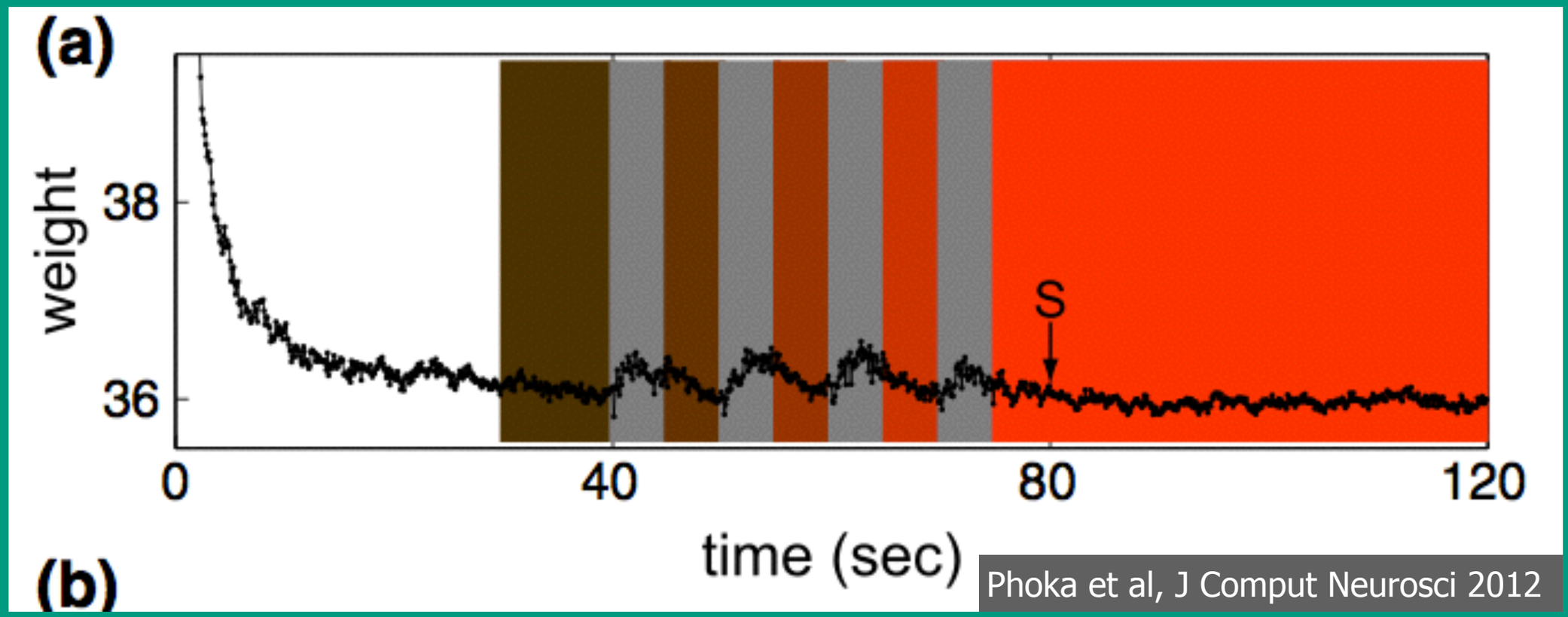

Phoka et al, J Comput Neurosci 2012

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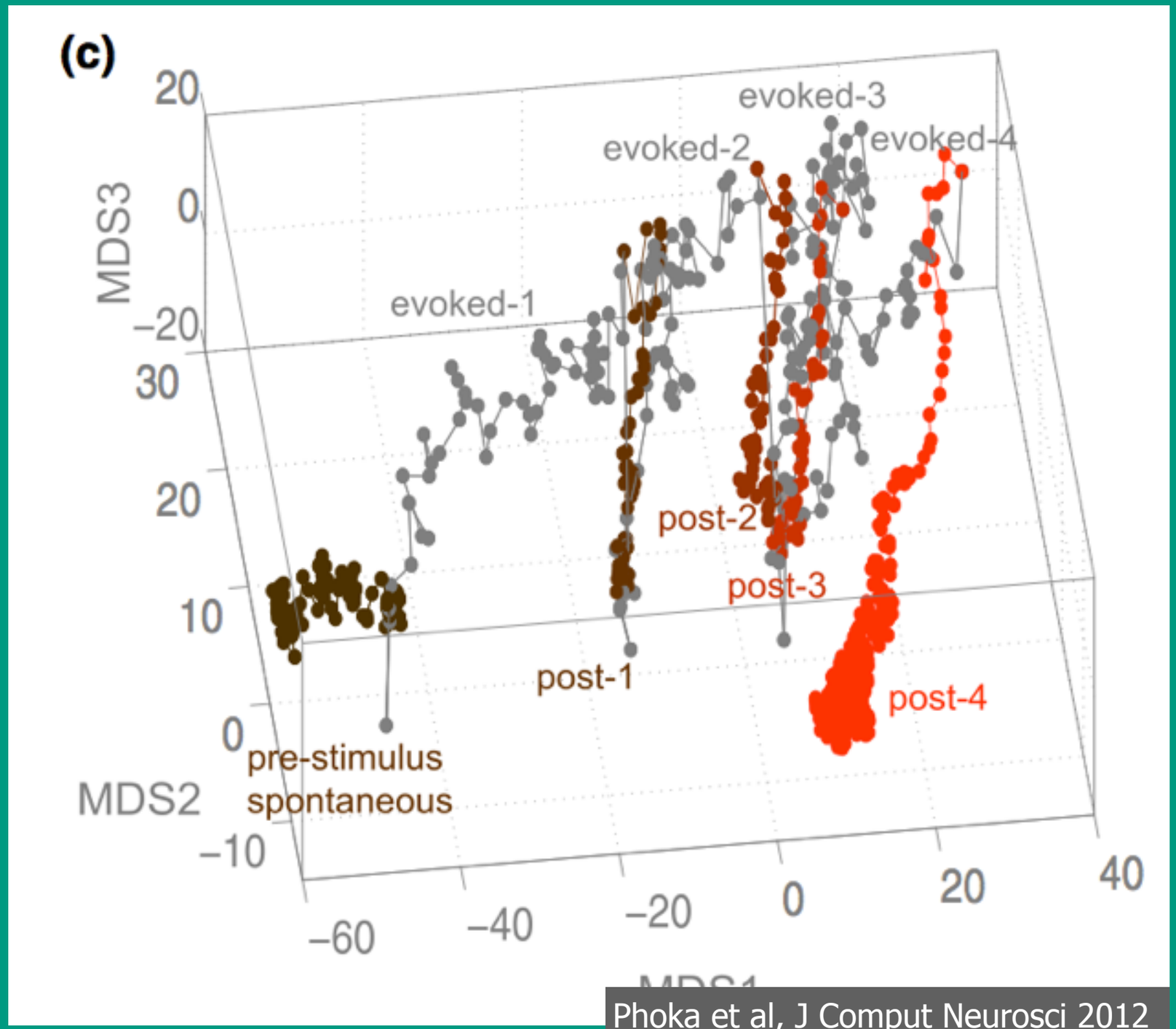
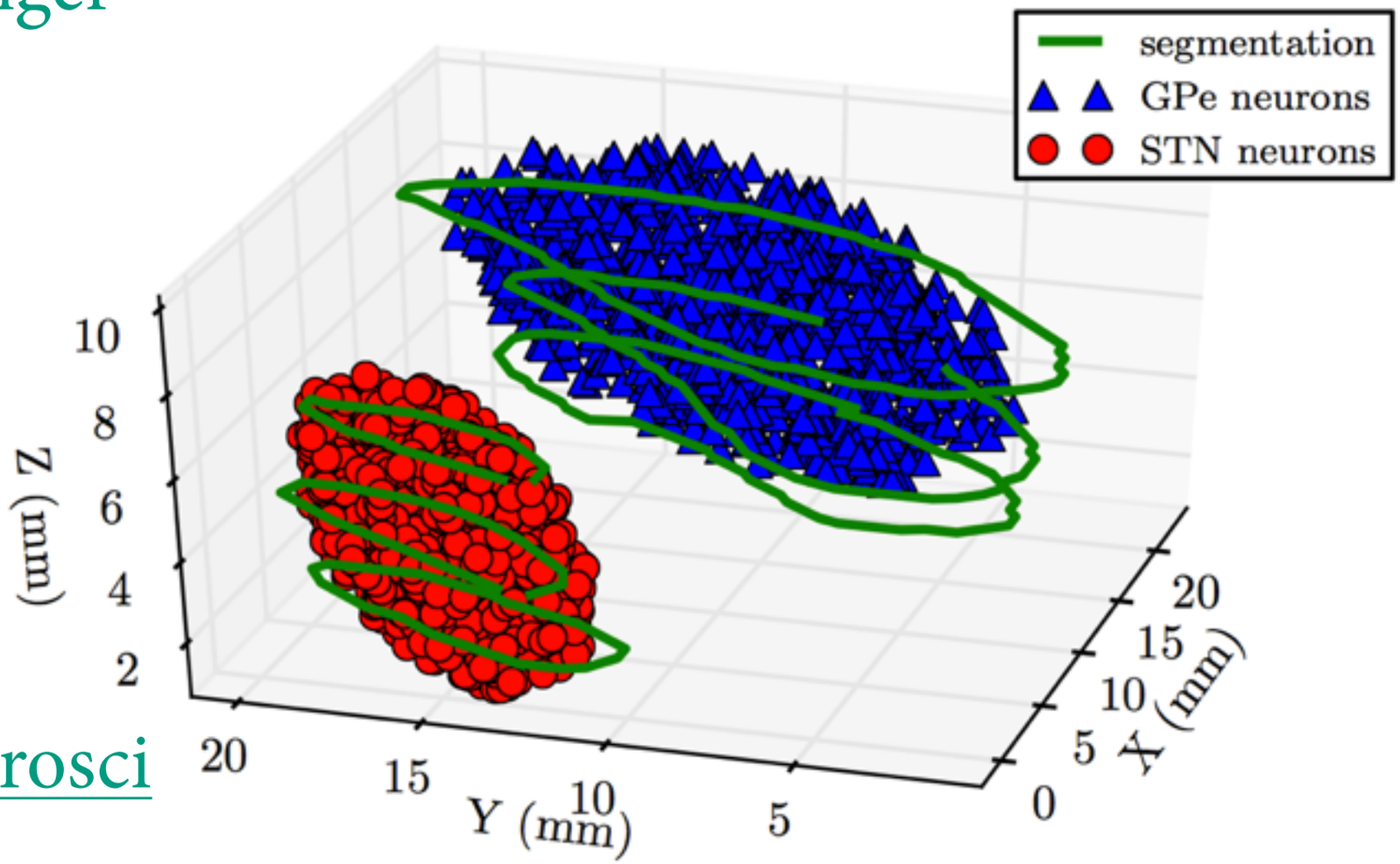


