University of Waterloo

Modelling the Brain

SYDE 556/750

Chris Eliasmith

Centre for Theoretical Neuroscience

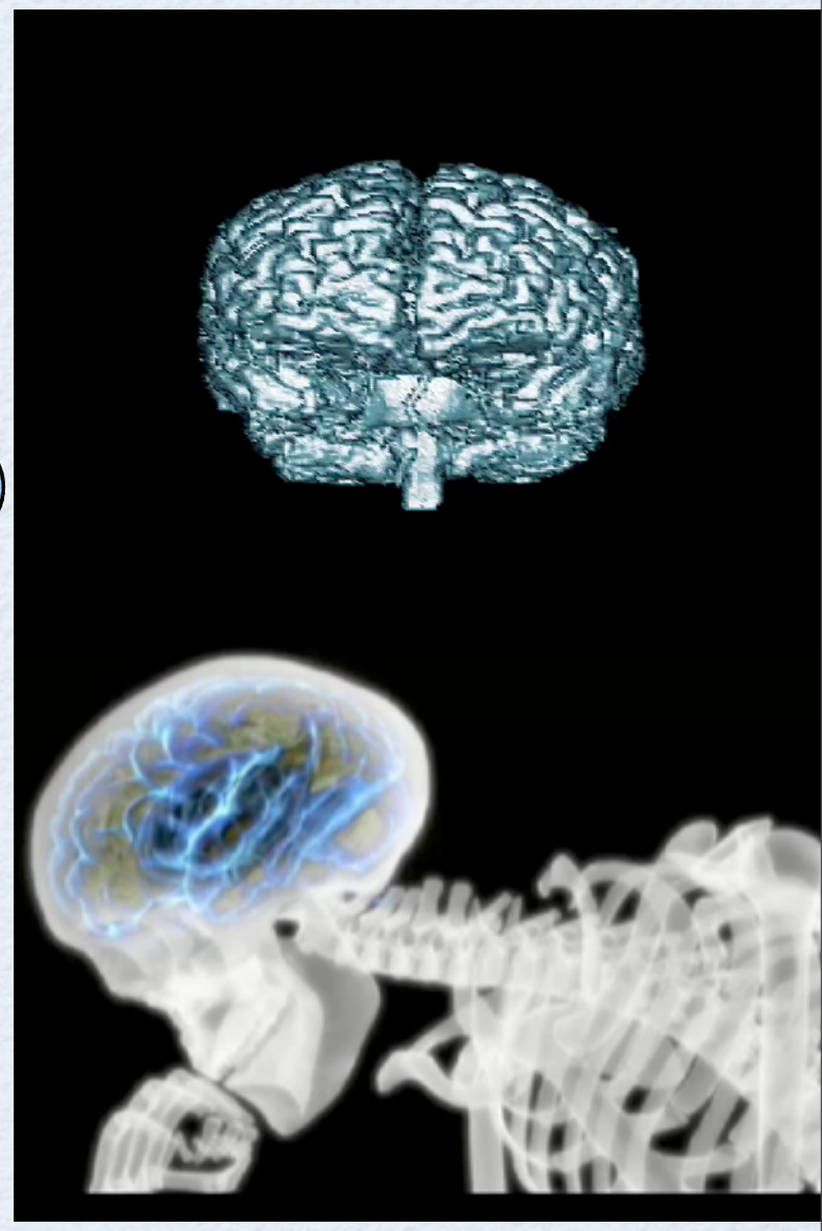
CTN Waterloo

CNRG computational neuroscience research group

compneuro.uwaterloo.ca

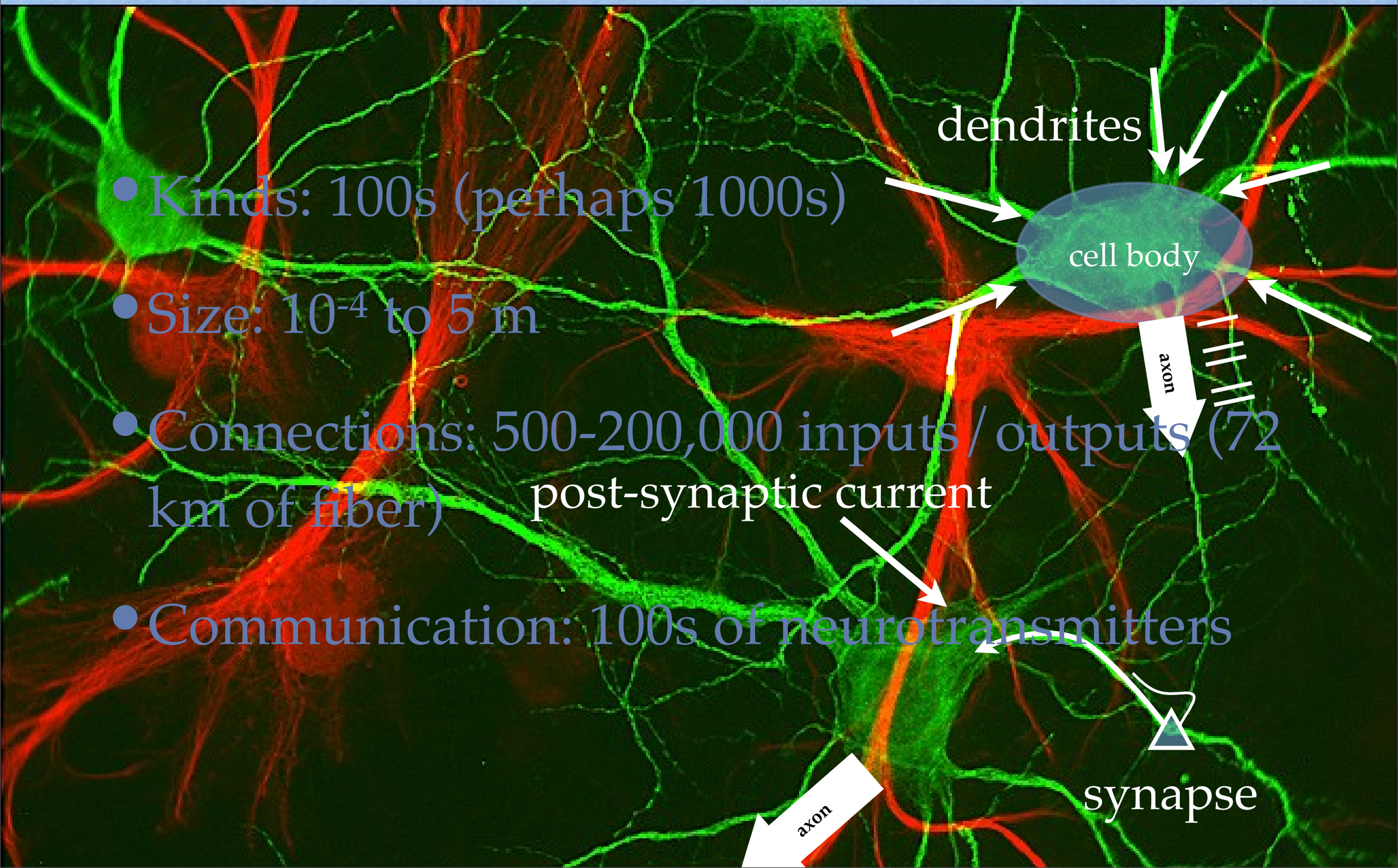
Brains

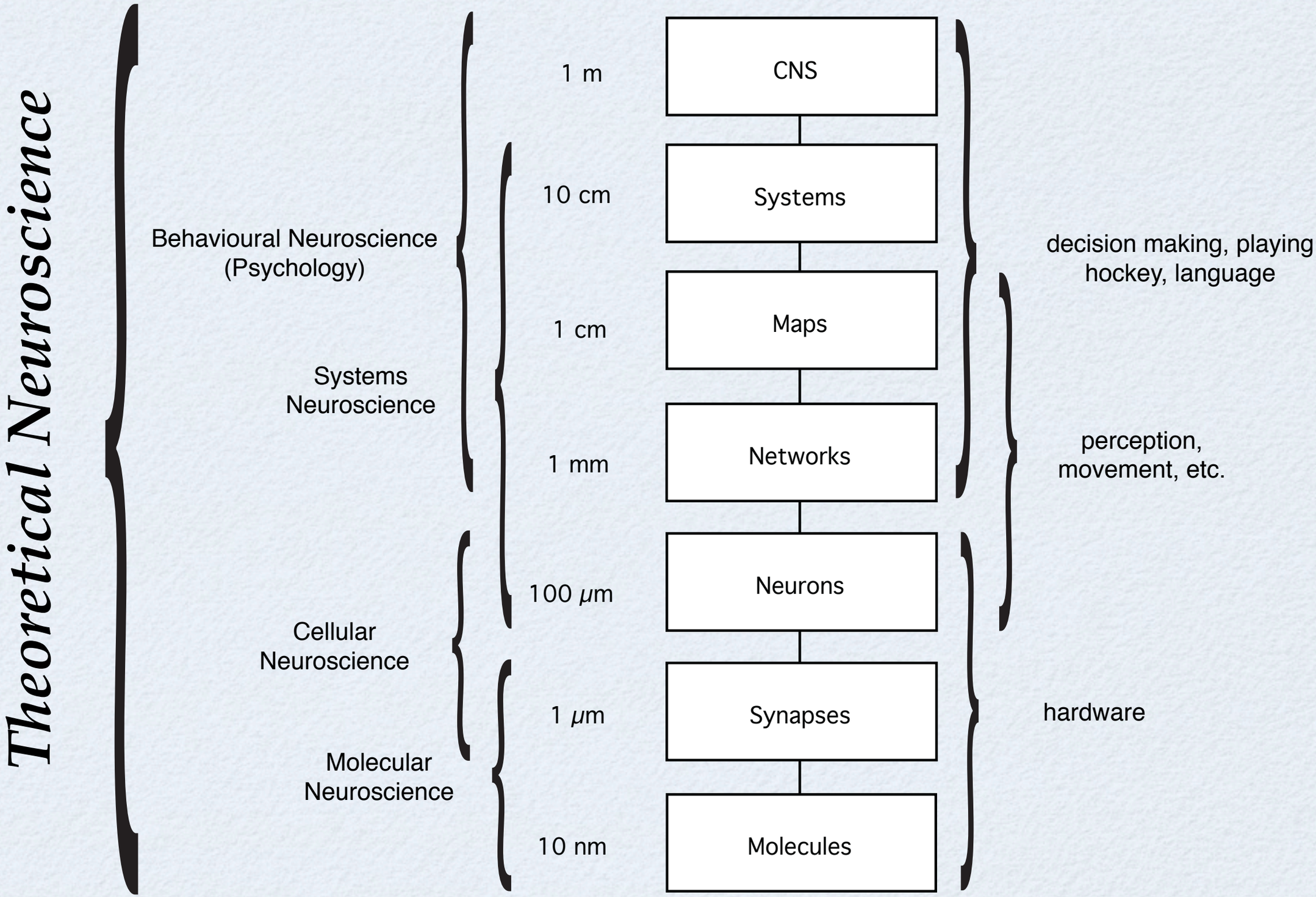
- Mass: 1-2 kg (2% body weight)
- 25% energy (glucose)
- Power: ~20 Watts
- Area: 4 sheets of paper
- Neurons: 100 billion
  - 150,000/mm^2



