Computational Neuroscience Introduction Day

- 14.00 Introduction
- 14.30 Computational Neuroscience Groups in Paris
- 15.00 Discussion of papers in groups: Questions
- 15.45 Break
- 16.00 Discussion of papers in groups: Answers
- 16.45 Presentation of Answers
- 17.30 Concluding comments

A brief introduction to Computational Neuroscience

Christian Machens
Group for Neural Theory
Ecole normale supérieure Paris

What's the brain good for?

Tree
no neurons

What's the brain good for?

Tree
no neurons

C. elegans
302 neurons

brains generate motion
(= behavior)

What's the brain good for?

Tree
no neurons

C. elegans
302 neurons

Fly
1 000 000

more complex brains generate a greater variety of behaviors

What’s the brain good for?

Tree
no neurons

C. elegans
302 neurons

Fly
1 000 000

Rat
1 000 000 000

Human
100 000 000 000

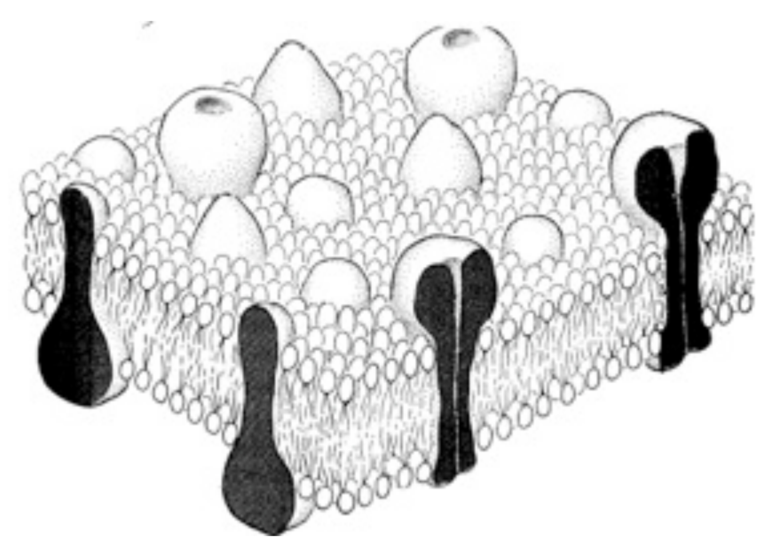
more complex brains generate a greater variety of behaviors

more complex brains can learn more behaviors

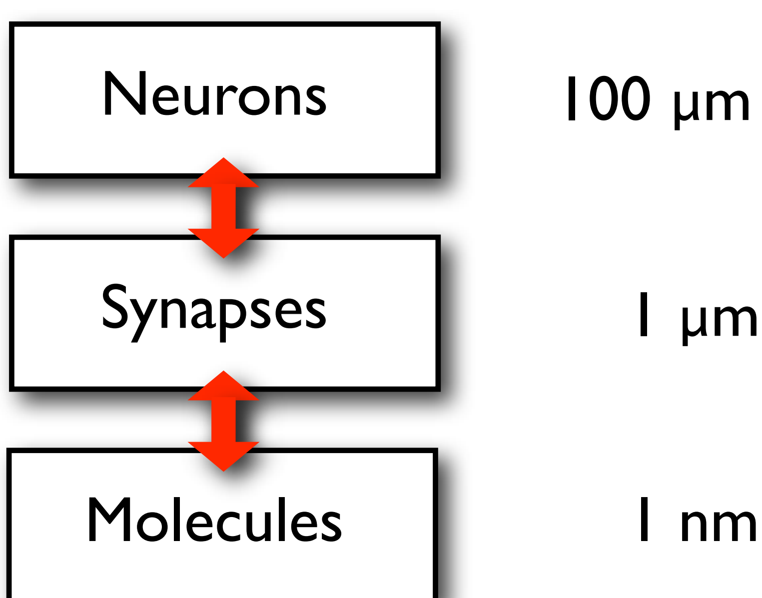
What's the brain made of?

Molecules

1 nm

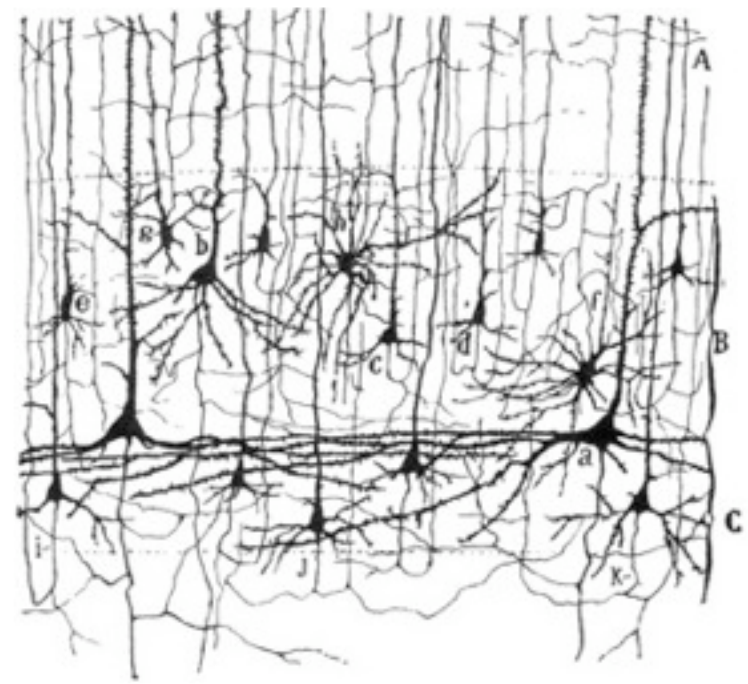


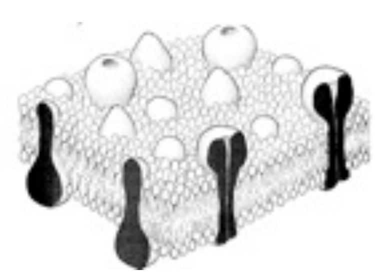
What's the brain made of?



What's the brain made of?

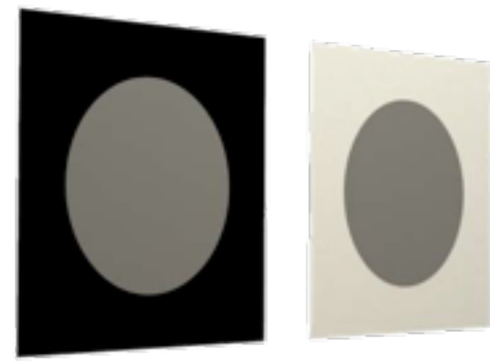
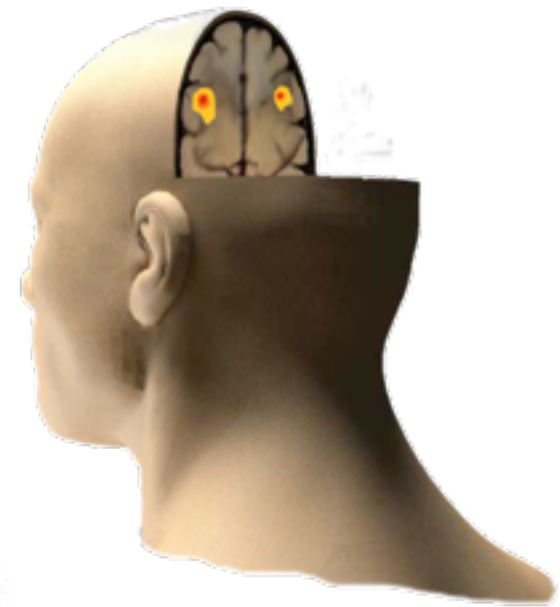
Maps	1 cm
Networks	1 mm
Neurons	100 μm
Synapses	1 μm
Molecules	1 nm





What's the brain made of?