Phoka et al, J Comput Neurosci 2012

Phoka et al, J Comput Neurosci 2012

Networks with Spatial Structure

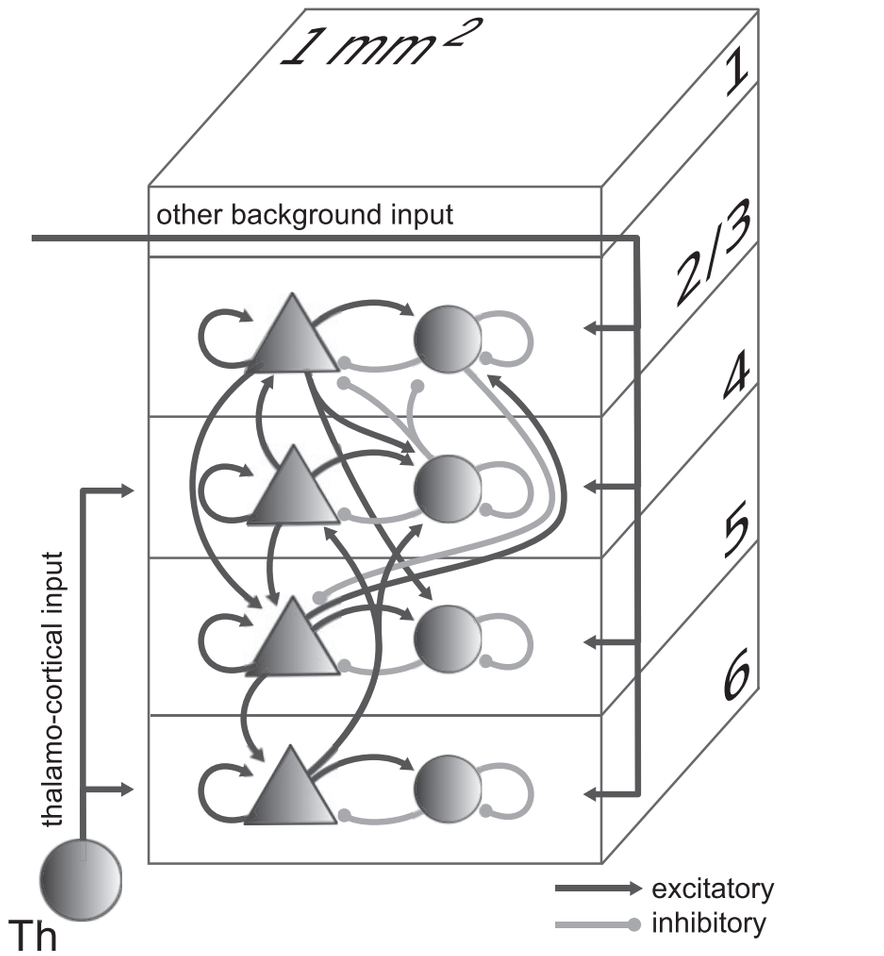
- Topology Module
- Plesser/Austvoll/Enger
- Full 3D-Support
- Applied to models of deep-brain stimulation (Tass Group, FZ Jülich)
- Ebert et al, Front Comput Neurosci 8:154 (2014)



Martin Ebert, PhD Thesis, 2012

Cortical Microcircuit

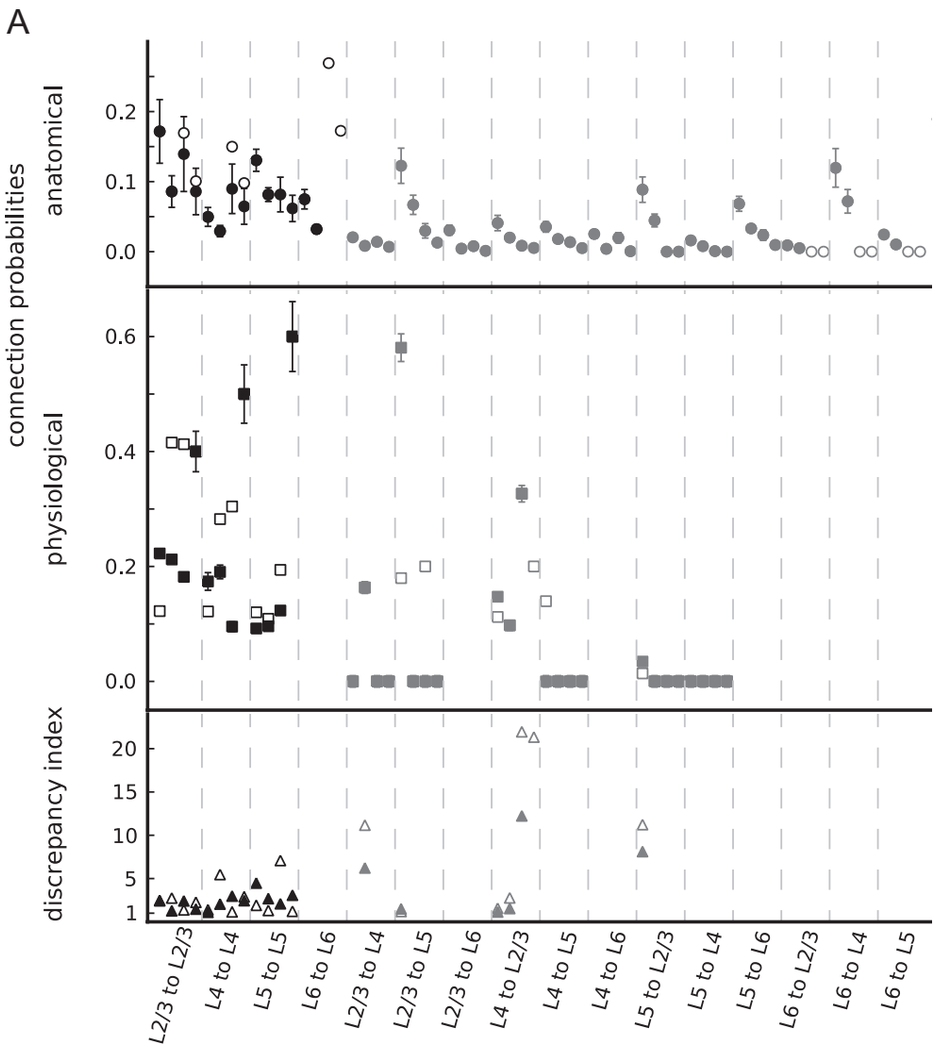
- Model of 1mm³ of neocortex
- T Potjans & Diesmann, Cereb Cortex 24:785 (2014)
- Detailed analysis of anatomical and physiological connectivity data
- Included in NEST 2.4
- Avail. on OpenSourceBrain
- Current lead scientist: Sacha van Albada, FZ Jülich