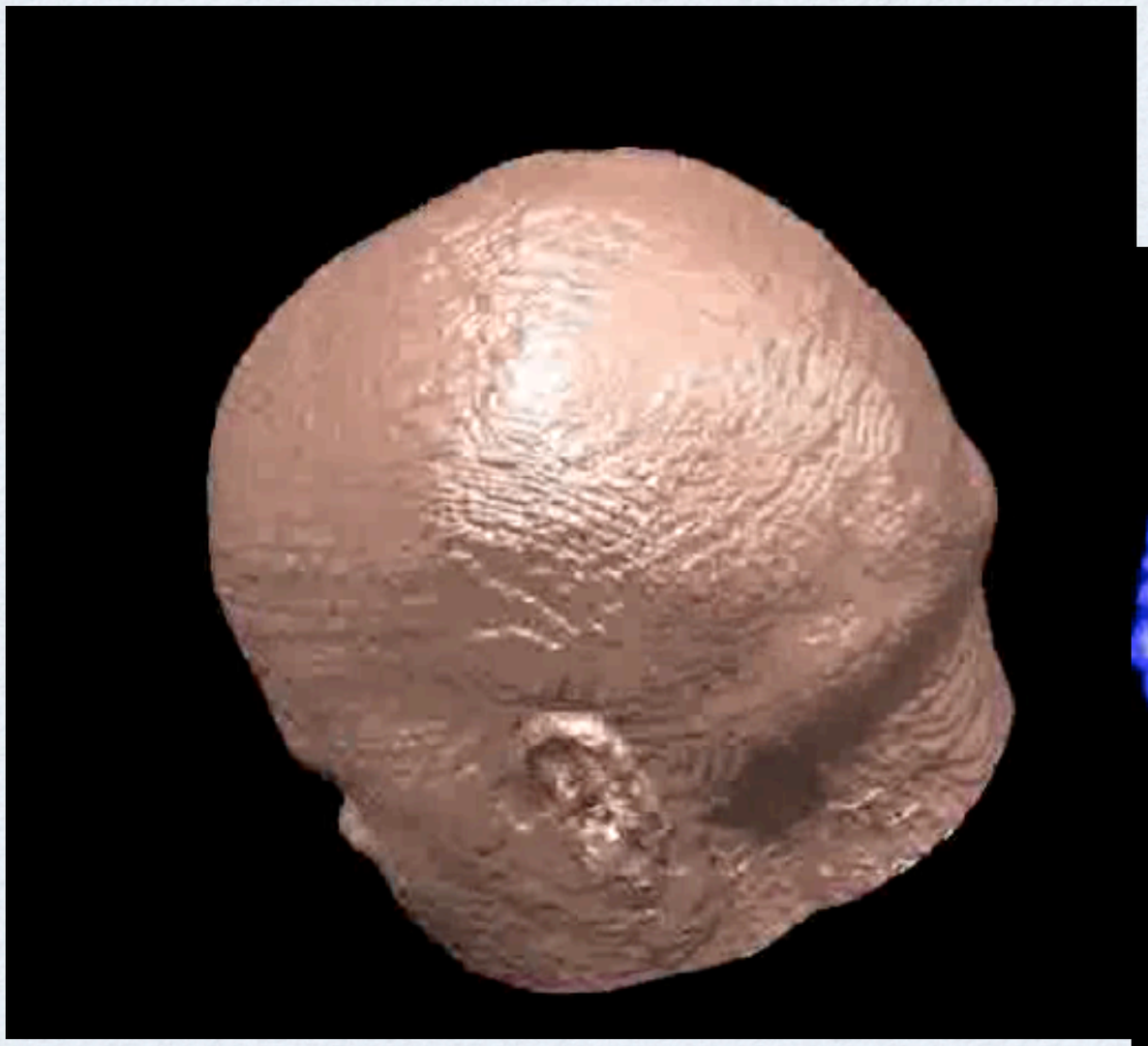
Neurons

- Kinds: 100s (perhaps 1000s)
- Size: 10^{-4} to 5 m
- Connections: 500-200,000 inputs / outputs (72 km of fiber)
- Communication: 100s of neurotransmitters



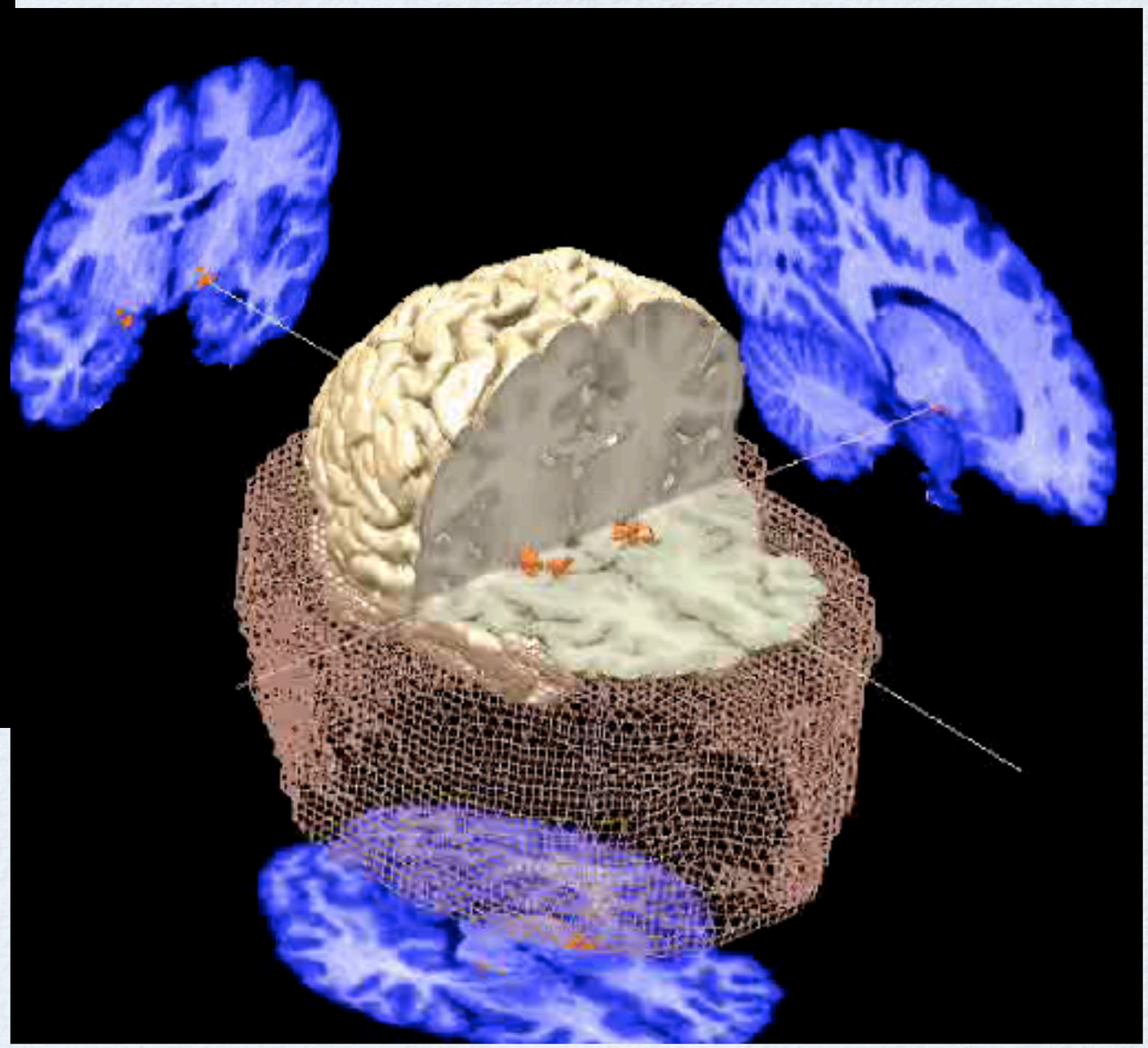

Theoretical Neuroscience
Behavioural Neuroscience
(Psychology)
Systems
Neuroscience
Cellular
Neuroscience
Molecular
Neuroscience
1 m
10 cm
1 cm
1 mm
100 μm
1 μm
10 nm
CNS
Systems
Maps
Networks
Neurons
Synapses
Molecules
decision making, playing
hockey, language
perception,
movement, etc.
hardware
Discipline
Scale
Level of Organization
Informative about