CNS	1 m
Systems	10 cm
Maps	1 cm
Networks	1 mm
Neurons	100 µm
Synapses	1 µm
Molecules	1 nm


How does the brain work?

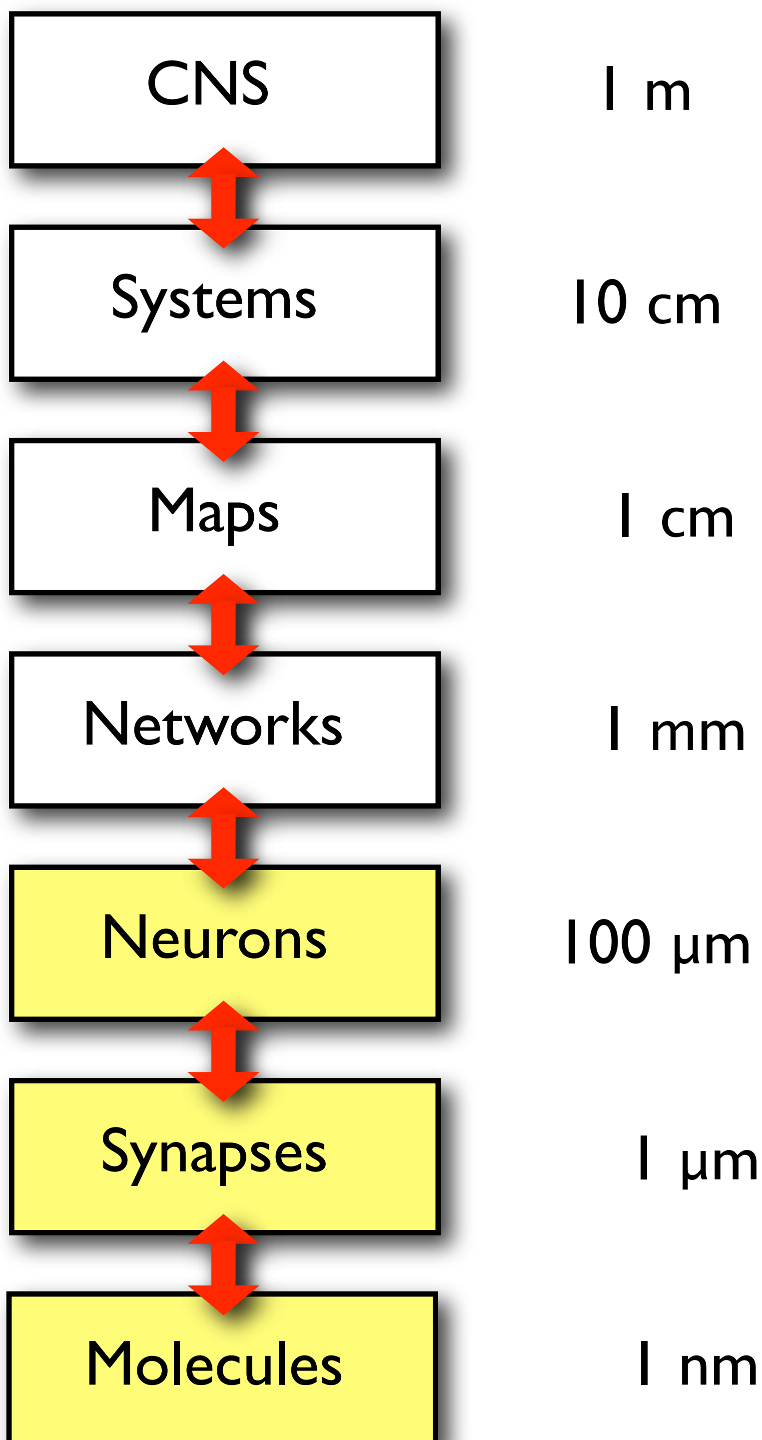
A physics/engineering approach

Just rebuild the whole thing

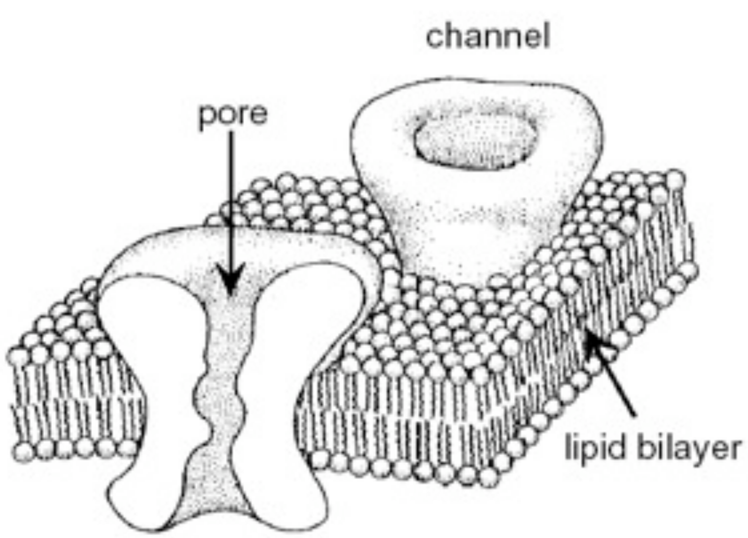
The quest for mechanisms: Constructing systems from parts