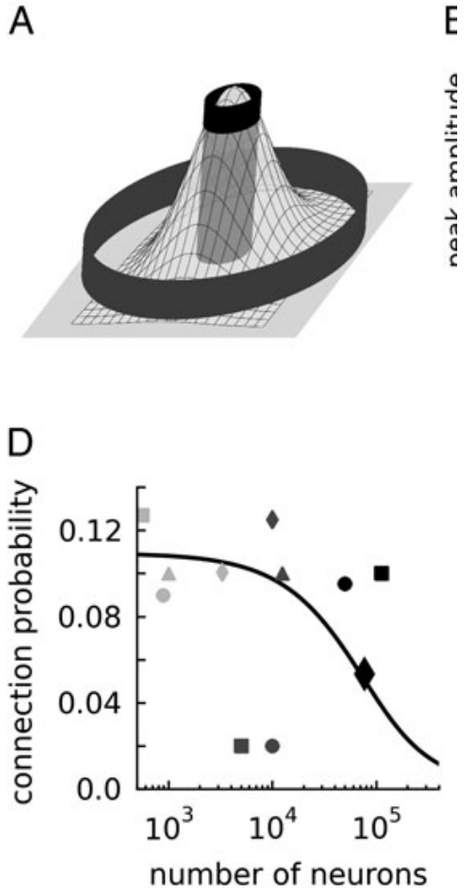


Potjans & Diesmann, 2014

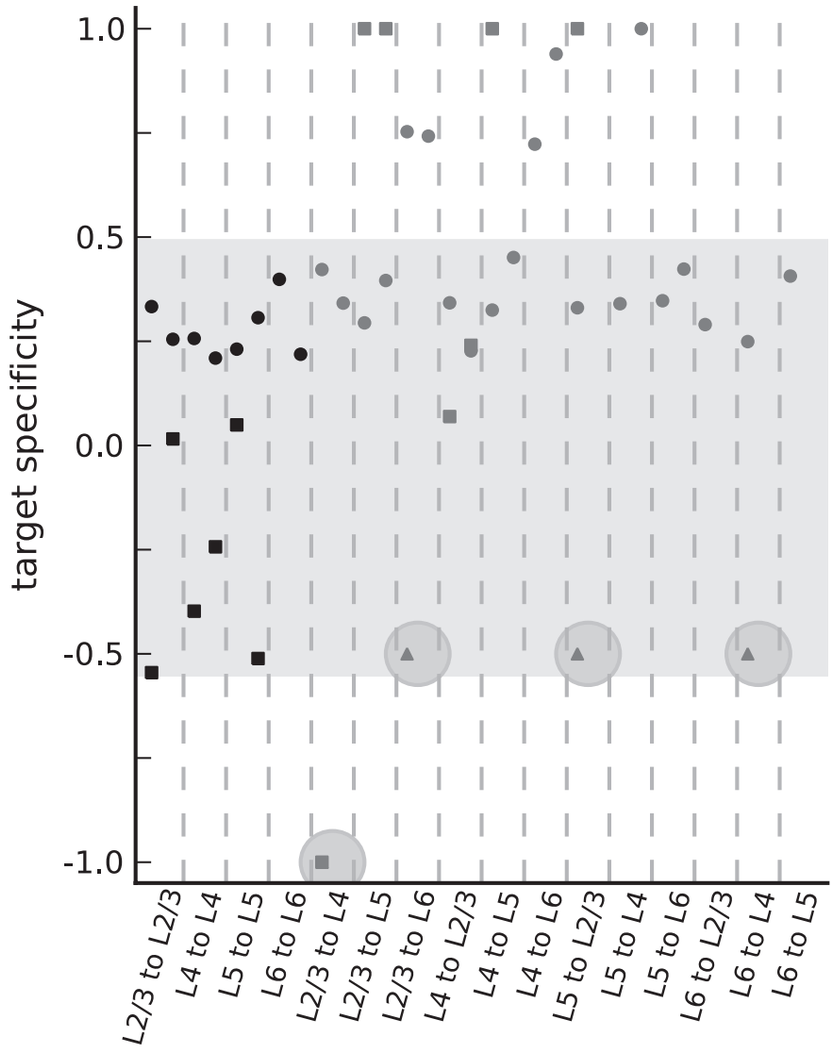
Connectivity & Specificity

Anatomy vs Physiology





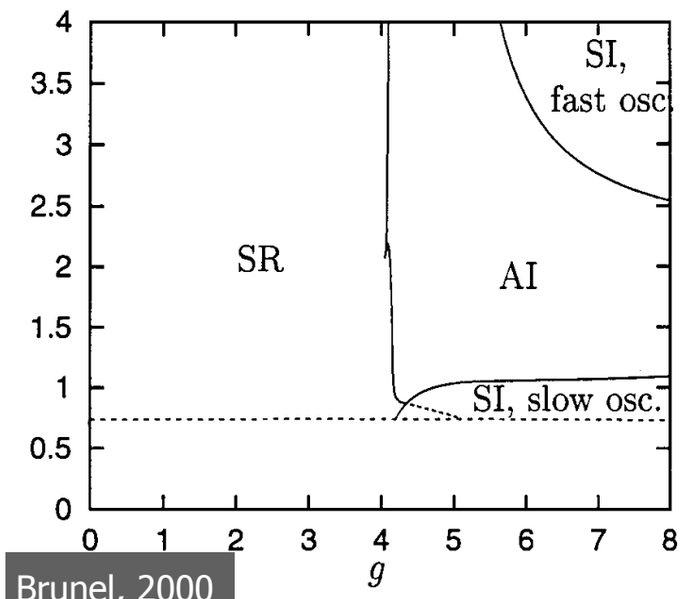
Specificity



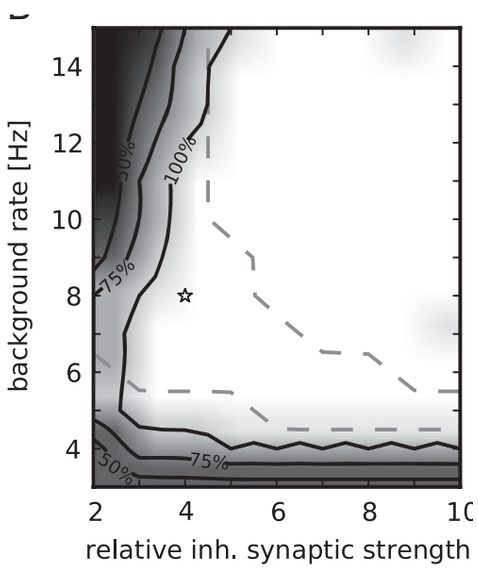
Potjans & Diesmann, 2014

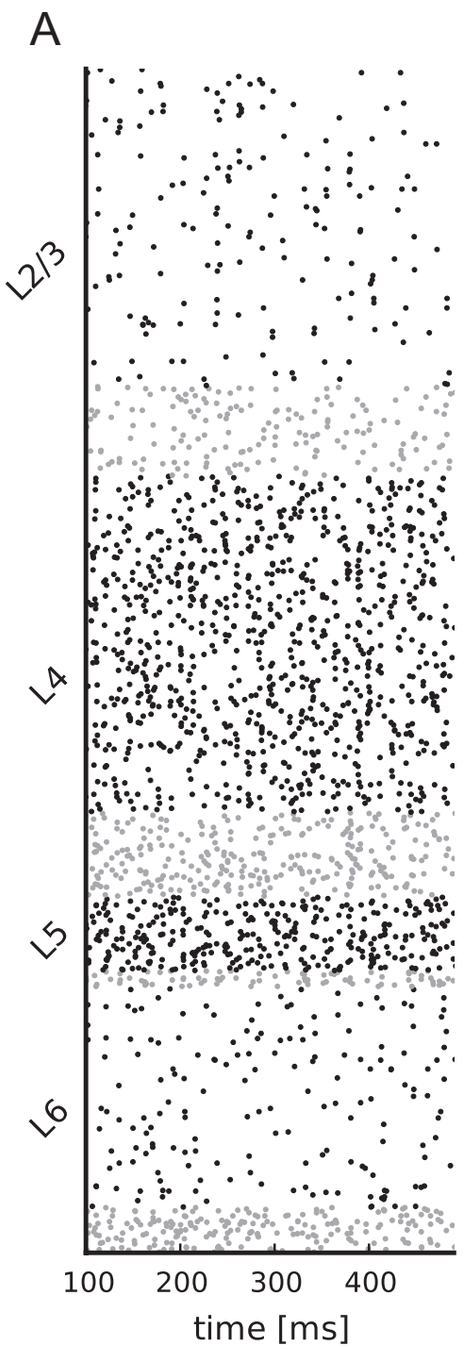
Model properties

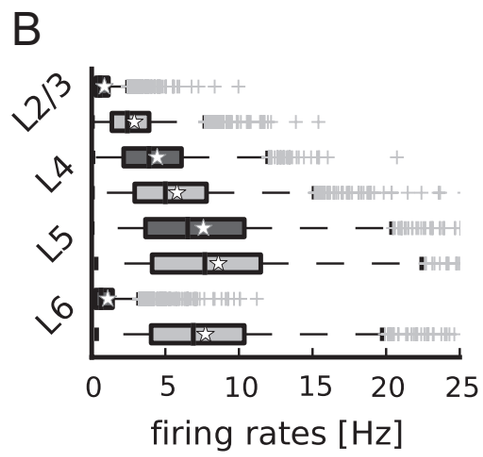
- 77.169 neurons
- 217 million excitatory synapses
- 82 million inhibitory synapses
- Leaky-integrate and fire neurons with current-based synapses
- No plasticity
- Reproduces Brunel-like spontaneous activity