fMRI: Systems

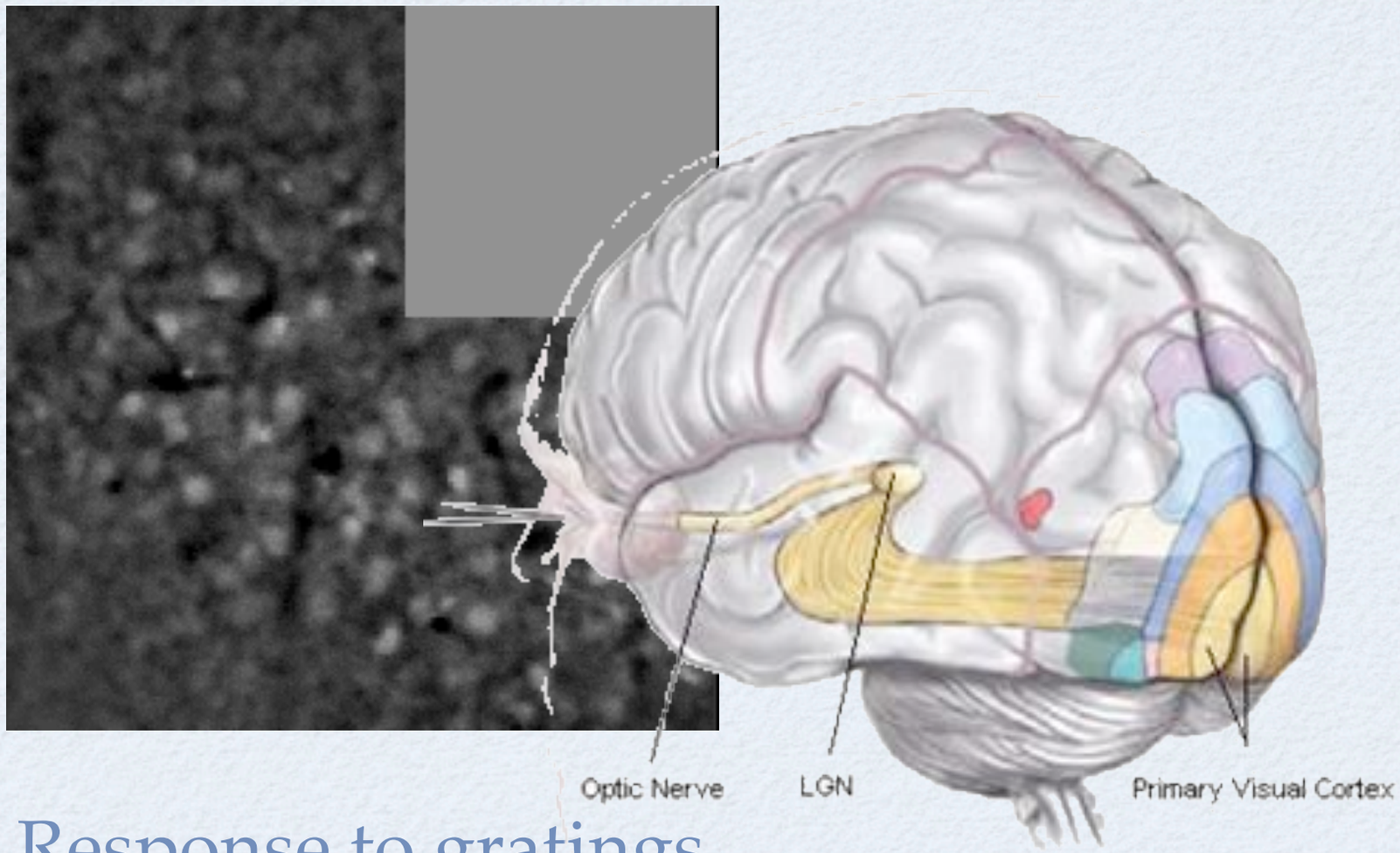


Mothers and children

Fear



Surface Imaging: Maps/Networks

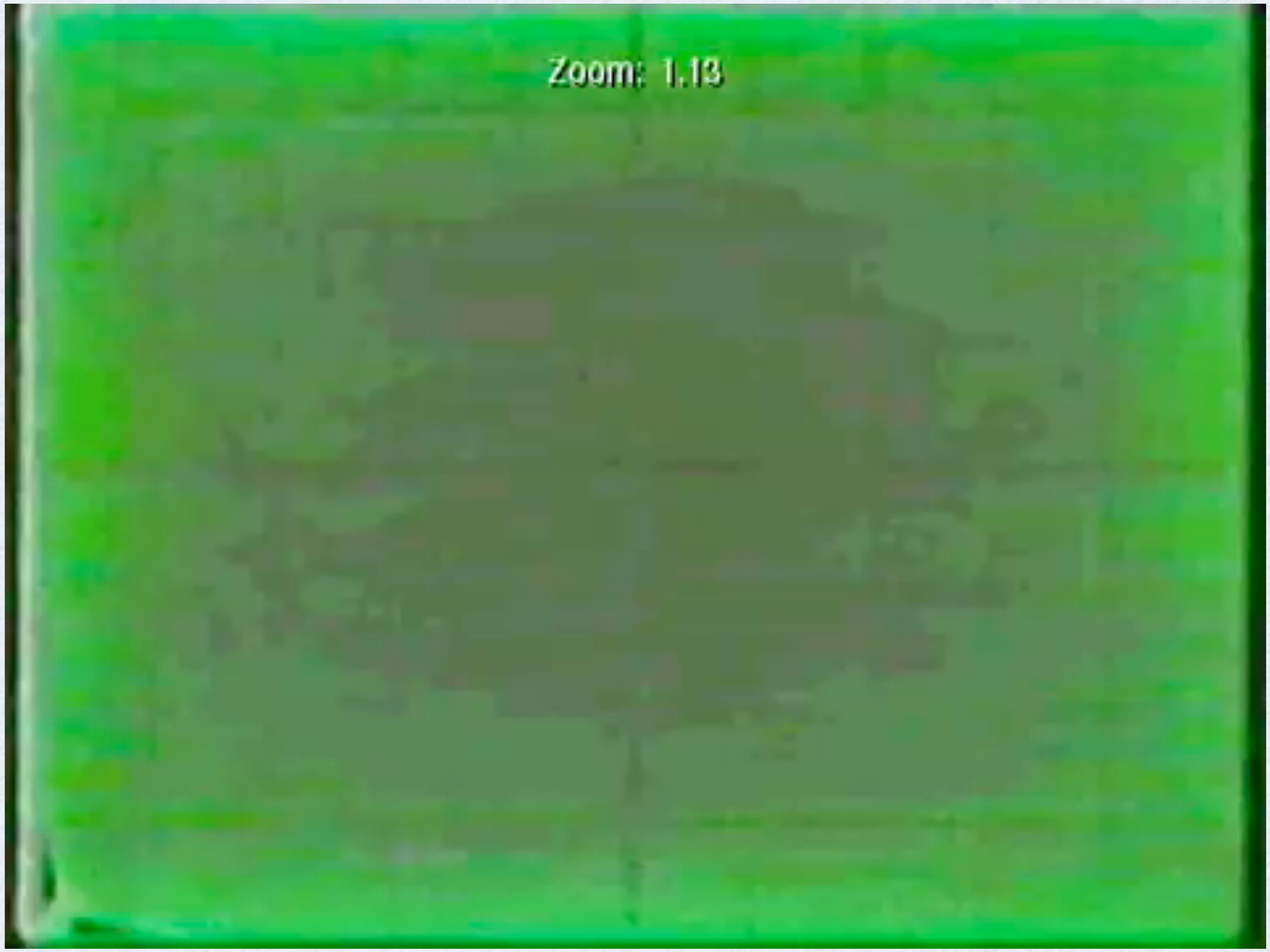


Response to gratings

Single Cell Electrodes: Neurons

Current→

Cell Response



Cortical cell with injected current

Cool, but so what?

- What can we do with all this data?
- Neuroscience is

  "Data rich and theory poor"

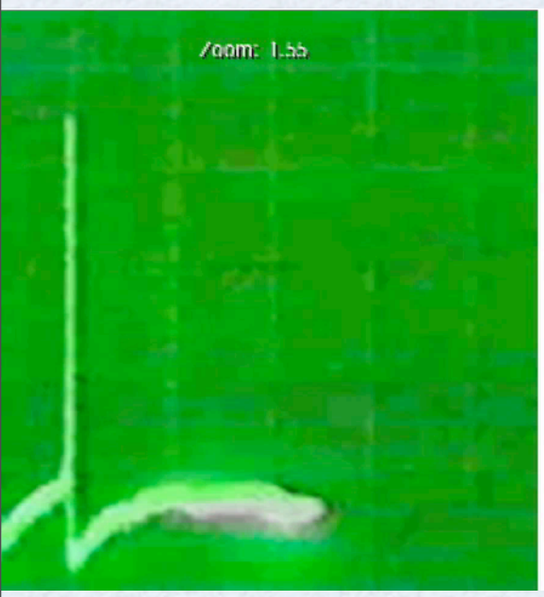
- *Unifying theories* are essential for a deeper understanding of neural phenomena

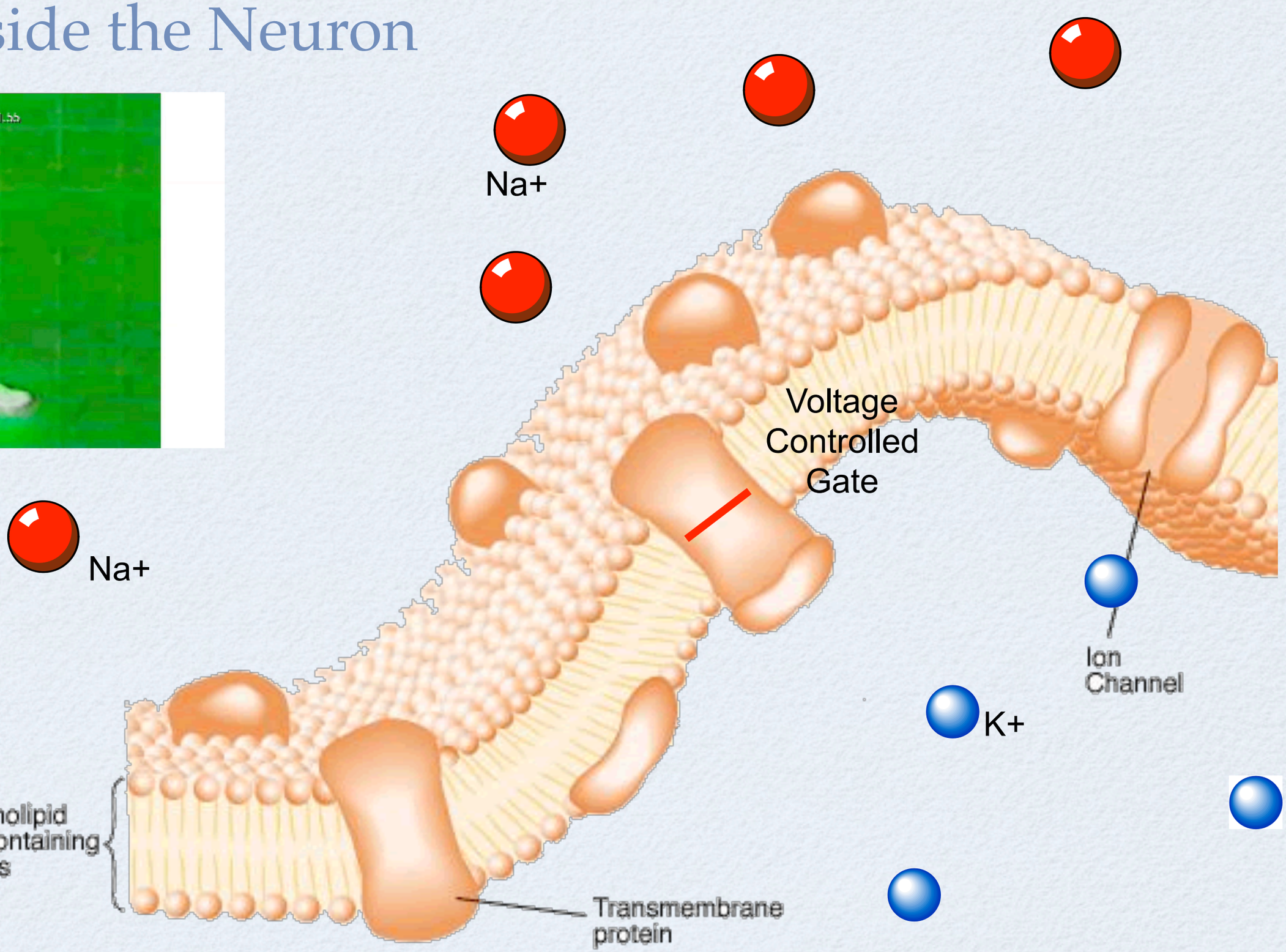
  Theoretical Neuroscience → Models

A fertile analogy

	Theoretical physics	Theoretical neuroscience
Quantify phenomena	$\mathbf{F} = m\mathbf{a}$	$\hat{\mathbf{x}} = \phi\mathbf{a}$
Summarize lots of data	motion of objects	neural representation of information
Speculative (generate hypotheses)	true for all velocities	true for all stimuli