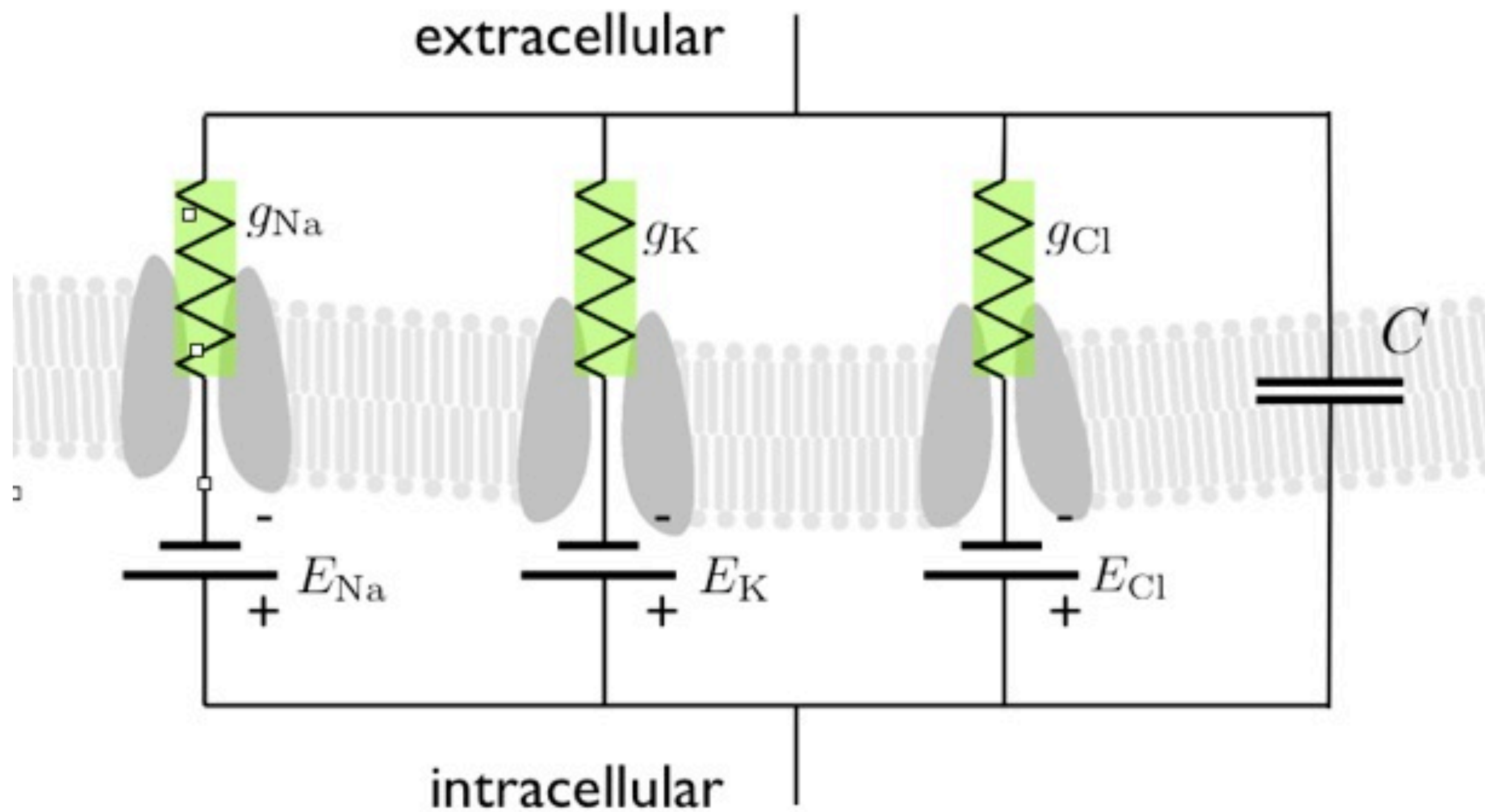
CNS	1 m
Systems	10 cm
Maps	1 cm
Networks	1 mm
Neurons	100 µm
Synapses	1 µm
Molecules	1 nm

The quest for mechanisms: Constructing systems from parts



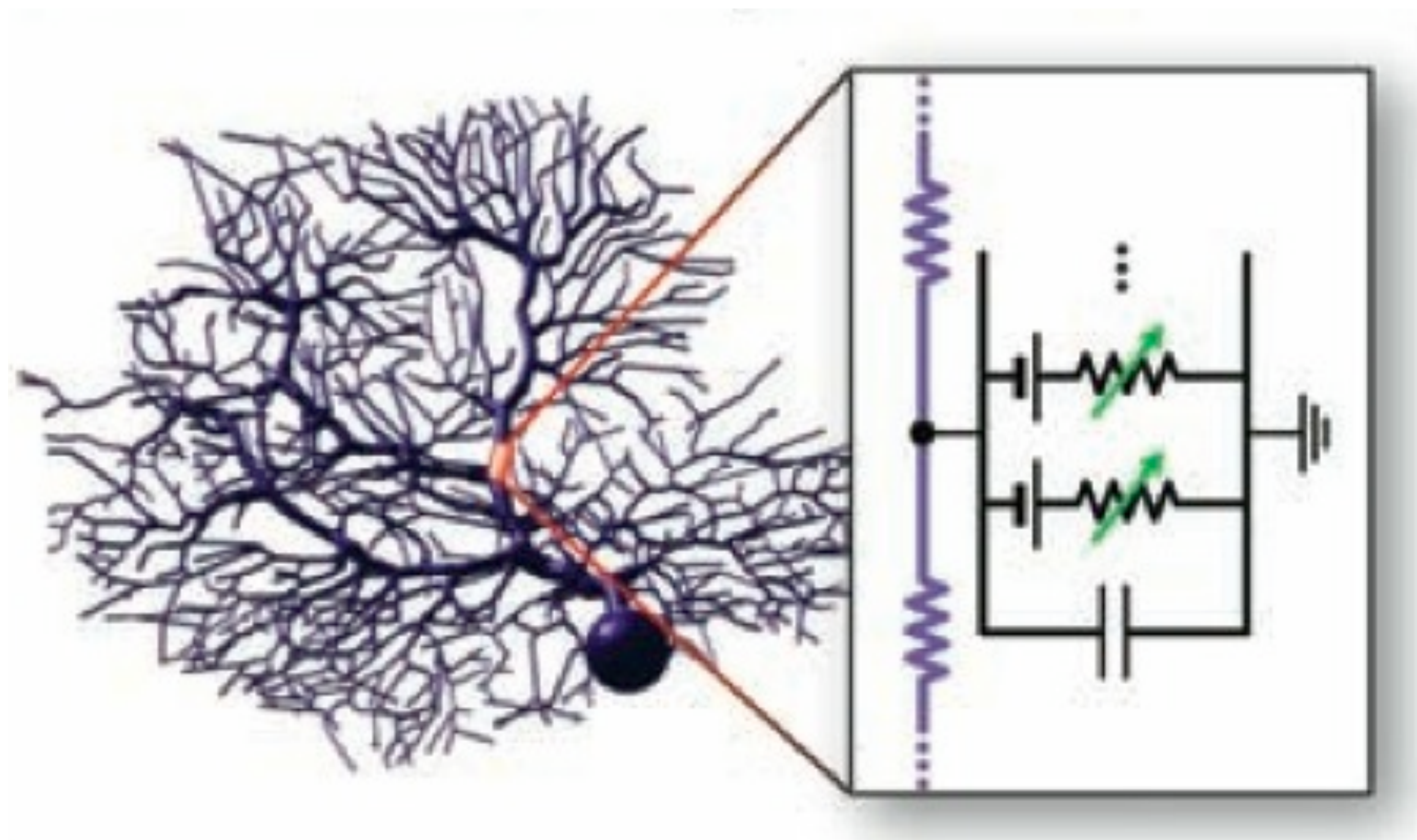
Biophysics of the membrane voltage:
The Hodgkin-Huxley Model





Reconstructing neurons:

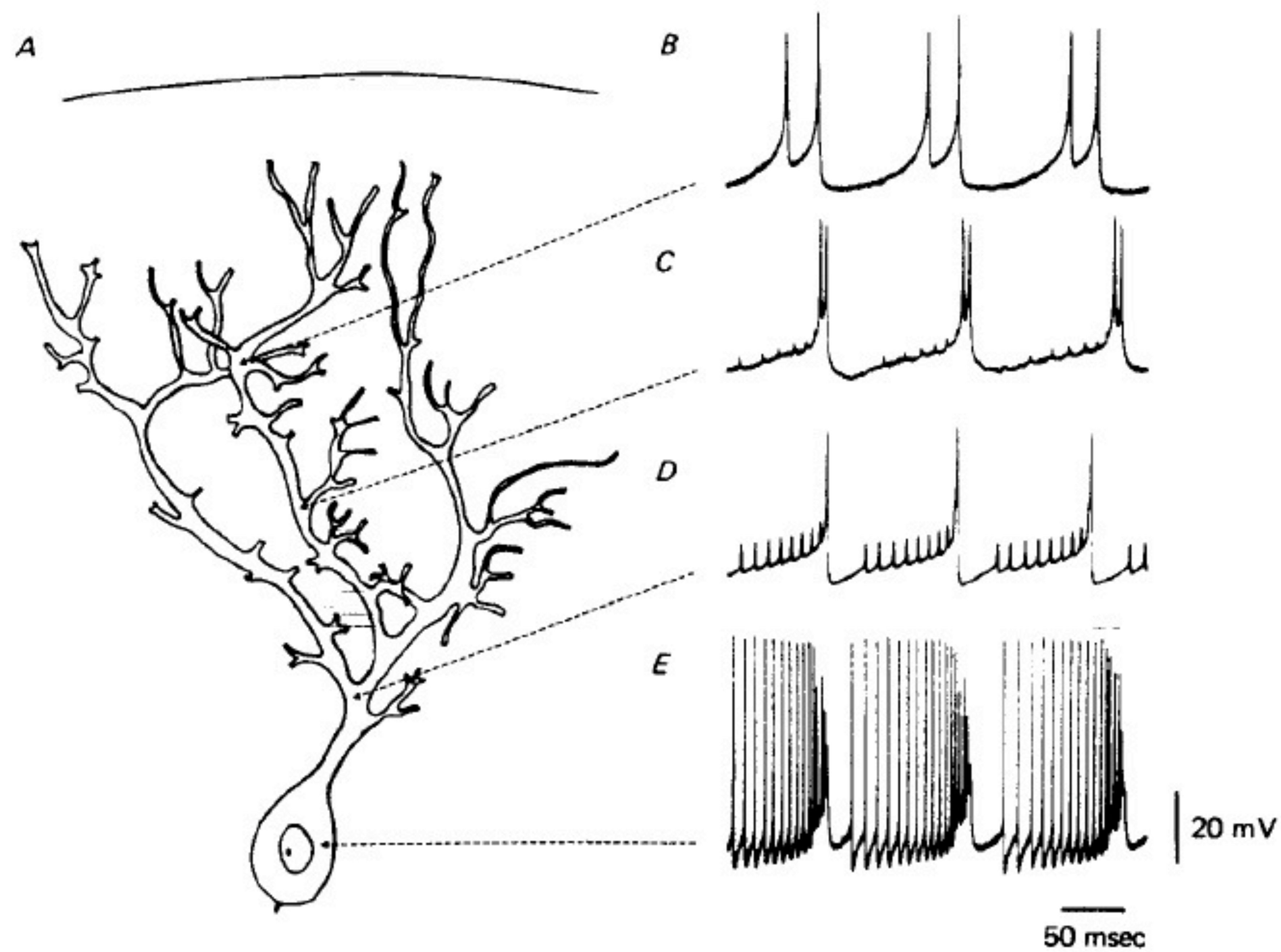
Ralls' cable theory and compartmental modeling



Detailed compartmental models of single neurons:
Large-scale differential equation models

Reconstructing neurons

Simulating the membrane potential



Llinas & Sugimori (1980)

The quest for mechanisms: Constructing systems from parts

CNS	1 m
Systems	10 cm
Maps	1 cm
Networks	1 mm
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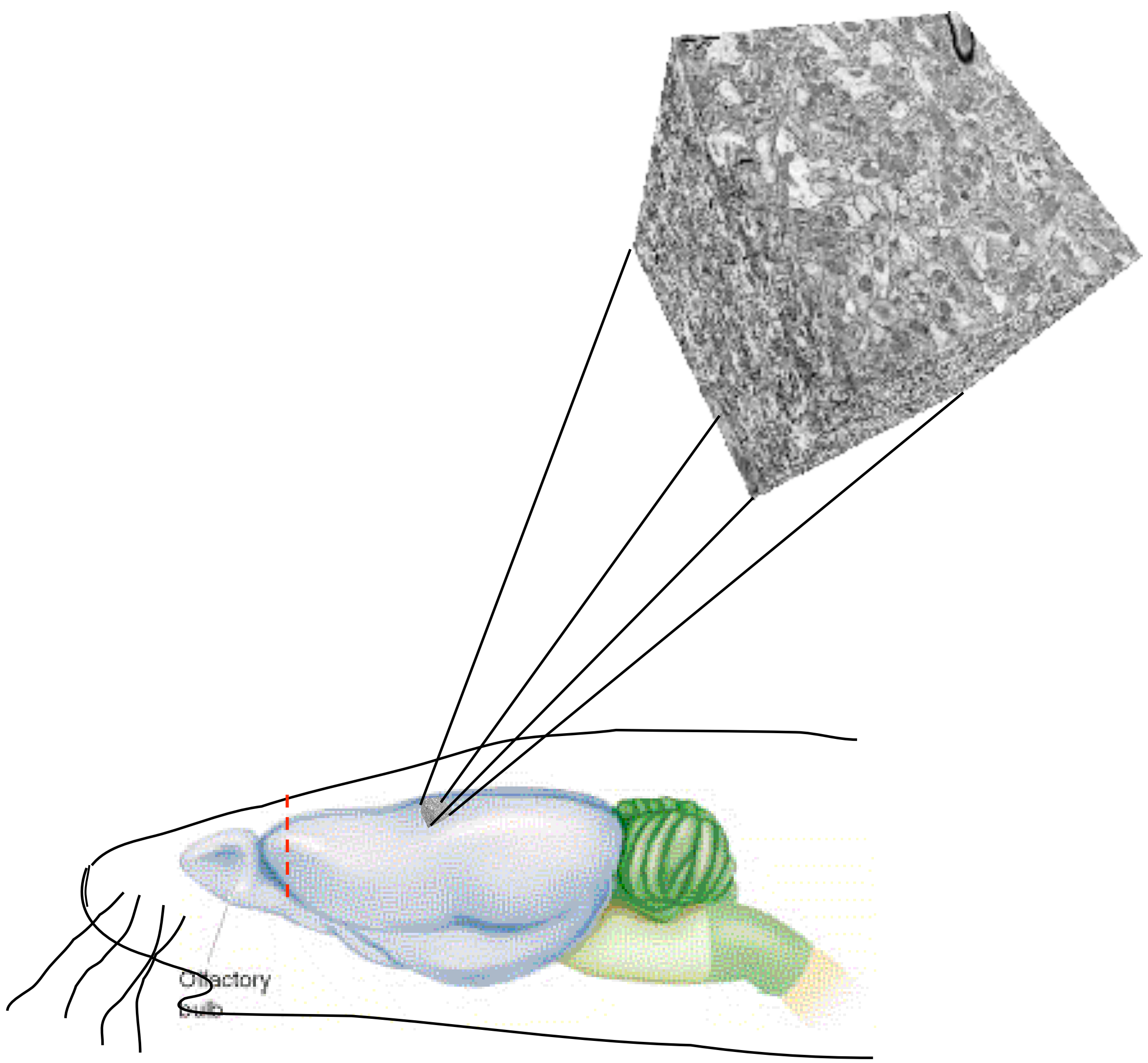
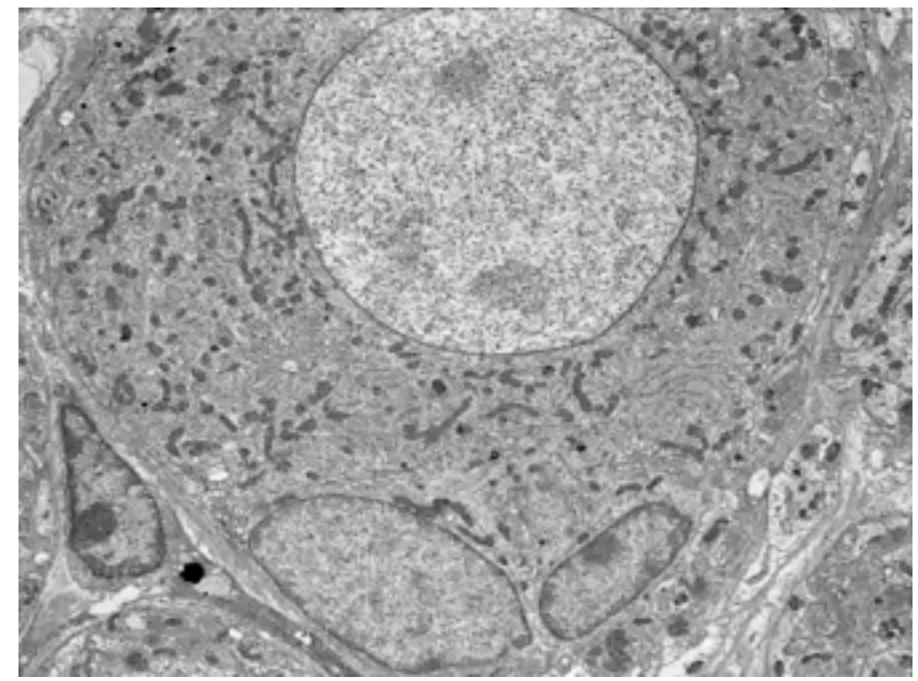
Synapses	1 µm
Molecules	1 nm