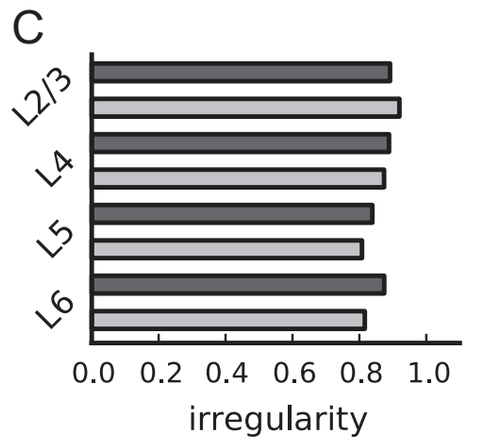


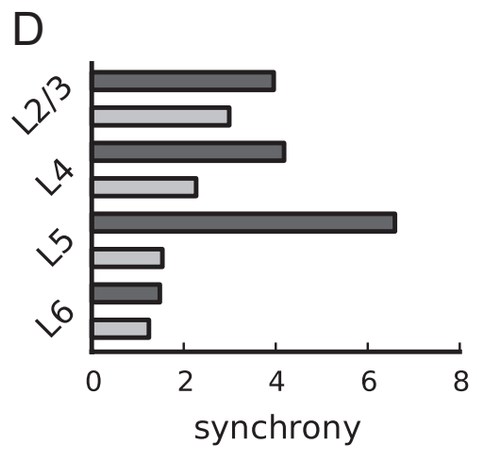
Brunel, 2000





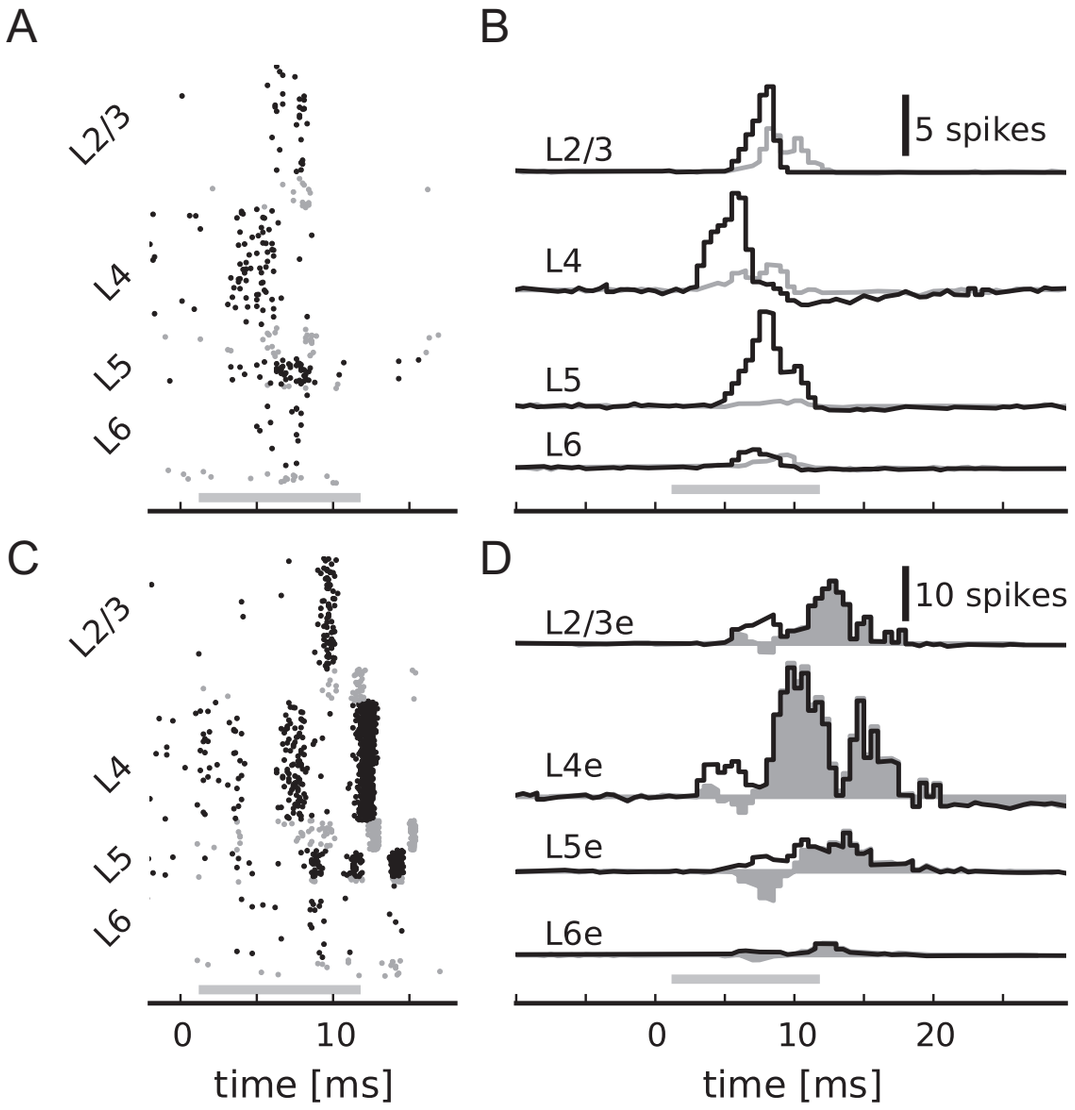


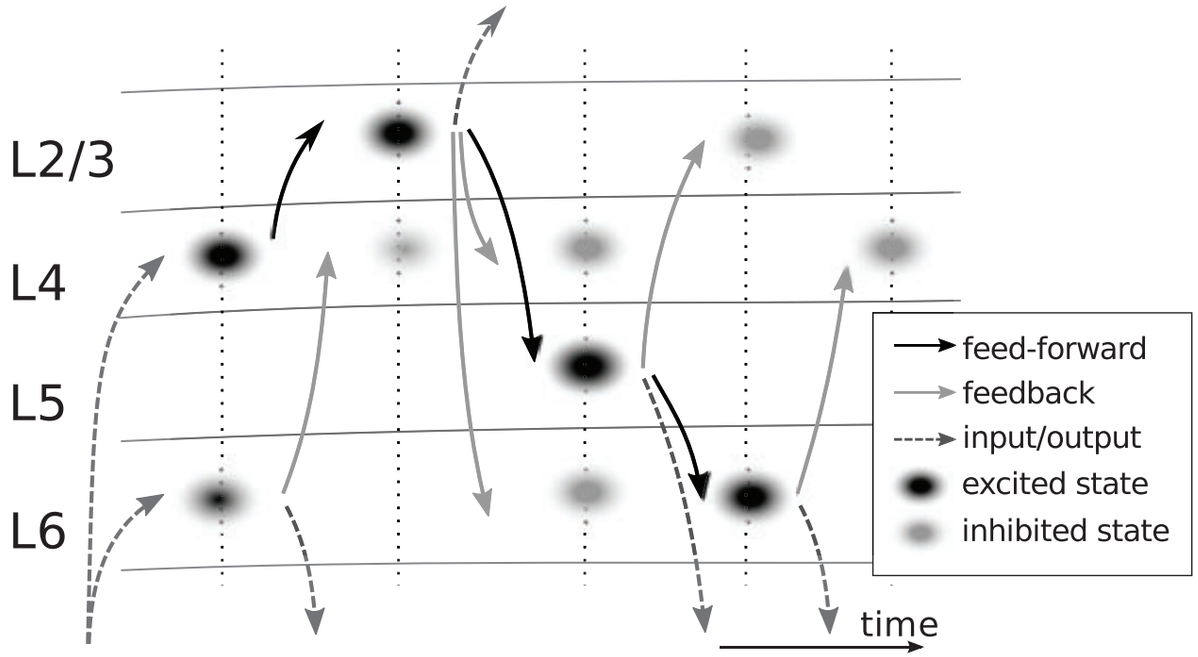




Potjans & Diesmann, 2014

Propagation of thalamic input