Outside the Neuron

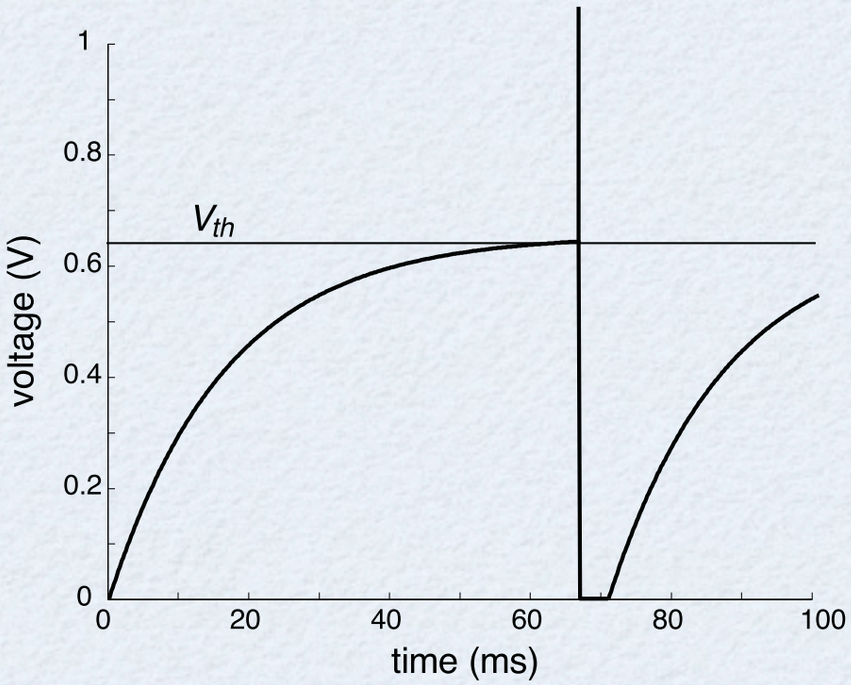




current from dendrites

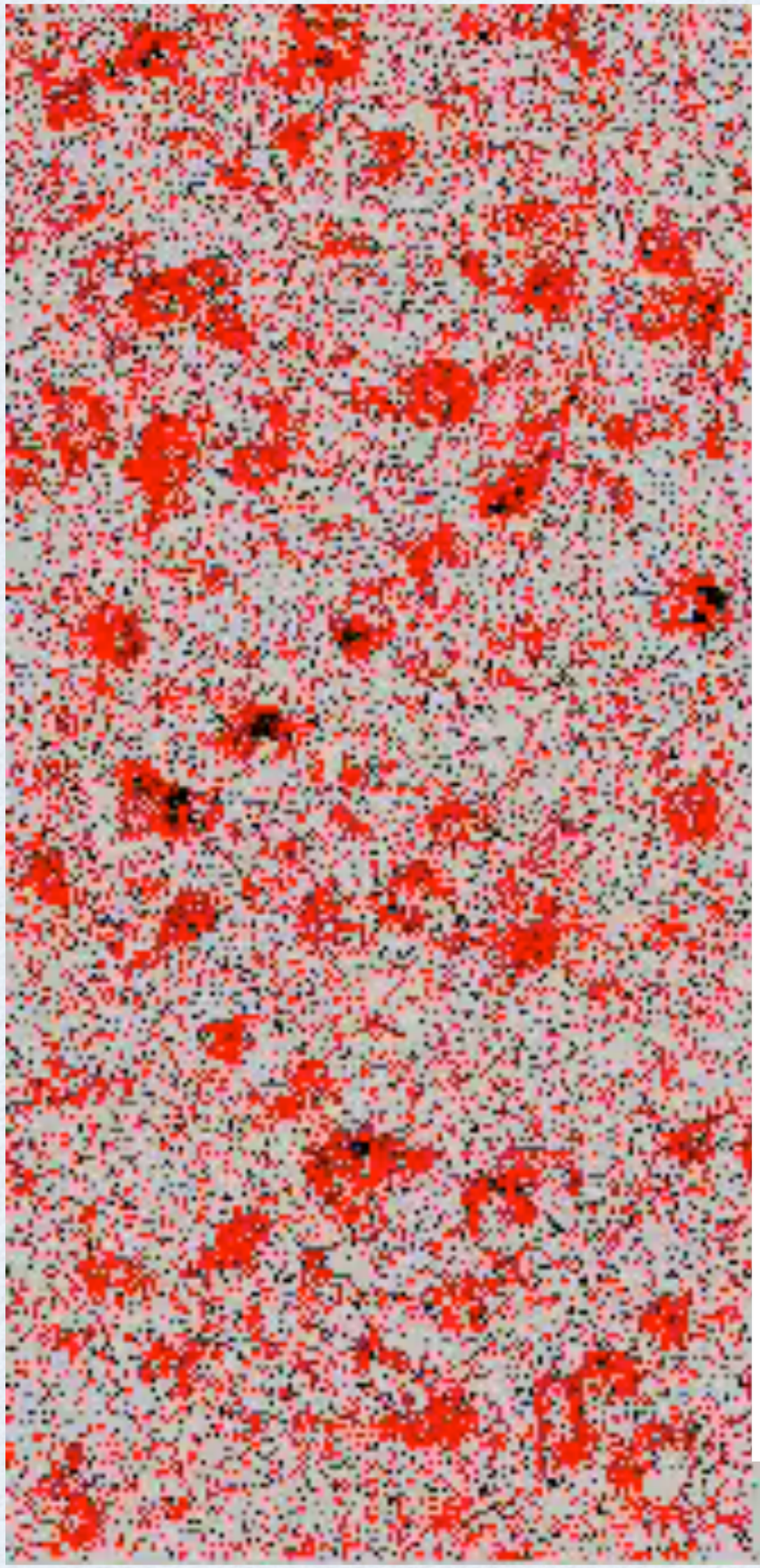
Inside the Neuron

Outside the Neuron



current from dendrites

Inside the Neuron



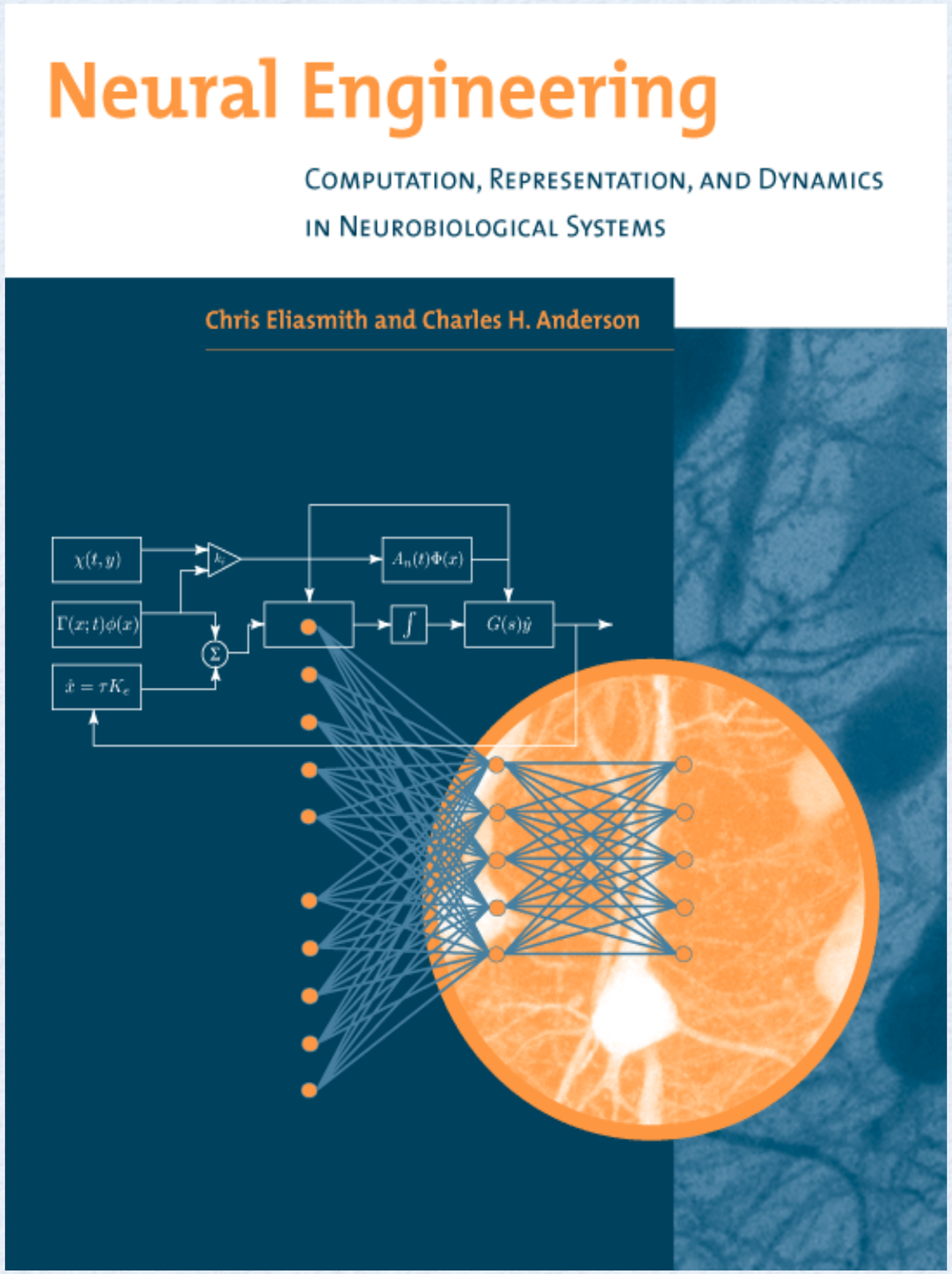
Large-scale model

100 billion simulated neurons

1 s of real time took 50 days on a supercomputer

Randomly connected

Our work at the CNRG

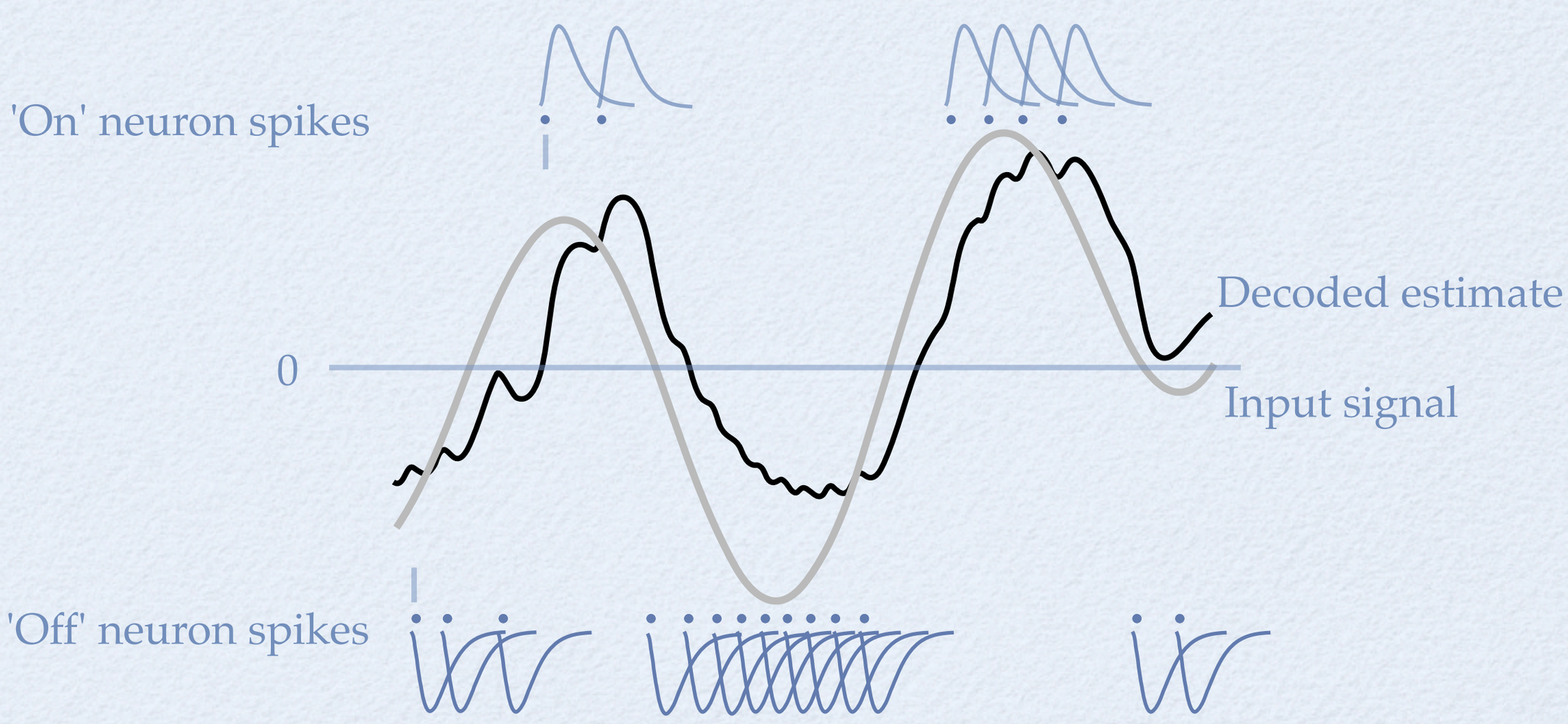


A theory, like Newton's theory of motion:

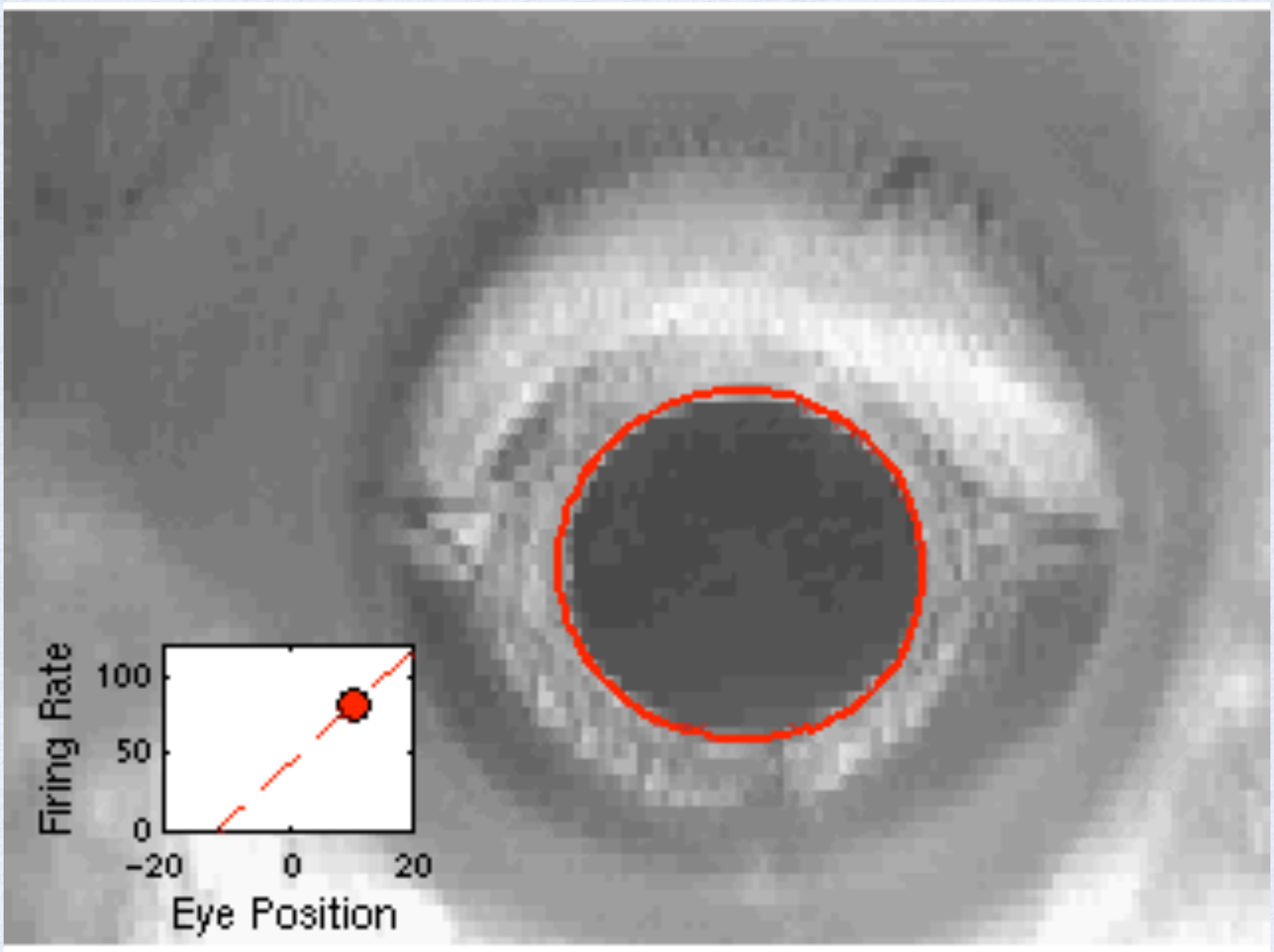
- Three basic principles
- General, unified approach
- Quantitative
- Wrong!