Reconstructing circuits

Serial Blockface Scanning Electron Microscopy





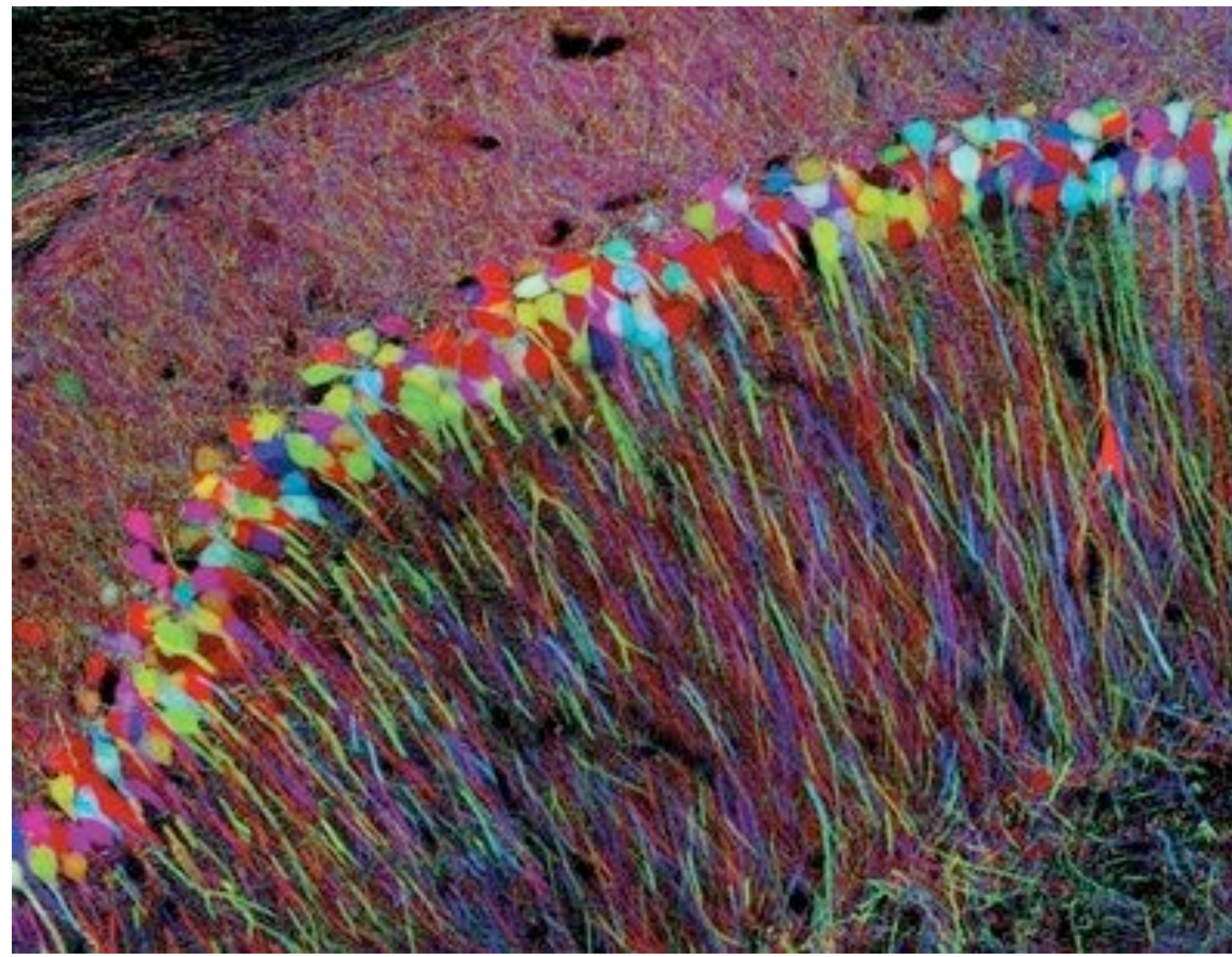
courtesy of W.Denk

Reconstructing circuits

The connectome

Scan brain slices and reconstruct the circuit...

but: the devil is in the details and when it comes to connectivity, details matter!