Potjans & Diesmann, 2014

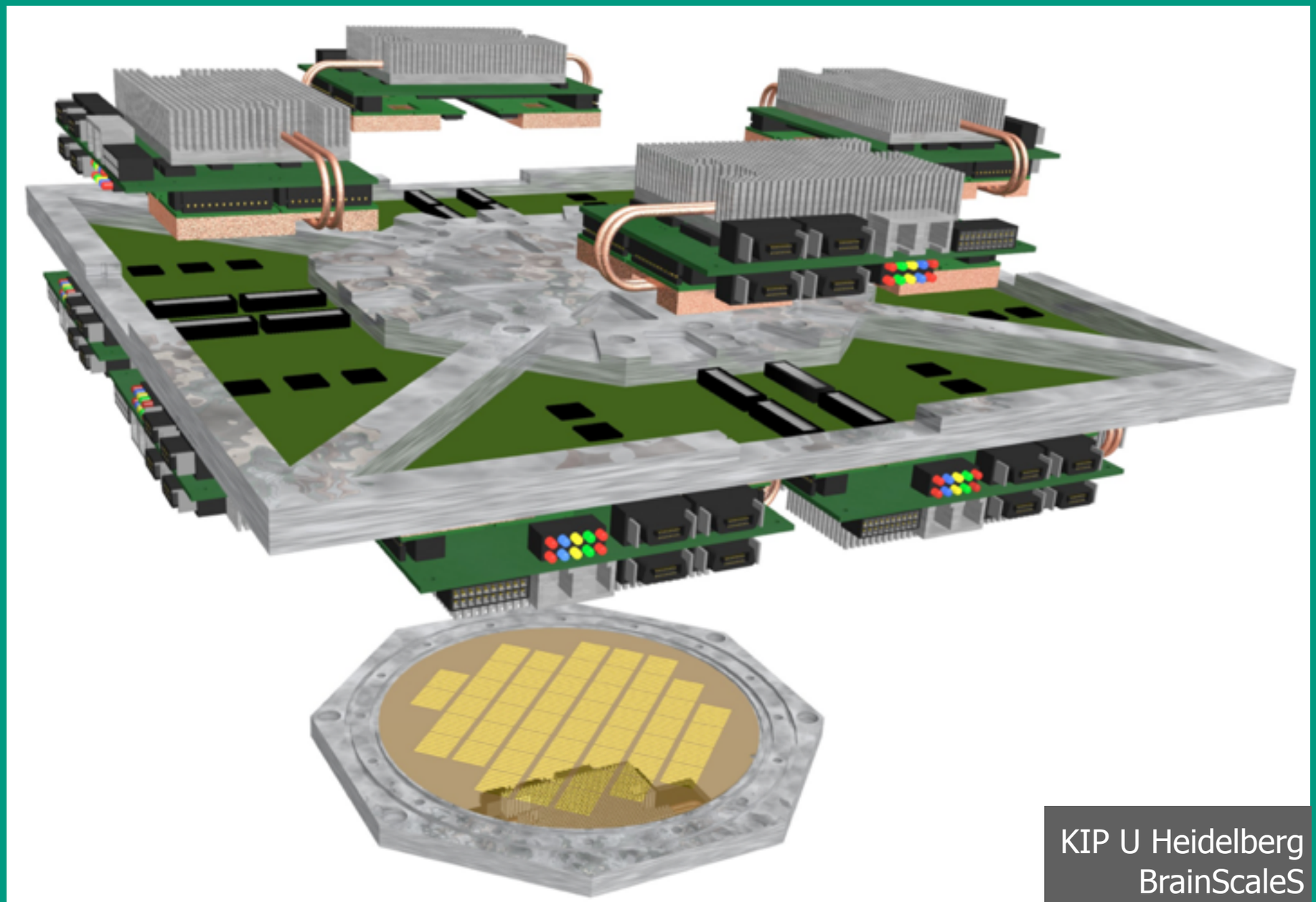
Specific inter-layer E -> I projections are essential

How to simulate networks?

- Neuromorphic hardware
- Specialized hardware
- Software for von Neumann machines