Principle 1: Representation

- Need two procedures to define representation
  - encoding (S O S → . . . - - - . . .)
  - decoding (. . . - - - . . . → S O S)

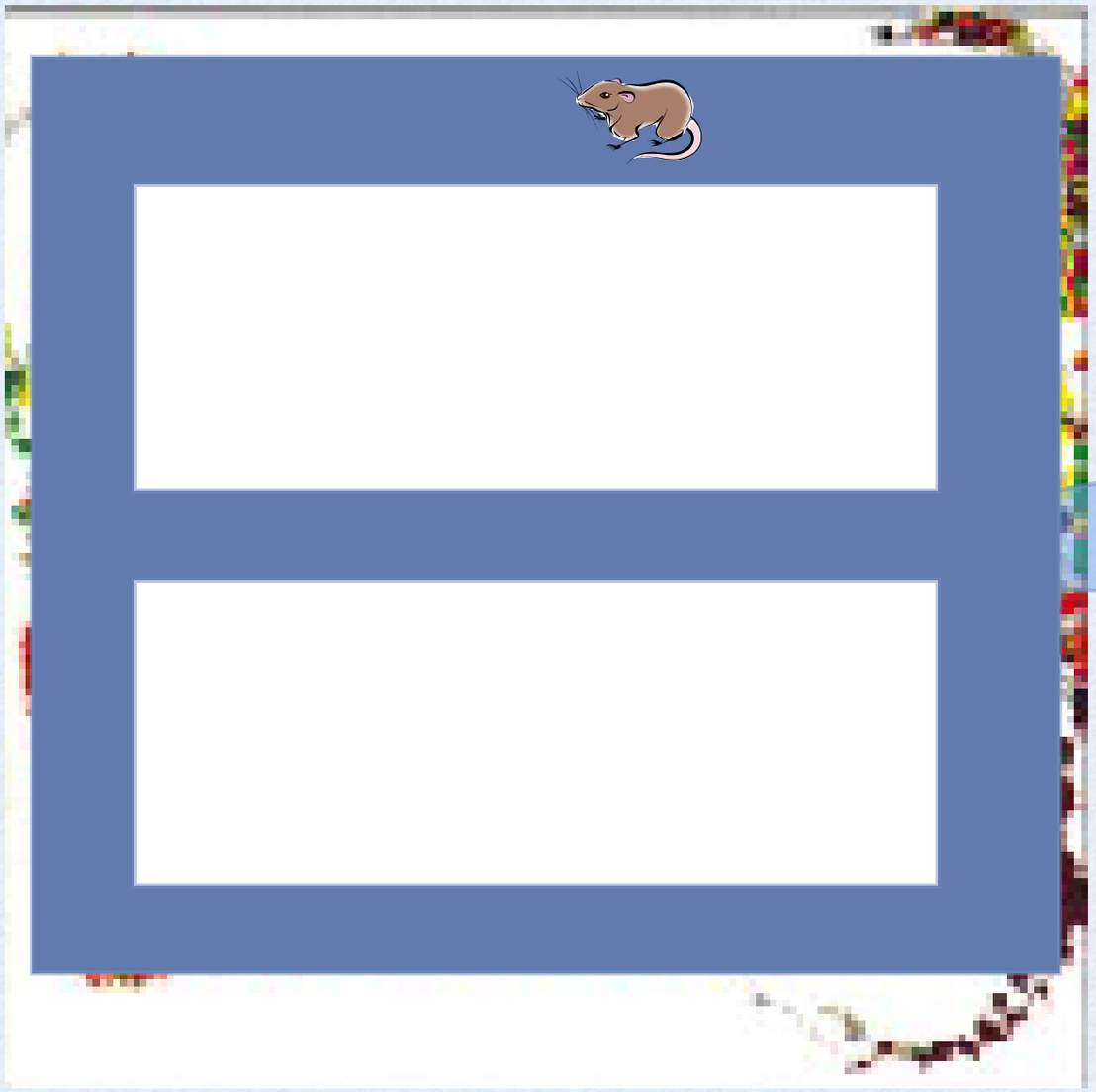


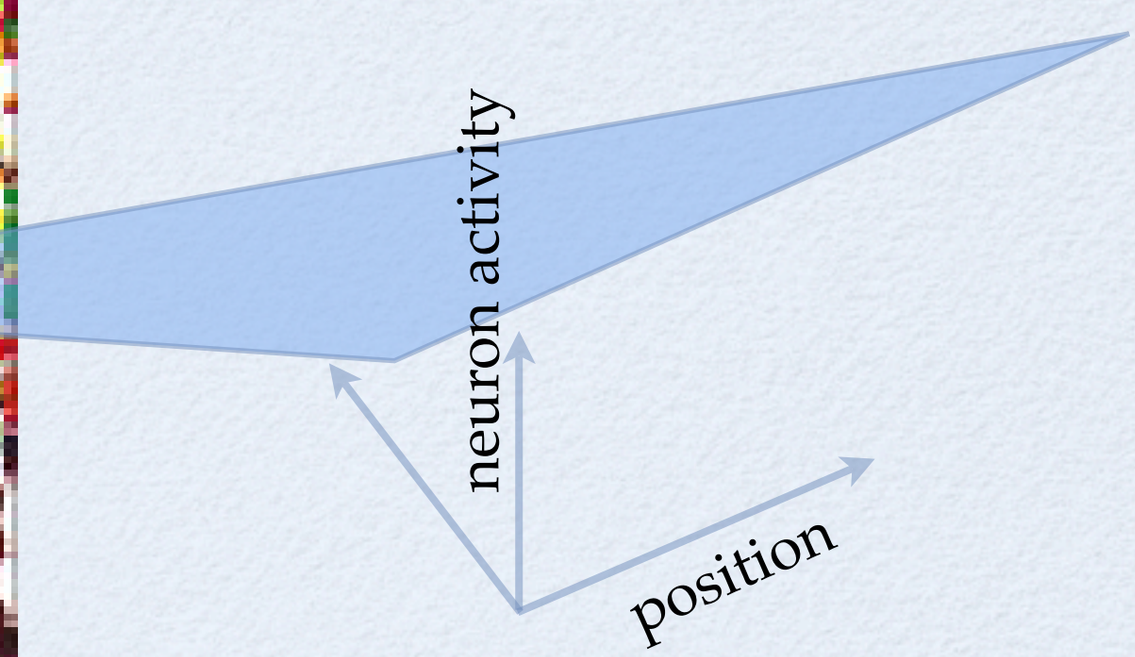
Scalar Representation



Principle 1: Representation

- A 'population' representation (rat navigation)