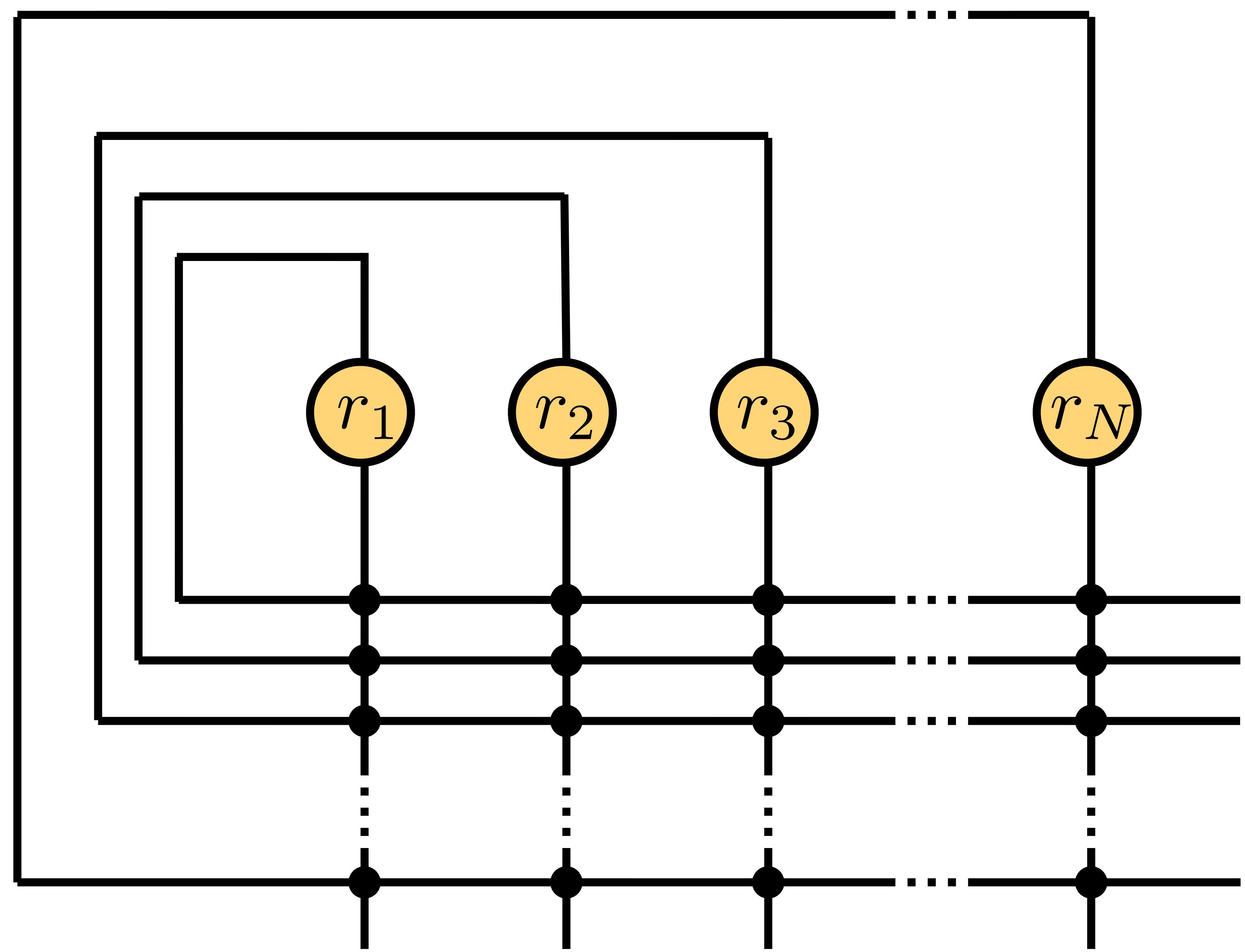


http://connectomes.org/

Theory of neural networks

Neurons, synapses ➡ network activity

$$\dot{r}_i = -r_i + f(\sum_{j=1}^{N} w_{ij} r_j + I_i)$$

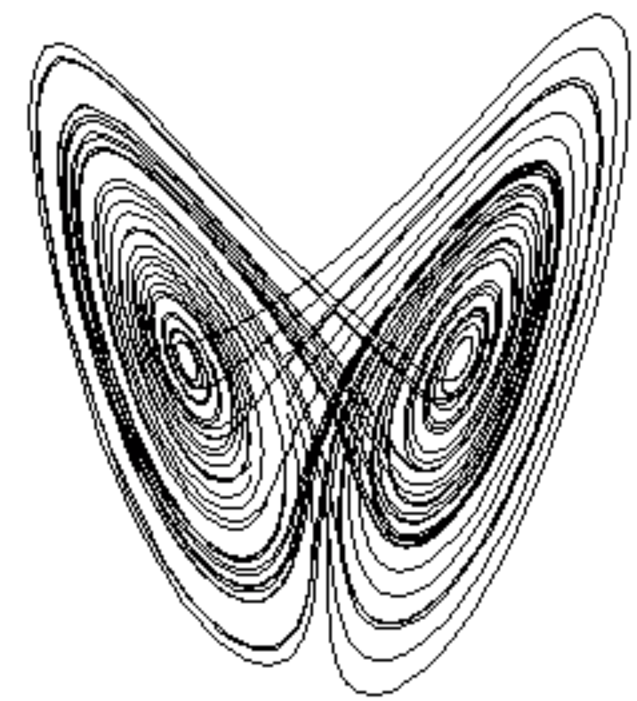


Network dynamics largely determined by connectivity

$$\dot{r}_i = -r_i + f(\sum_{j=1}^{N} w_{ij} r_j + I_i)$$

Possible dynamics:

- stable/ unstable fixed points
- limit cycles
- chaotic attractors



Note: different attractors can co-exist in different parts of the state space!