FACETS / BrainScaleS / HBP

Neuromorphic Hardware

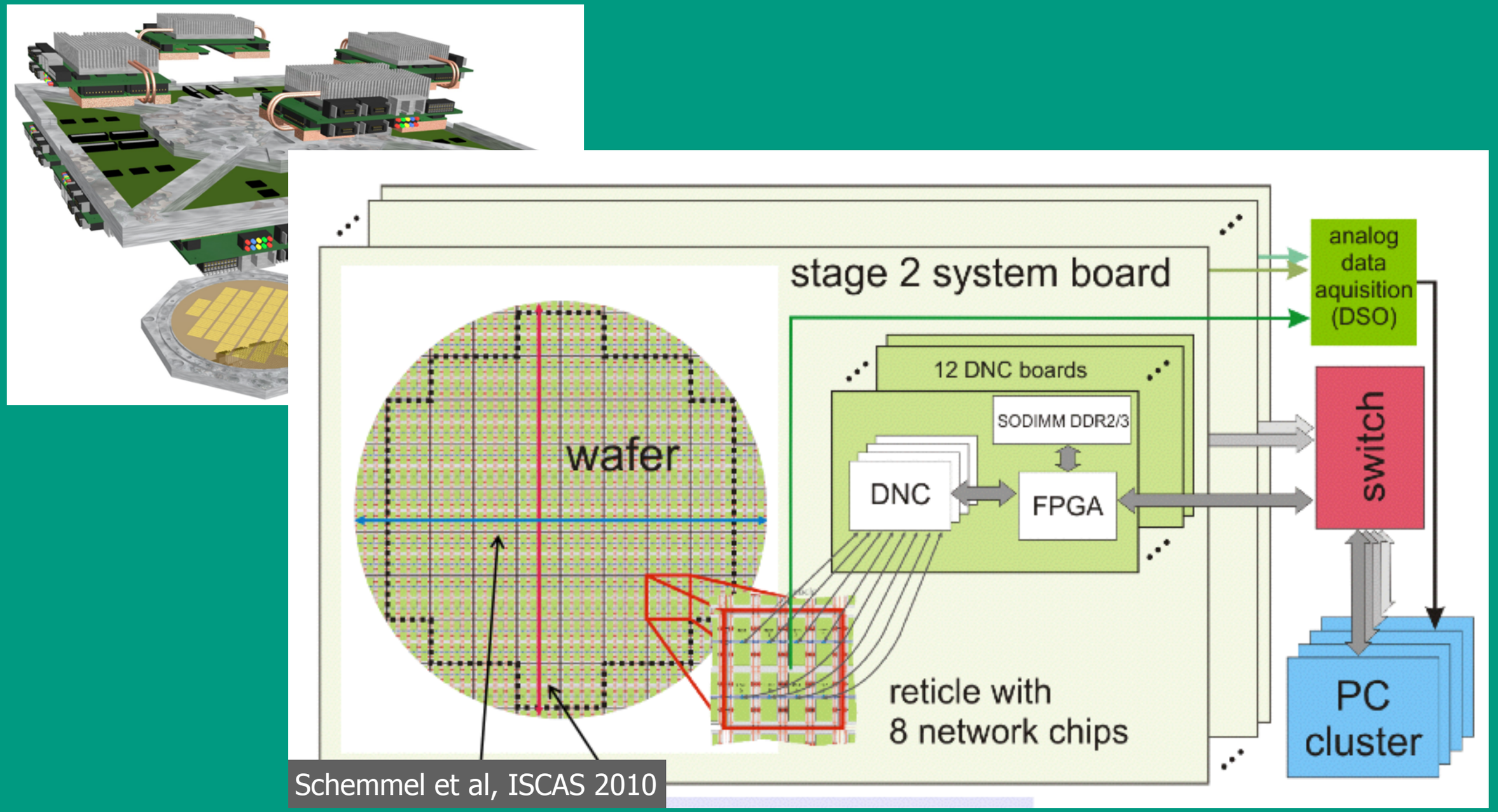


KIP U Heidelberg
BrainScaleS

Schemmel et al, ISCAS 2010

FACETS / BrainScaleS / HBP

Neuromorphic Hardware



Schemmel et al, ISCAS 2010

Schemmel et al, ISCAS 2010

FACETS / BrainScaleS / HBP

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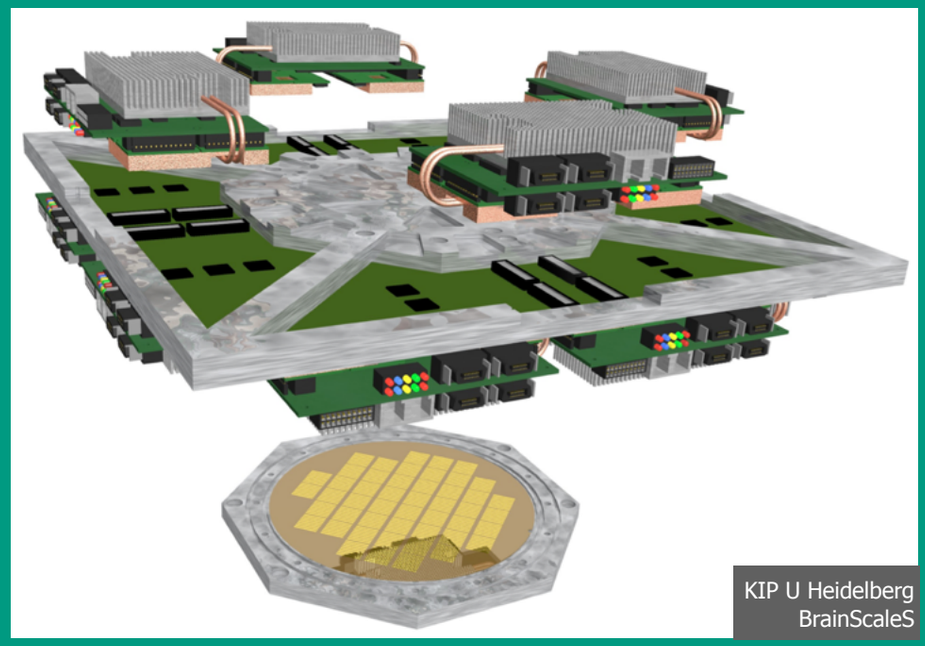
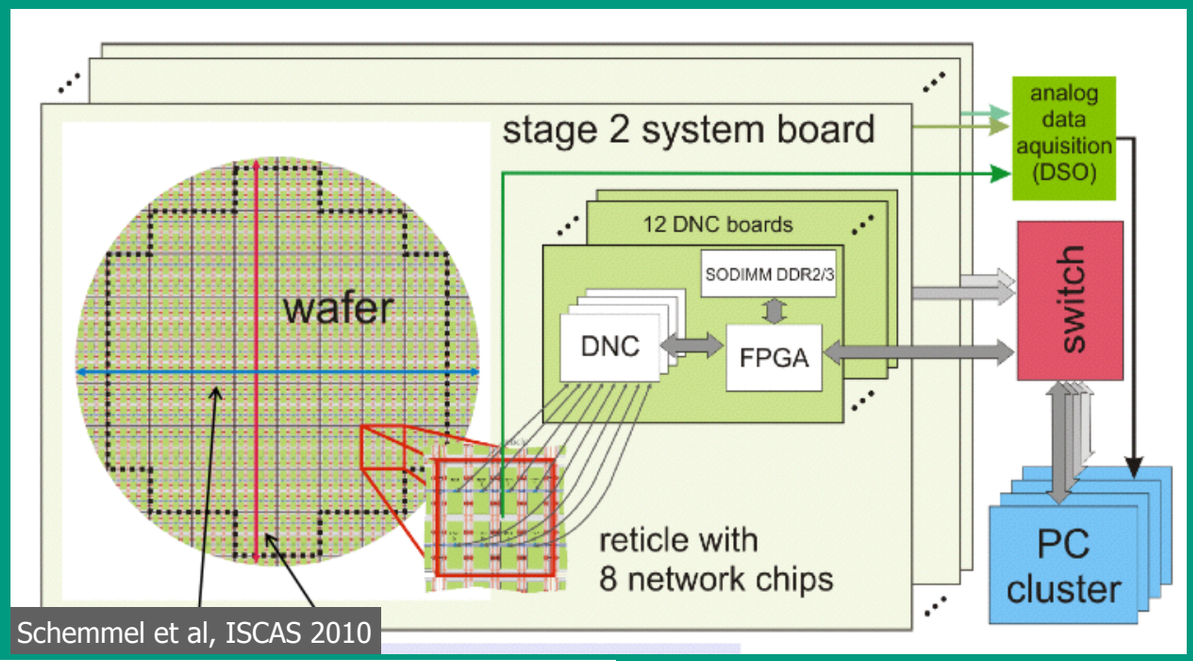
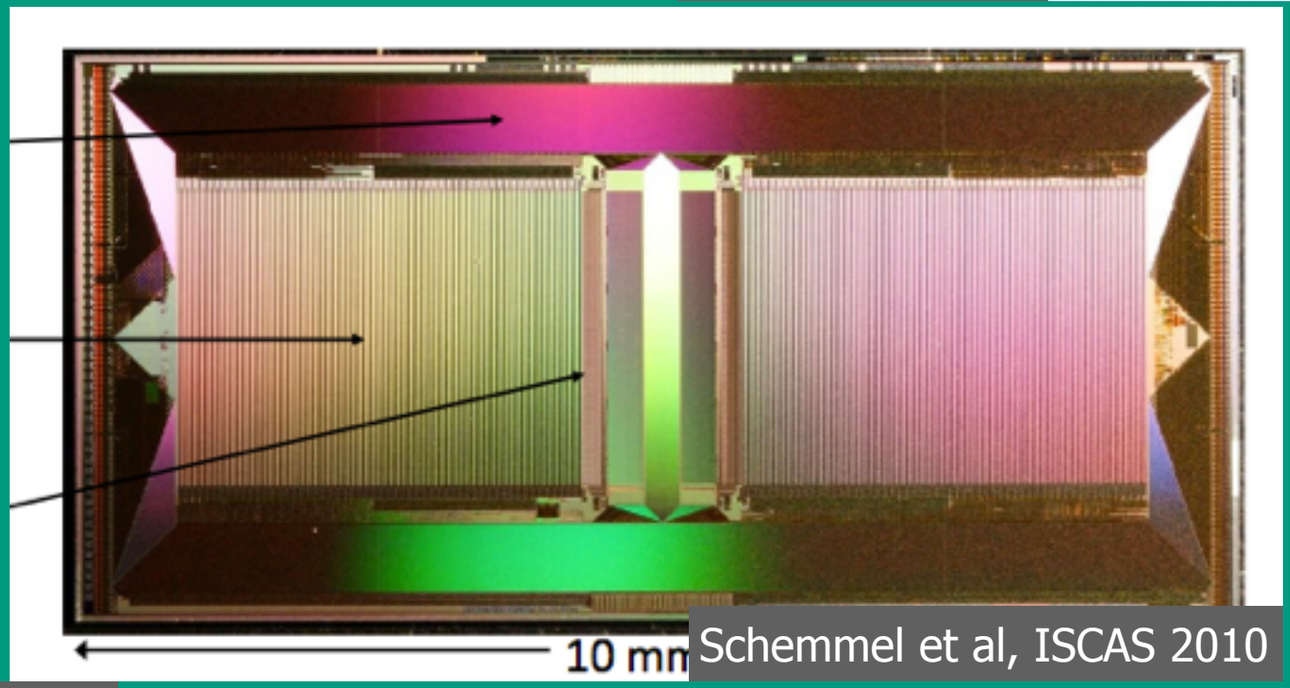