Principle 2: Transformation

'On' neuron spikes

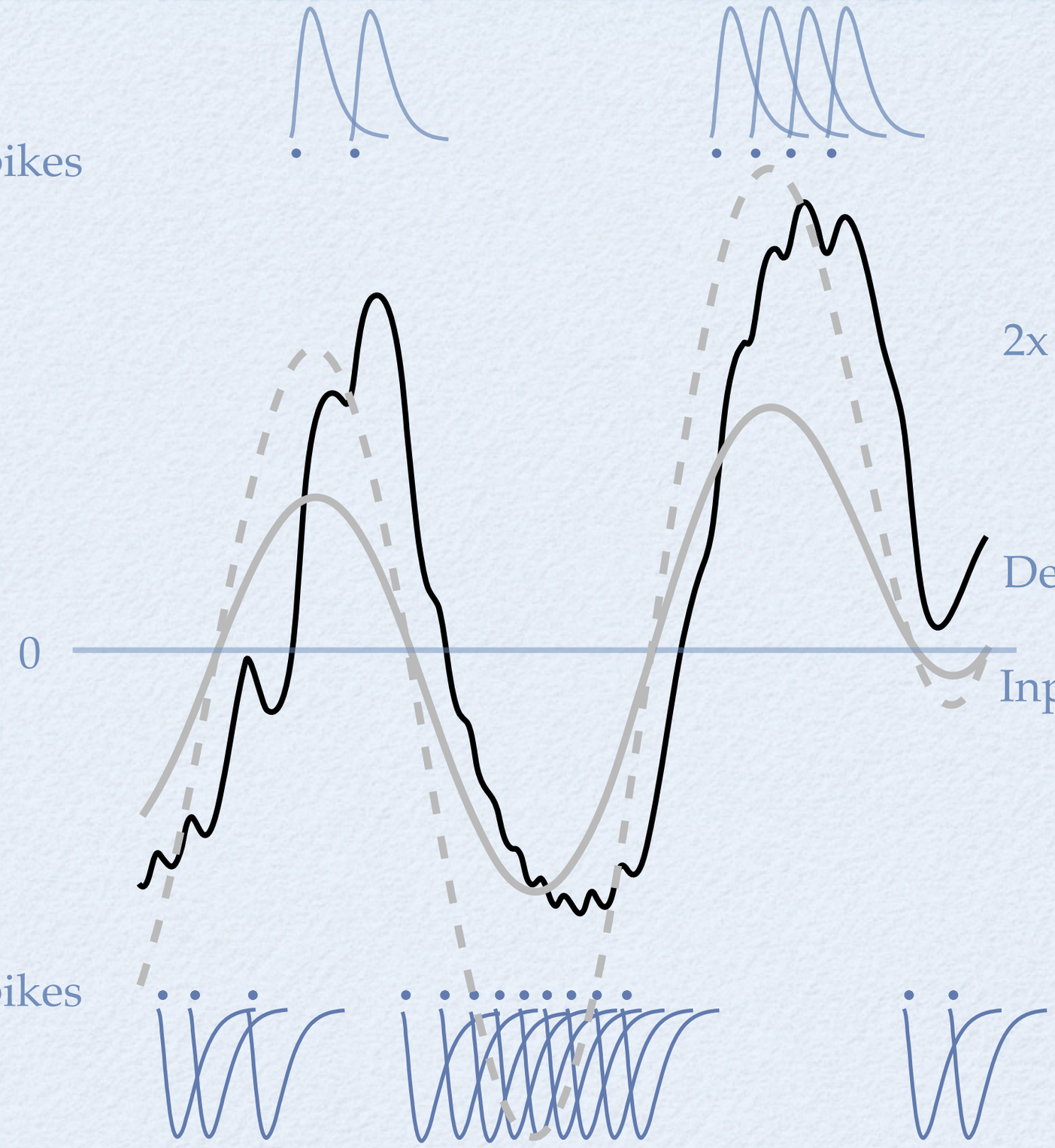
2x Input signal

Decoded estimate

0

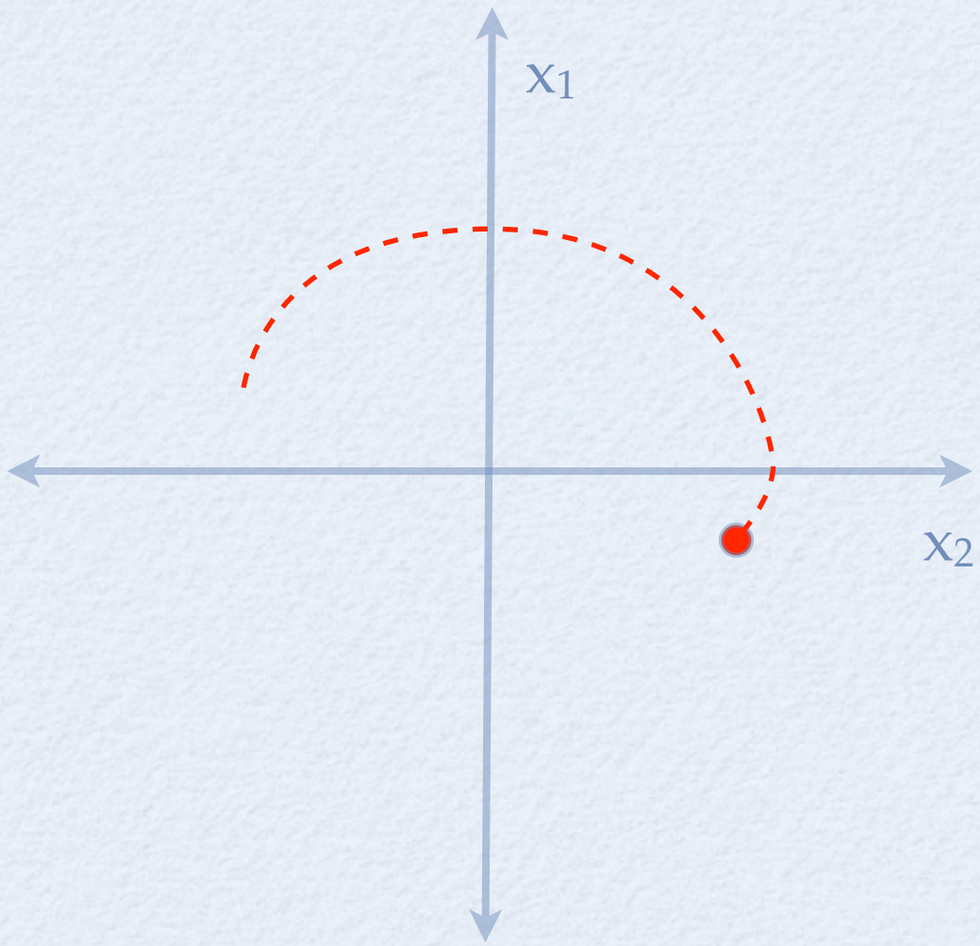
Input signal

'Off' neuron spikes



Principle 3: Dynamics

- There are general ways to write descriptions of time-varying phenomena



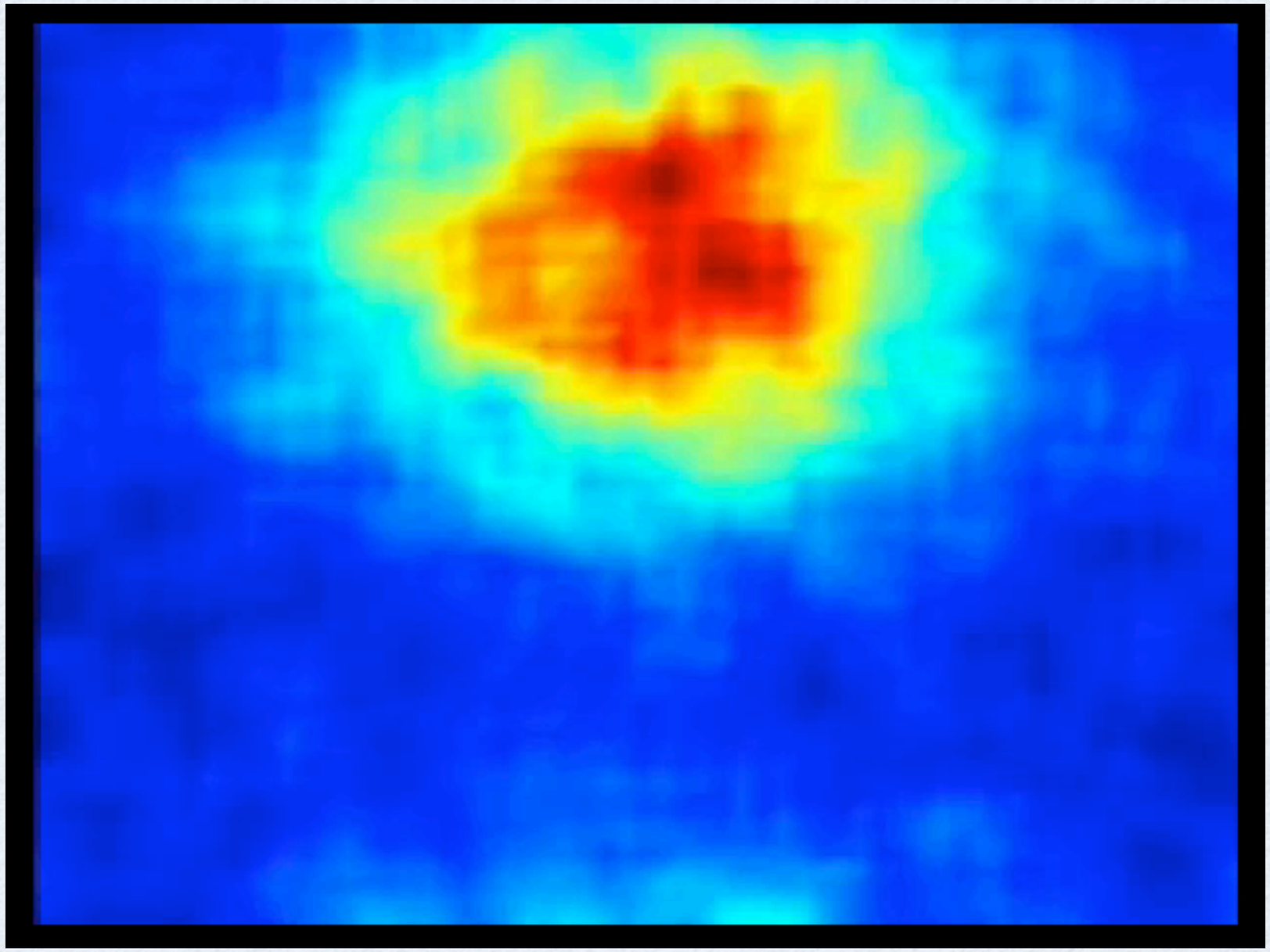
neural dynamics

neural transformation

$$\dot{\mathbf{x}} = f(\mathbf{x}, t)$$

neural representation

- All together: Biologically realistic models that *explains behaviour*



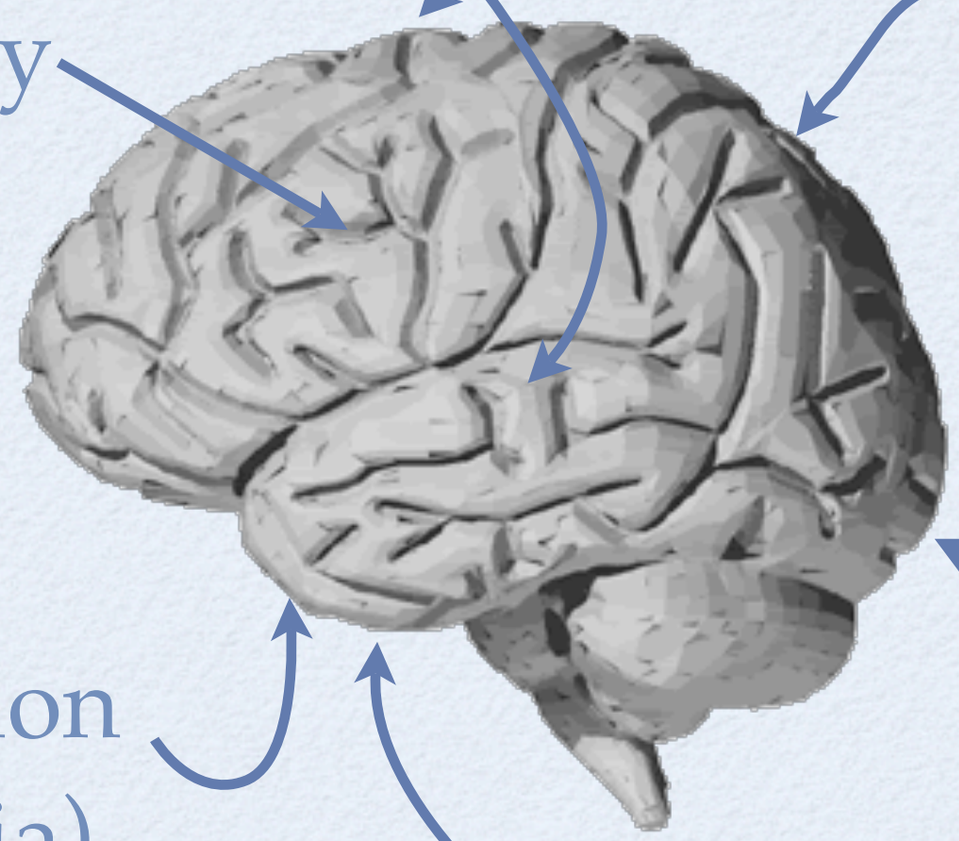
- this model: 11% error with 4000 cells
- best previous model: 100% error with 300 000 cells

Applications

Language-based reasoning

Working memory

Hemineglect



Vision

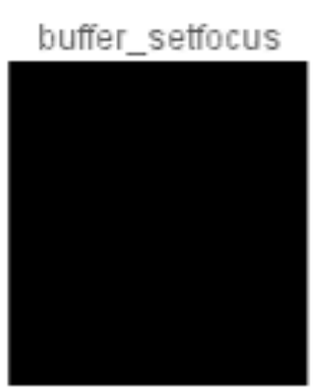
Complex action
(basal ganglia)

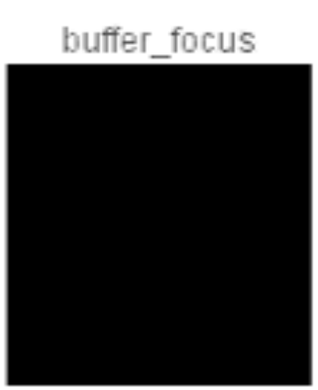
Navigation

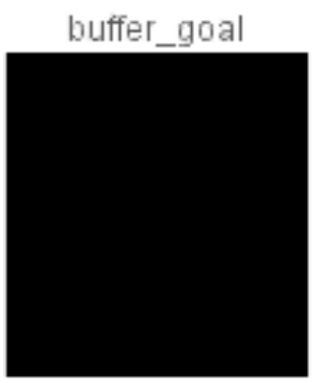
Tower of Hanoi

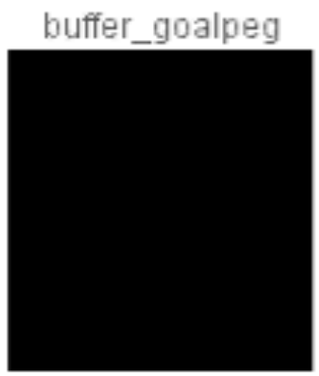
- Classic AI problem: planning, goals, structure representation, memory
- No psychologically plausible neural models