For $N \rightarrow \infty$

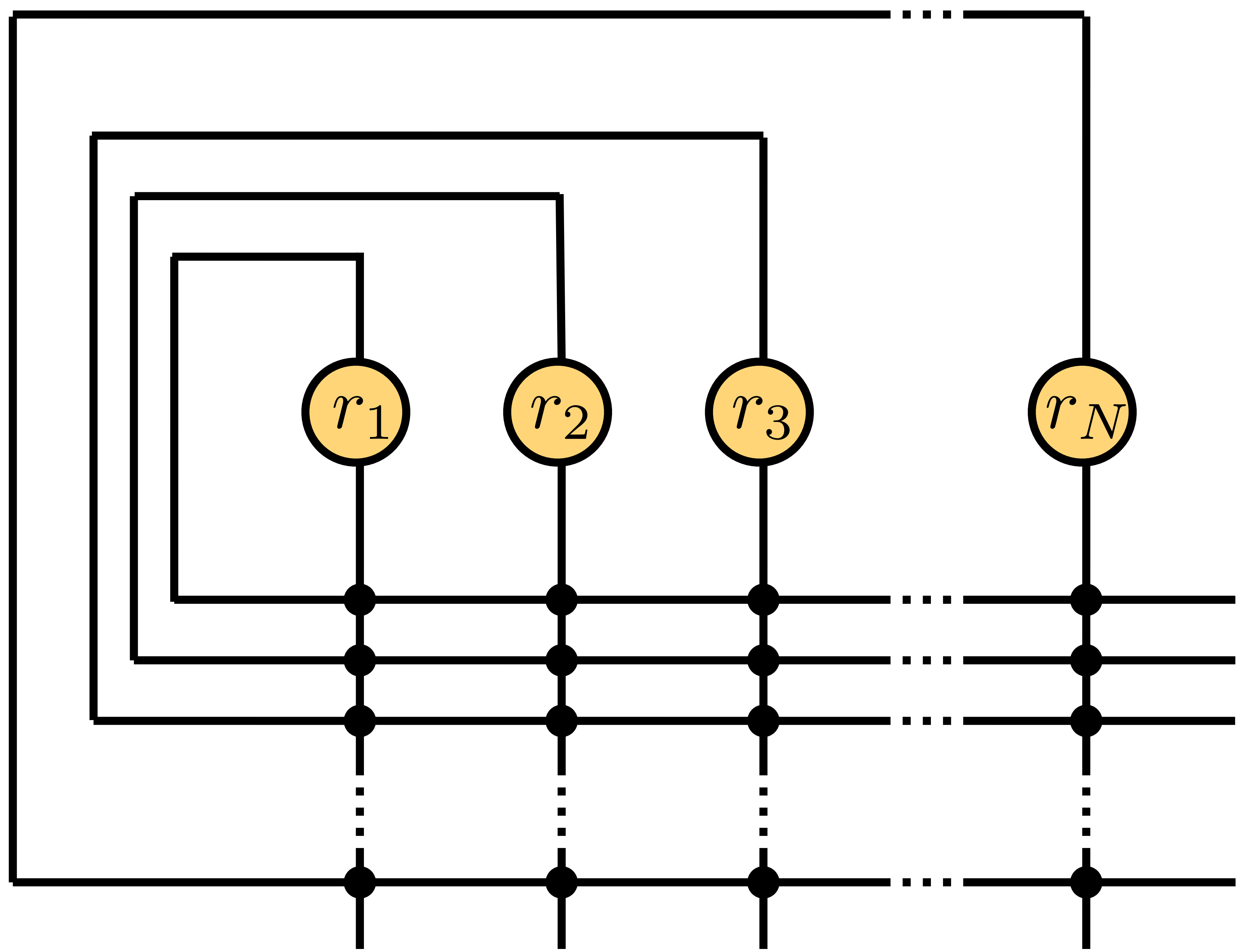
- neural networks can compute anything

(Statistical) theory of neural networks

Neurons, synapses → network activity

Under what conditions do you get

- only fixed points
- synchronous activity
- asynchronous activity
- Poisson spike trains
- oscillations
- spatial patterns
- ...



The quest for mechanisms: Constructing systems from parts

CNS	1 m
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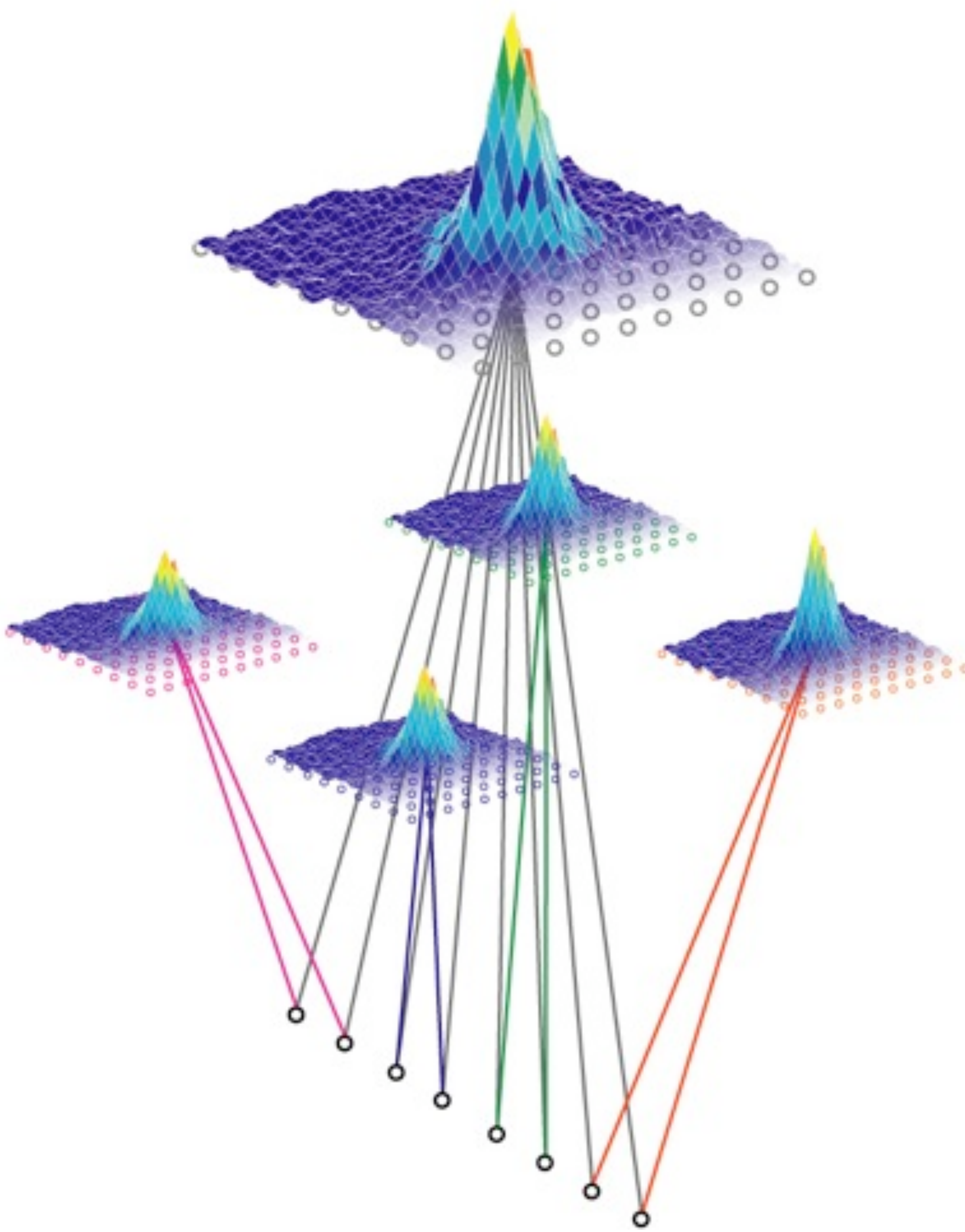
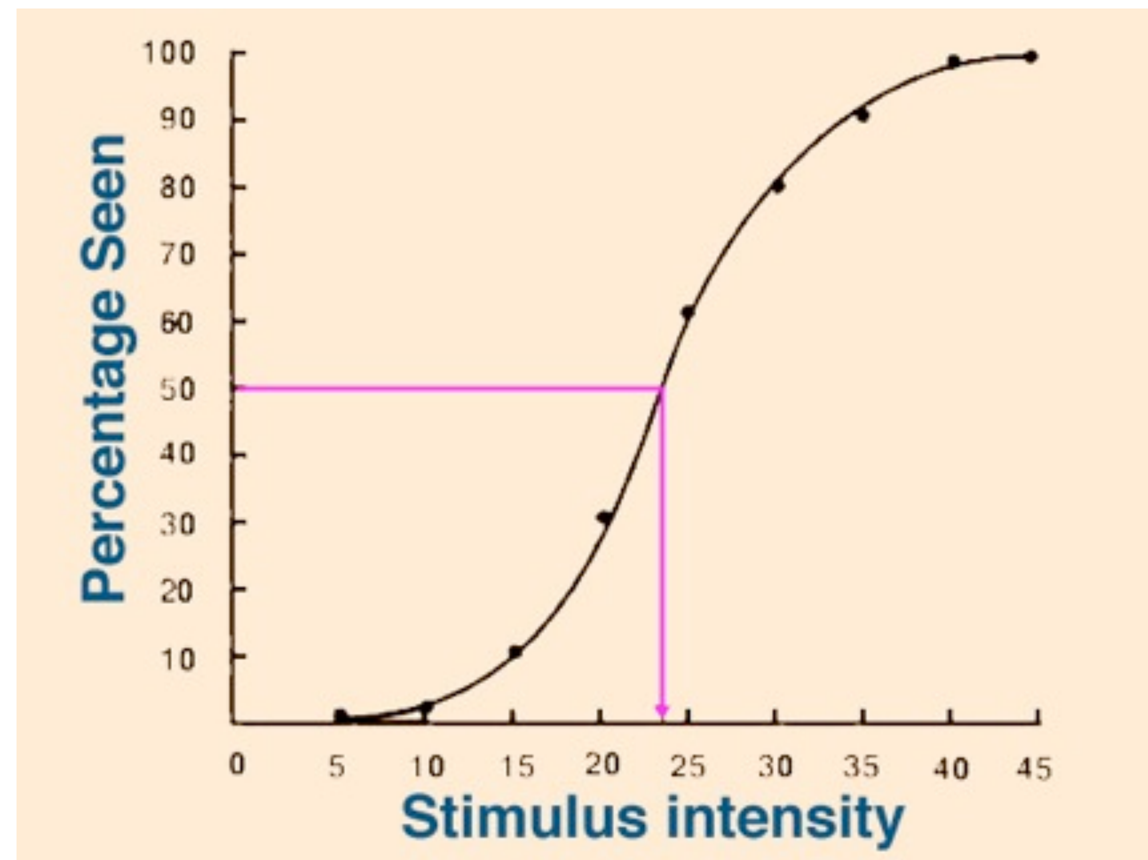
Connectionist models: From networks to behavior