KIP U Heidelberg
BrainScaleS



Schemmel et al, ISCAS 2010

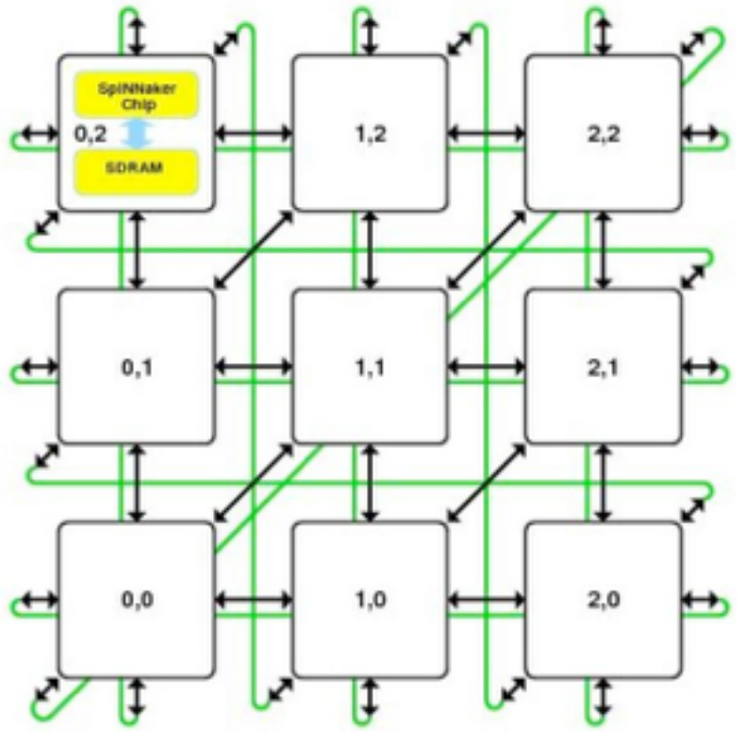


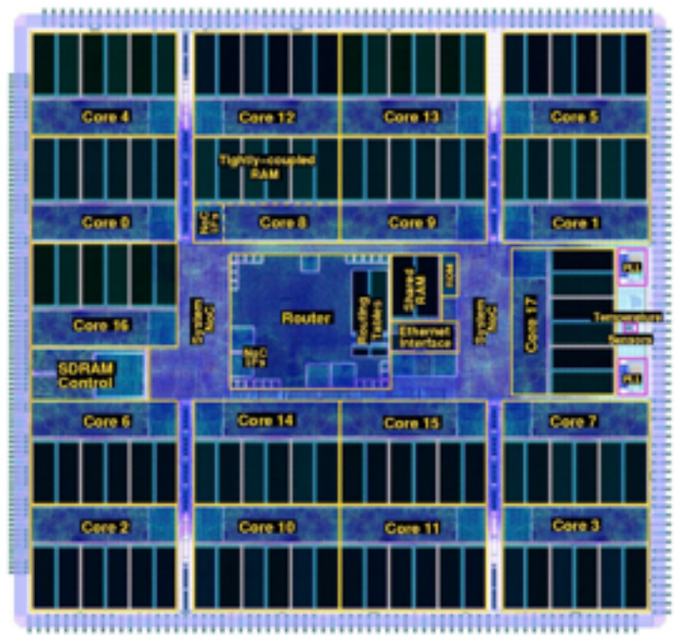
Schemmel et al, ISCAS 2010

Schemmel et al, ISCAS 2010

SpiNNaker

- 1 million ARM9 cores
- 7 TB RAM
- integrated on 57k SiP nodes
- torus, specialized routers
- 5 billion packets/s bandwidth
- < 100kW
- programmable neuronal dynamics
- 1 billion neurons
- Steve Furber / U Manchester & Co.
- Part of BrainScaleS & HBP
- Cortical Microcircuit is currently being ported to SpiNNaker

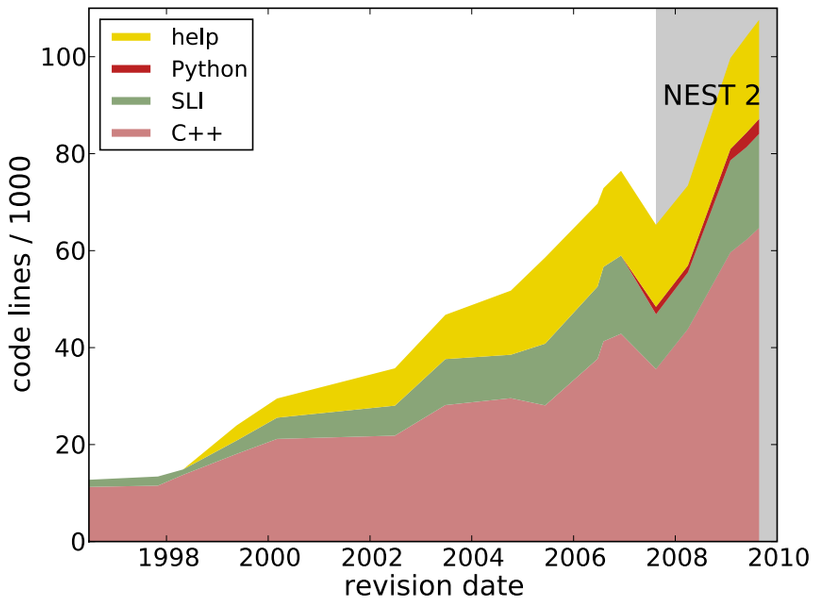


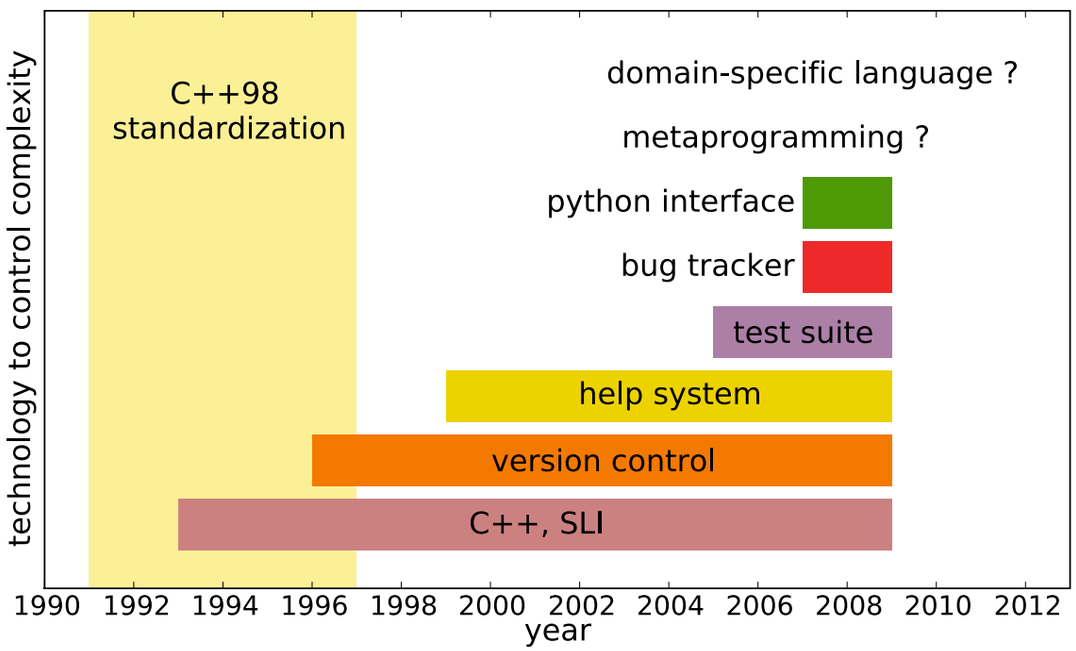


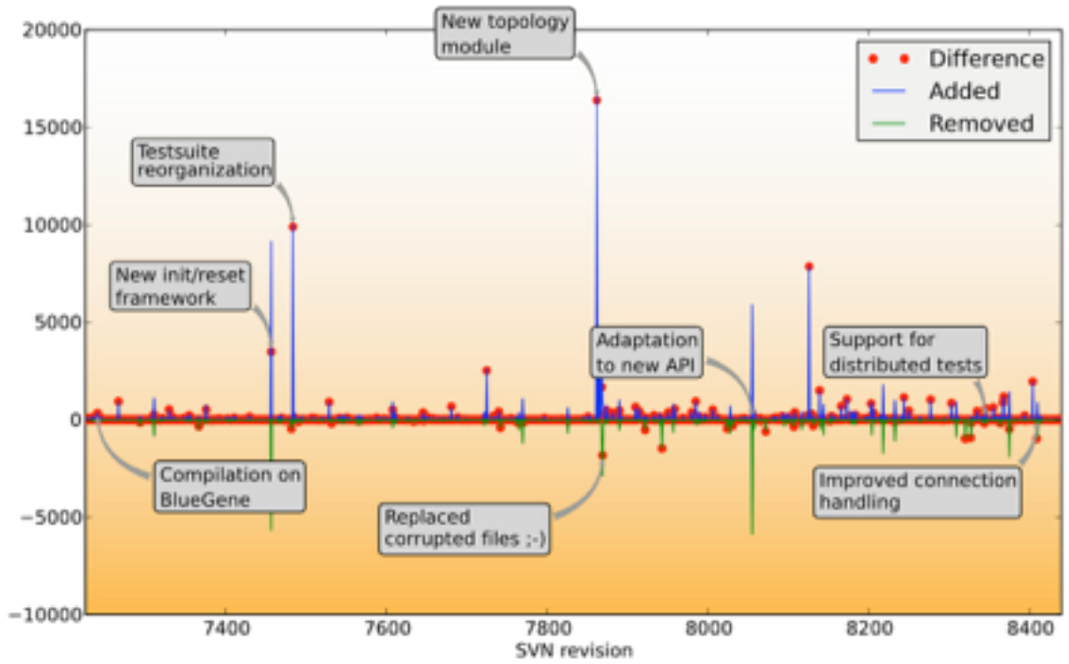
The NEST Simulator

Development history

- SYNOD
- SYNOD2
- BKernel/BLISS/ParaSynod/Paranel
- NEST
- NEST2
- Currently: NEST 2.6.0