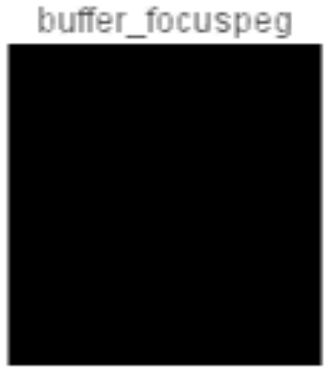
Tower of Hanoi

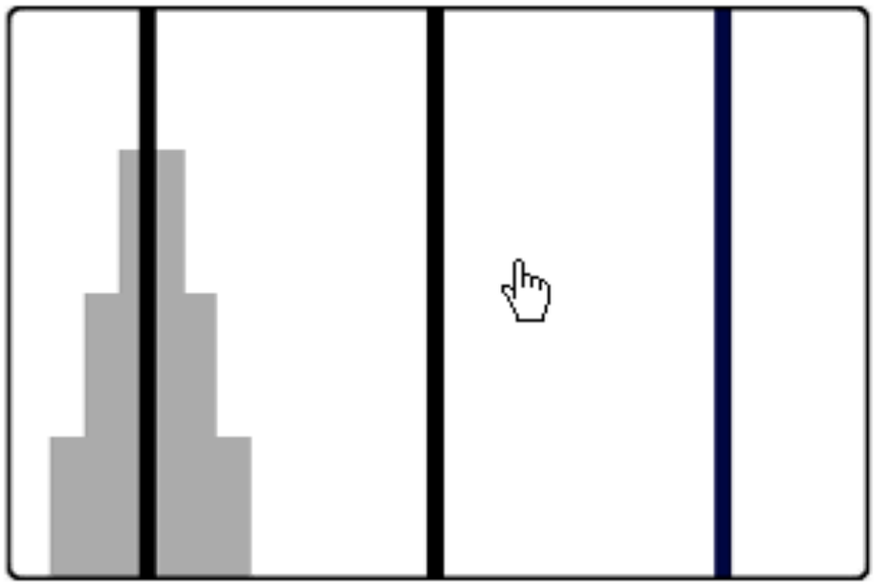


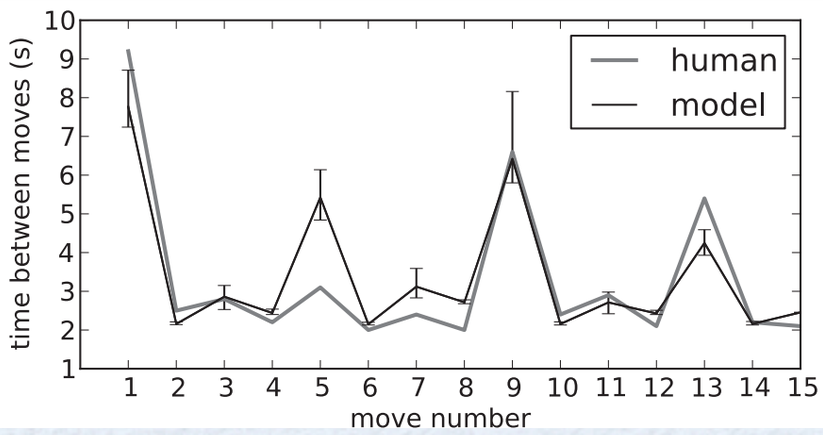


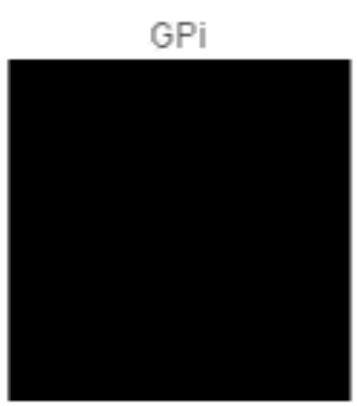


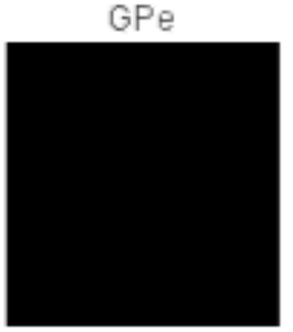








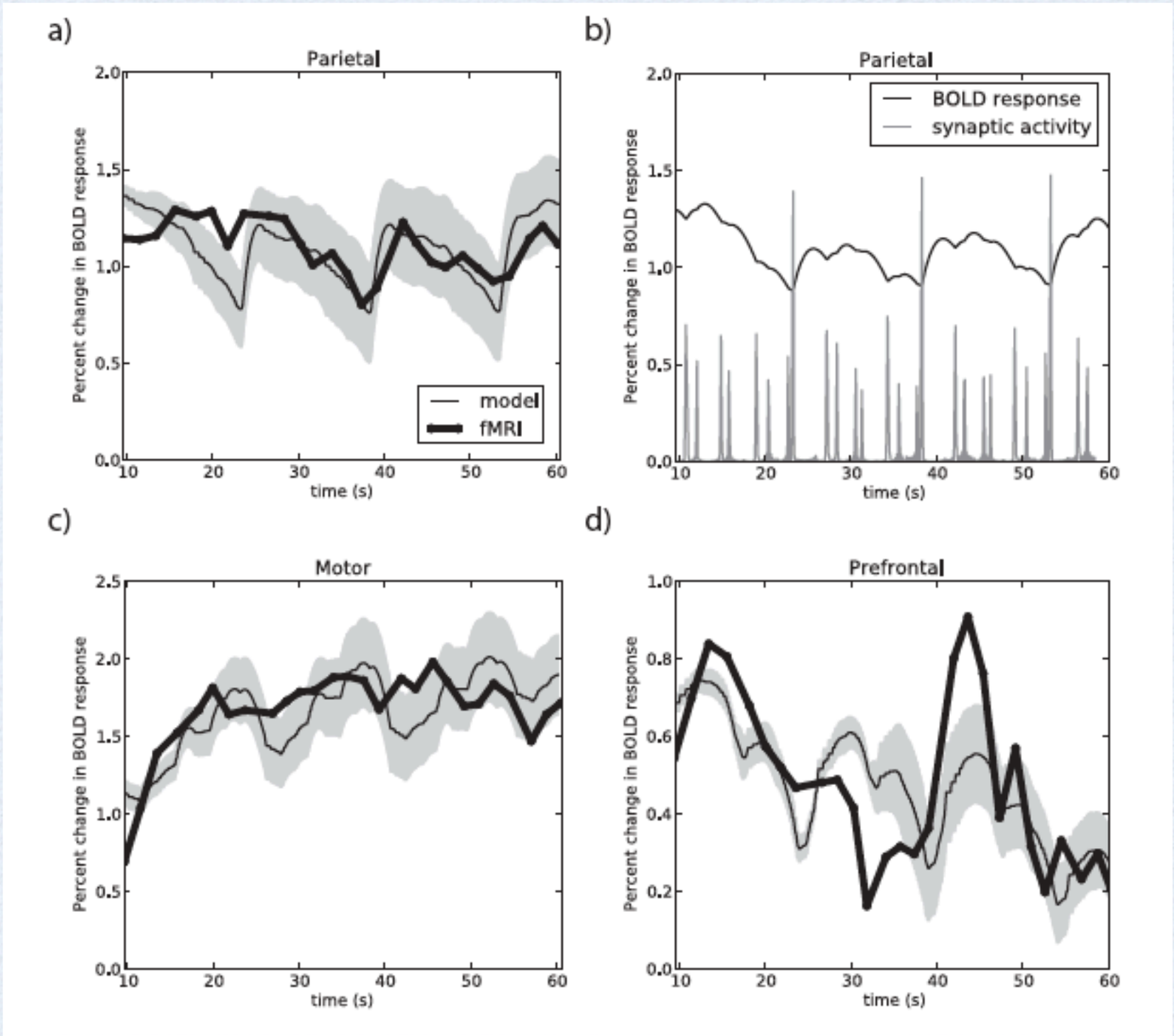




(Data from Anderson, et al., 1993)

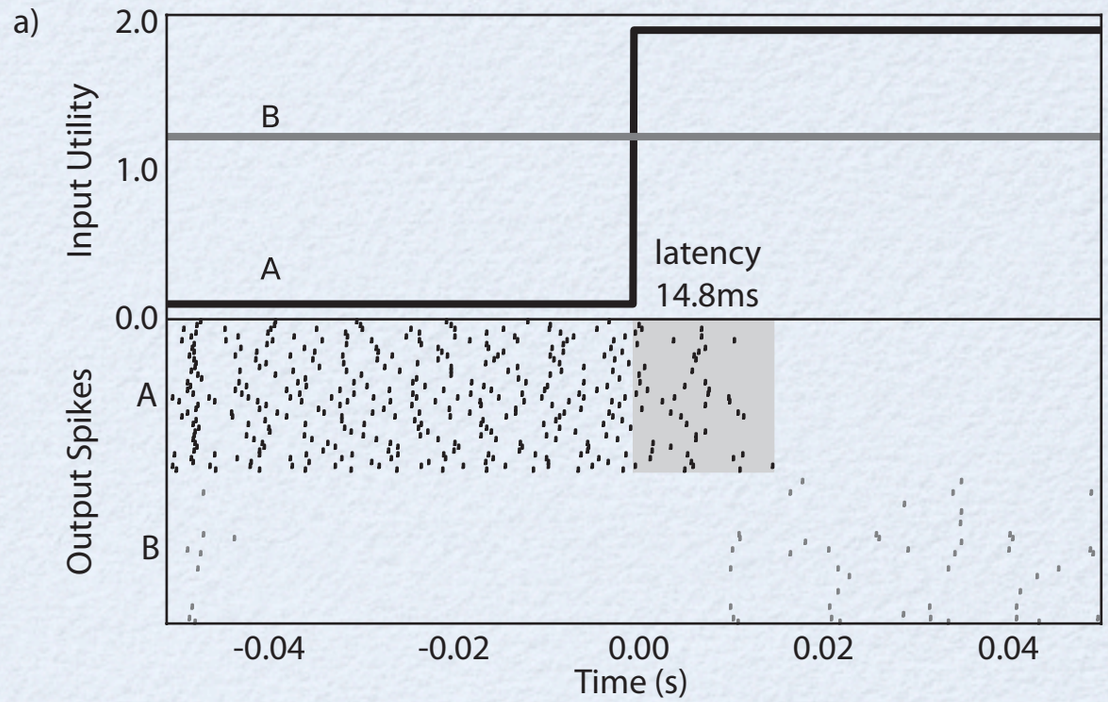
Tower of Hanoi

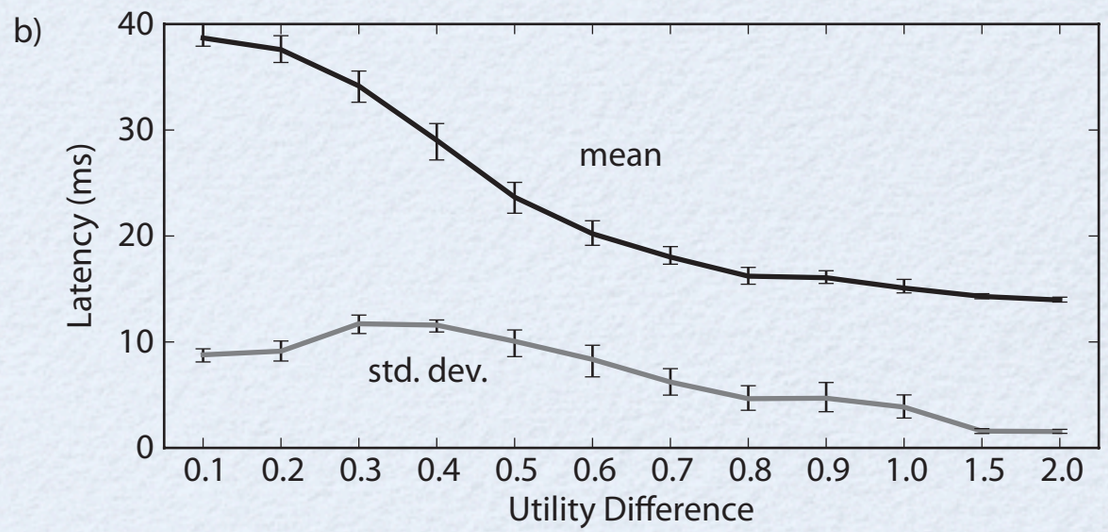
- fMRI Data comparison 3 cortical areas:



SPA: Timing

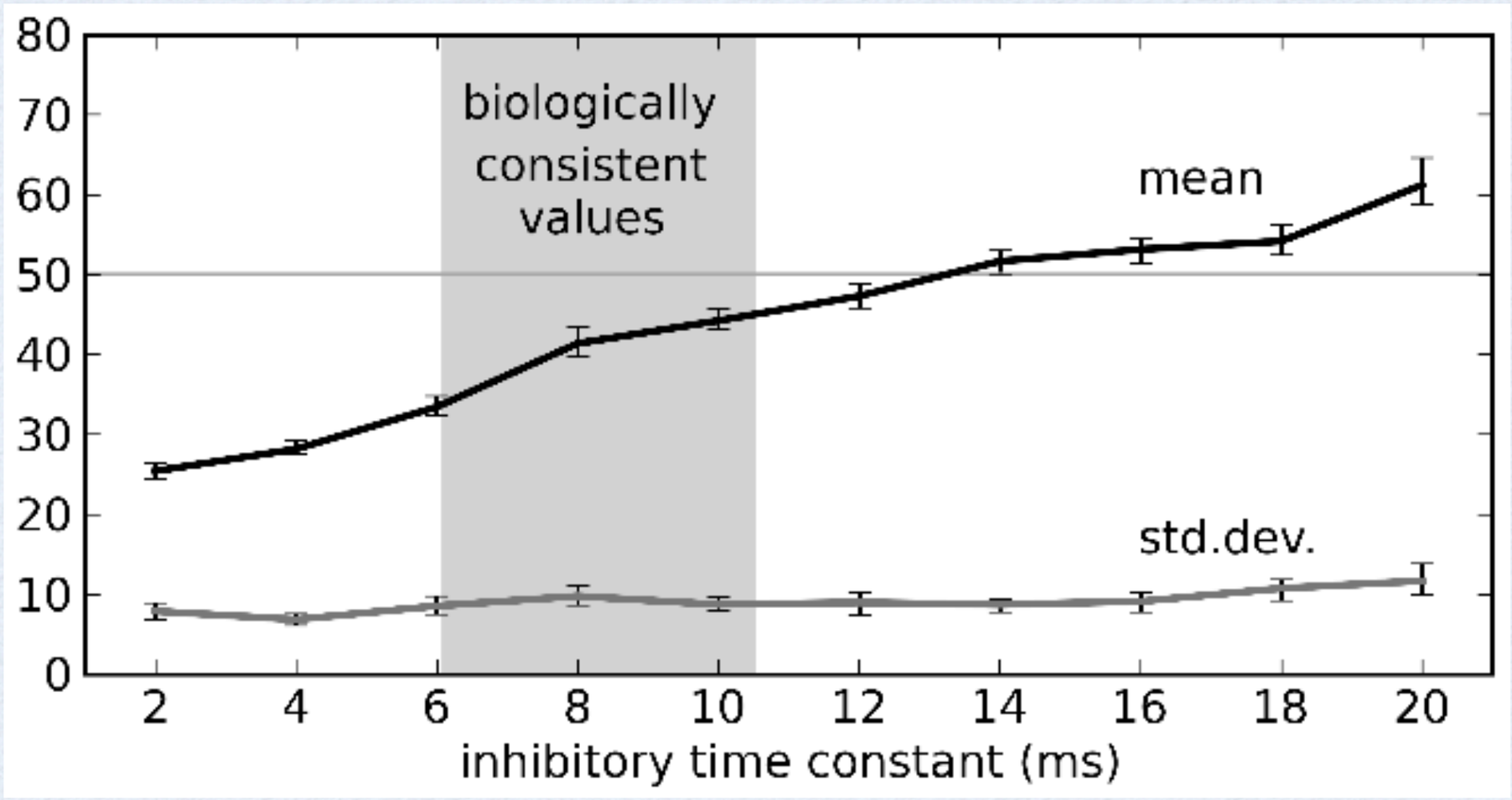
- Ryan and Clark (1991): GPe stops 14-17ms after rapid utility change

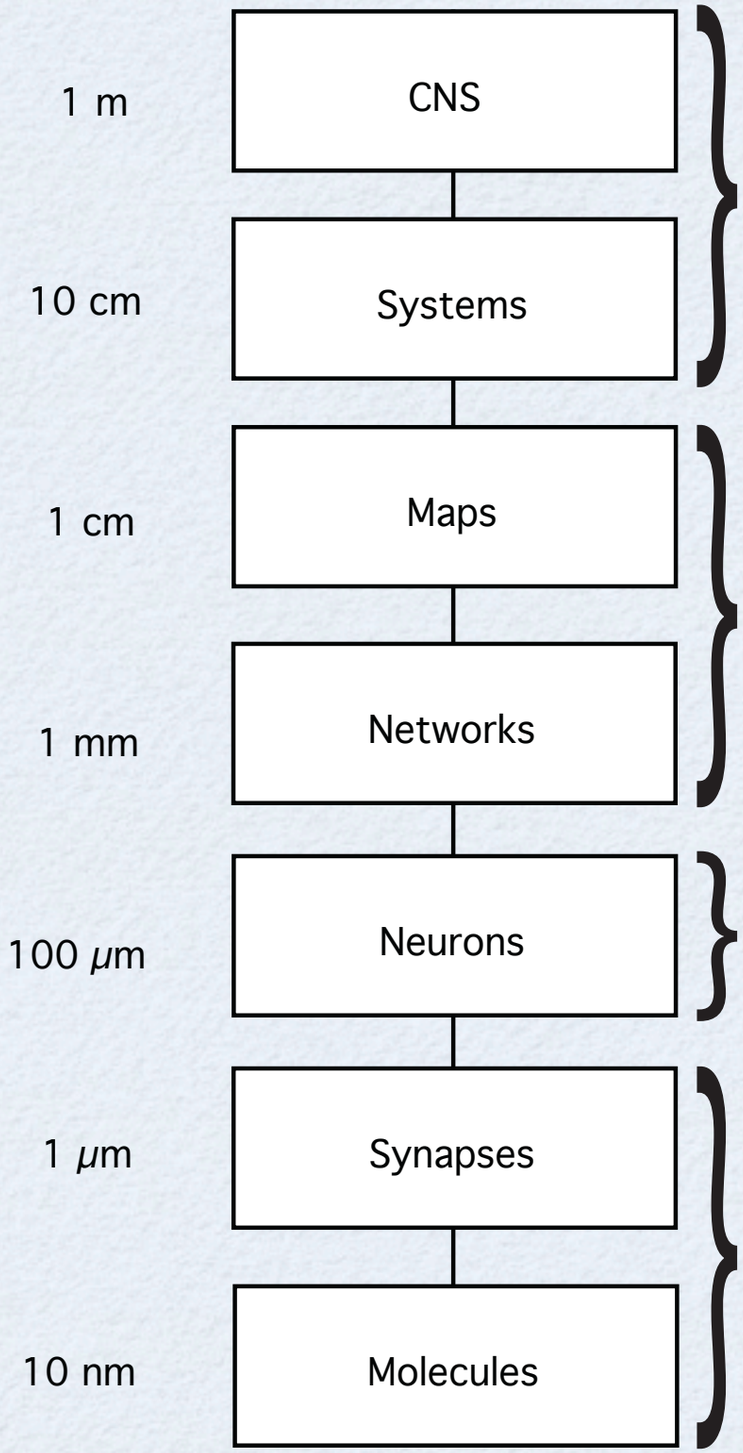




SPA: Timing

- Timing predictions based on GABA neurotransmitter time constant (simple actions)





Frontal, left, cingulate cortex, reasoning systems

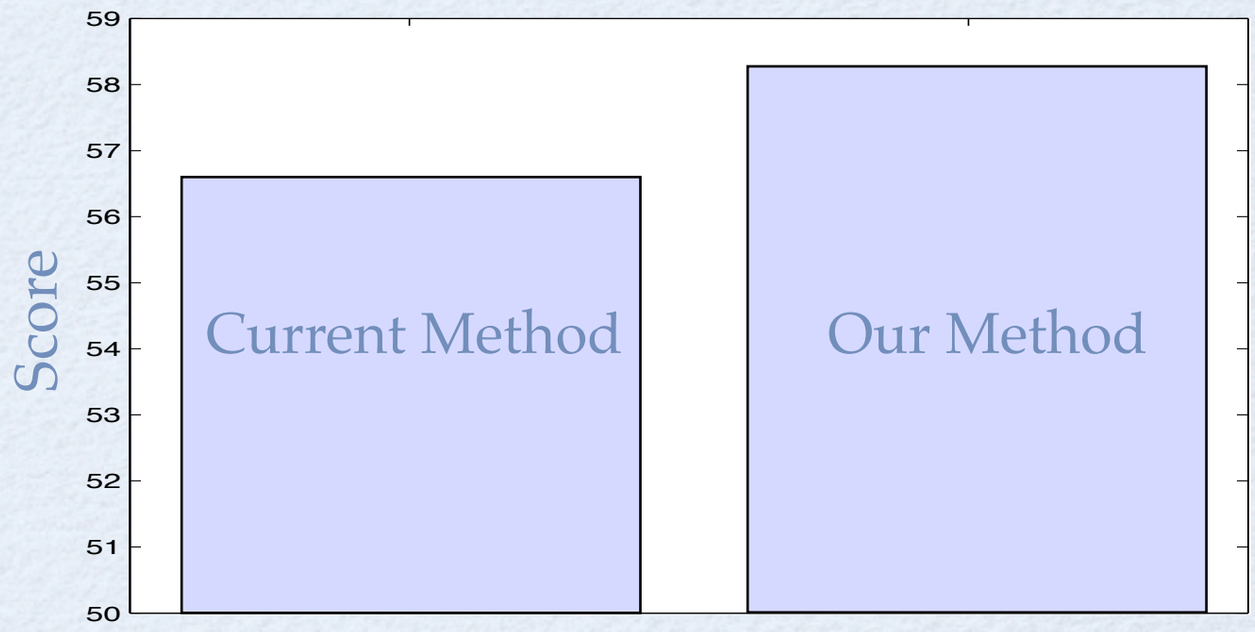
Maps of conceptual space, 20,000 neurons

Spiking neurons

Fast-type receptors, most common in cortex

What's the payoff?

- Explicit (quantitative) hypotheses
- New practical applications
  - Medicine
    - Parkinson's disease, addiction, etc.
  - Machine Intelligence
    - Text classification

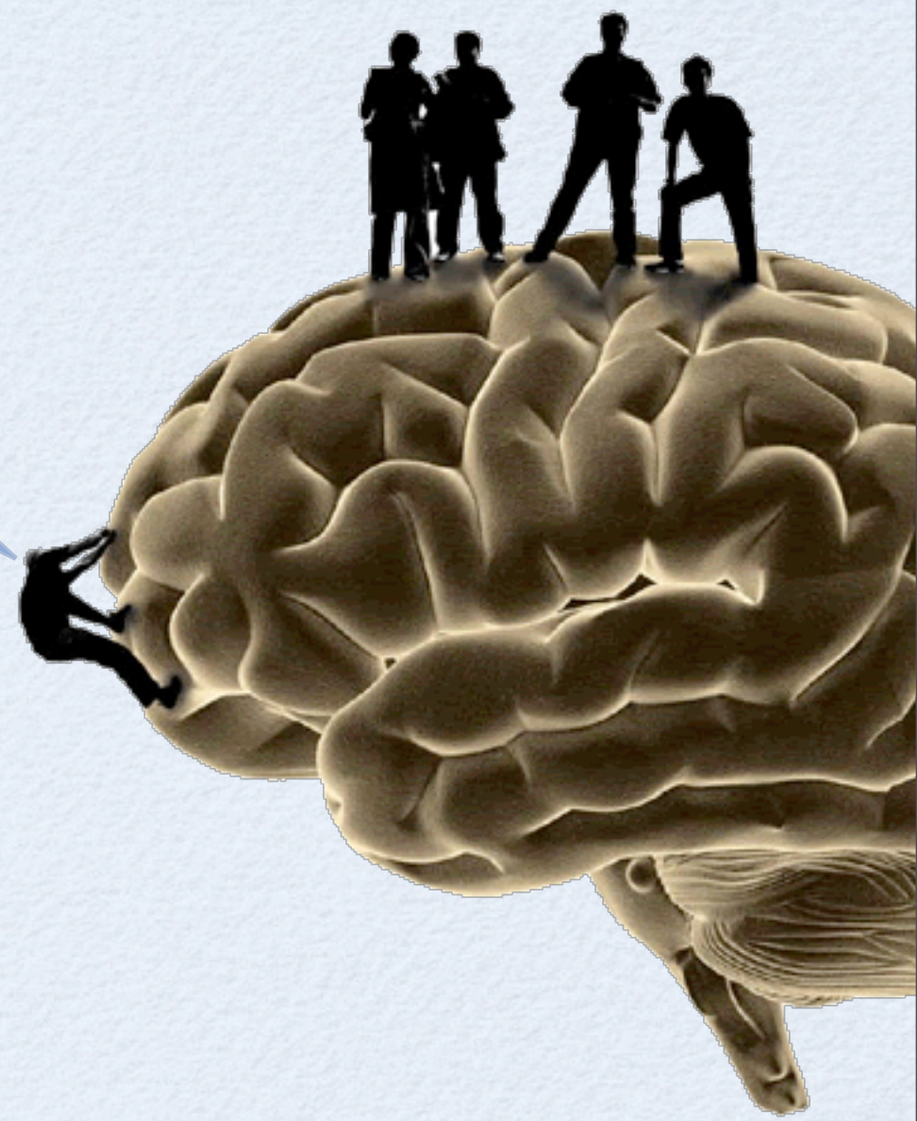


Aren't you in philosophy?

- Architecture of the mind
  - Is the mind like a computer?
- Mental representation
  - Are mental representations symbolic?

So, who are we?

We are this person



At the very beginning of a
long climb...

...but at least we now have
a few footholds

More about brains...

- Centre for Theoretical Neuroscience
- http://ctn.uwaterloo.ca
- Mailing list for CTN seminars: celiasmith@uwaterloo.ca
- Brain day April 4th, 2012
- SYDE 556 - Sim. Neur. Sys.