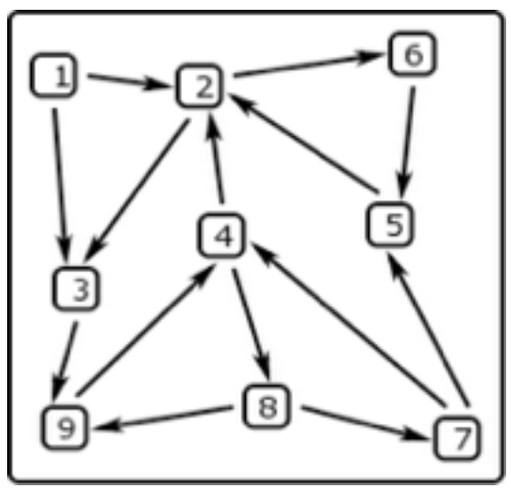


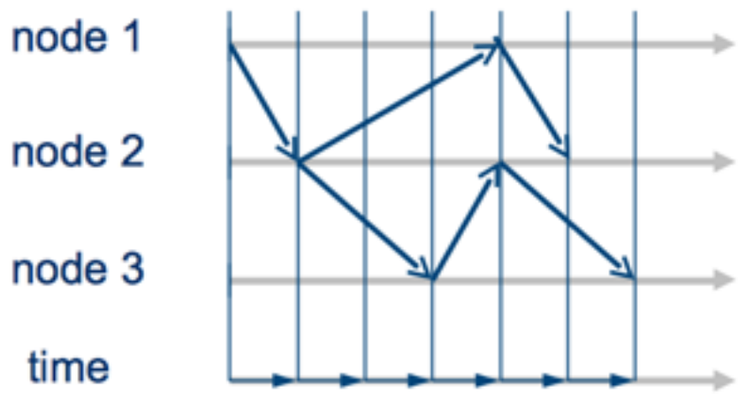


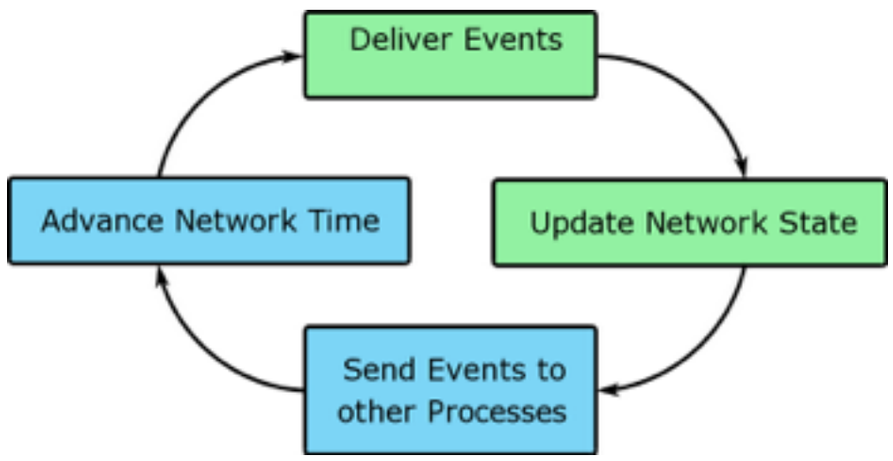


NEST History

- Simulator for large spiking networks
- C++-kernel controlled by PostScript-based interpreter
- **1995**: Serial simulator (SYNOD, Diesmann & Gewaltig)
- **1999**: Nature paper on synfire chains (Diesmann et al)
- **2001**:
    - MPI parallelization (Paranel; Mehring, Morrison)
    - Thread-parallelization (NEST 1; Gewaltig)
- **2005**: Hybrid MPI-Thread parallelization (Plesser, Eppler)
- **2008**: Python interface







Going Brain Scale: The Memory Crunch

- Ultimate goal: 10^{11} neurons, 10^{15} synapses
- Memory for neurons
  - 1 kB / neuron, incl recent spike history

  ➡ 100 PB
- Memory for synapses
  - 10 B / synapse (optimistic)

  ➡ 10 EB
- Memory for adjacency tables and other infrastructure????

K in Kobe

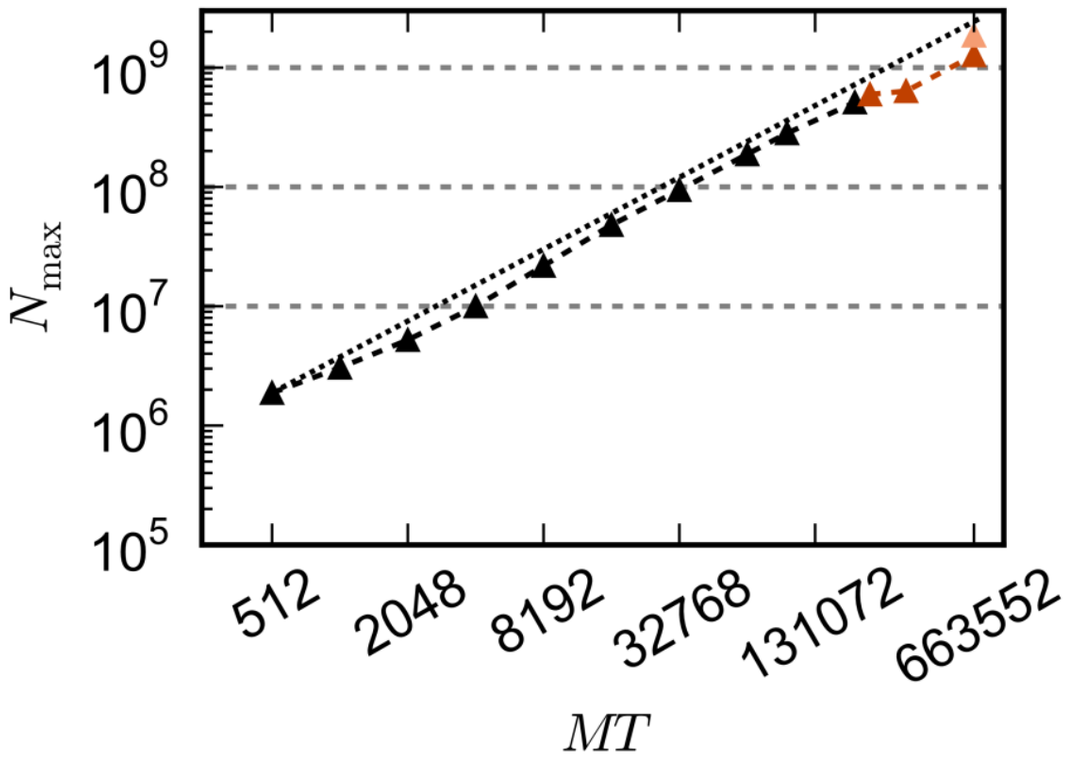
- 88.128 compute nodes
- 8 cores per node
- 705.024 cores
- 2GB RAM per core
- Fujitsu Sparc64 VIIIfx @ 2GHz
- Tofu interconnect (1D-3D, OpenMPI)
- 9.89 MW
- 8.2 PFlops

JuQueen

- IBM BlueGene/Q
- 24.576 nodes @ 16 cores
- 393.216 cores in total
- 1GB RAM per node
- IBM PowerPC A2, 1.6 GHz
- 5D Interconnect

Maximum network size

- up to 5.73x10^8 neurons on 229,376 cores of JUQUEEN
- up to 1.27x10^9 neurons on 663,552 cores of K
- 11,250 synapses per neuron (exc-exc STDP)



- largest general network simulation performed on K in July 2013 (1.73x10^9 neurons, 6000 synapses per neuron)

Status & Perspective

- Well-scaling simulator from laptop to world's largest machines
- Record-holder for very large simulations
- Selected as Network Simulator Component for the HBP
- Active developer community
- Available Github since Spring 2015
- www.nest-simulator.org

The People