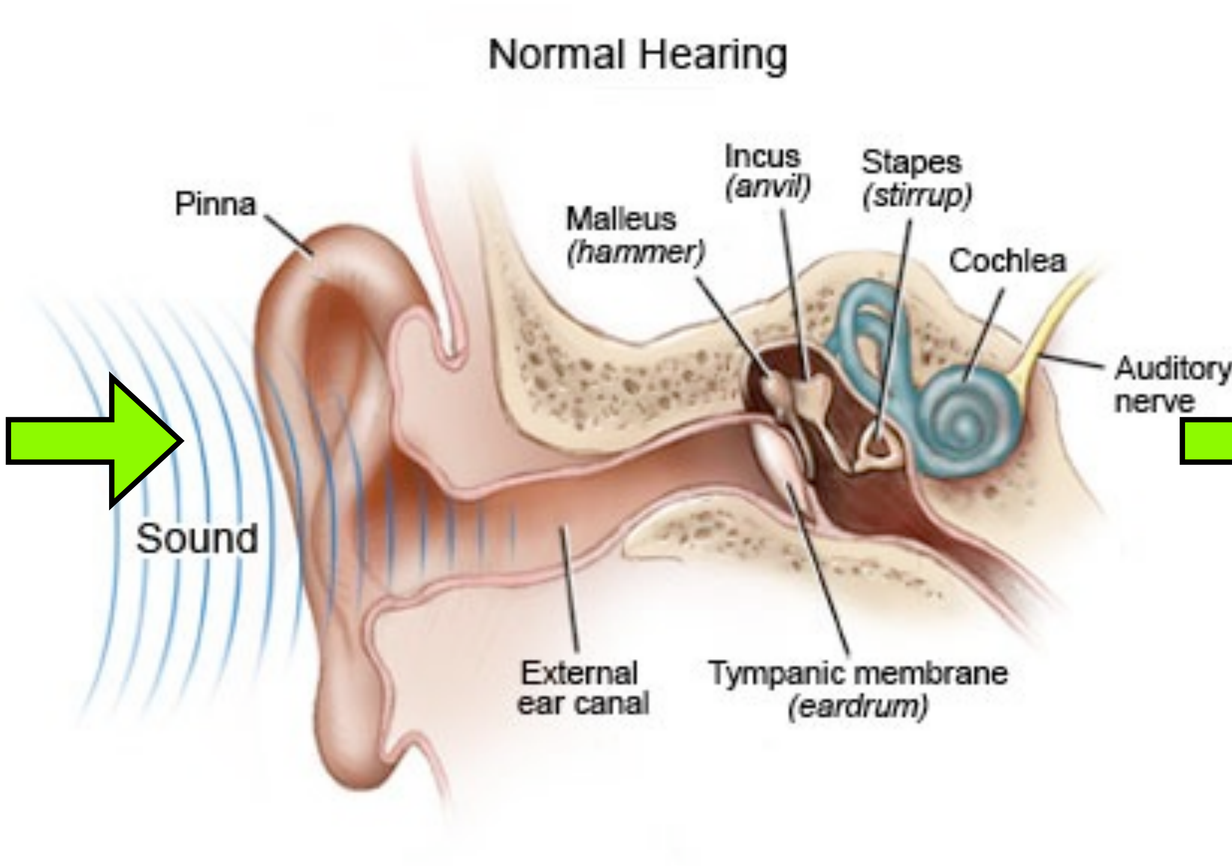


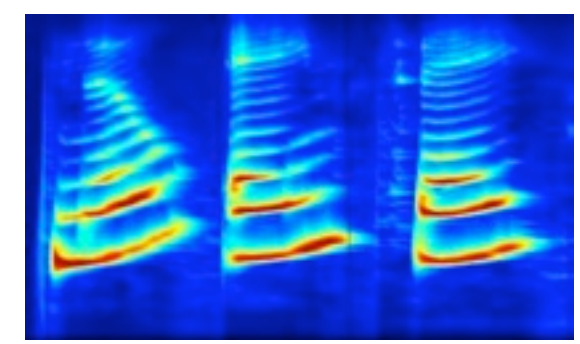
A computer science approach

Study the computational problems

Computation: manipulating information

sound pressure wave





cochleogram
(time-frequency
representation of sound)

Representation of information, more or less lossy

Example music:

sheet notes

Sound

CD

Language

The other day, I heard this cool jazz CD with this drummer...

Why represent information differently?

Example numbers:

`XXIII`	Roman System
`23`	Decimal System
`00010111`	Binary System

Representations allow for easier algorithms

Example numbers:

`XXIII`	in ...?
`23`	in multiples of 10
`00010111`	in multiples of 2

Can you add these numbers?

```
   29         00011101        XXIX
+ 33       + 00100001    + XXXIII
----       ----------    --------
```

Representations allow for easier algorithms

Example numbers:

```
XXIII
23
00010111
```

in ...?
in multiples of 10
in multiples of 2

Can you add these numbers?

```
   29        00011101        XXIX
 + 33      + 00100001    + XXXIII
 ----      ----------    --------
   62
```

Representations allow for easier algorithms

Example numbers:

`XXIII`	in ...?
`23`	in multiples of 10
`00010111`	in multiples of 2

Can you add these numbers?

```
   29        00011101         XXIX
 + 33      + 00100001     + XXXIII
 ----      ----------     --------
   62        00111110
```

Representations can ease certain computations

Example numbers:

XXIII	in ...?
23	in multiples of 10
00010111	in multiples of 2

Can you add these numbers?

```
   29
+  33
-----
   62
```

easy

```
  00011101
+ 00100001
----------
  00111110
```

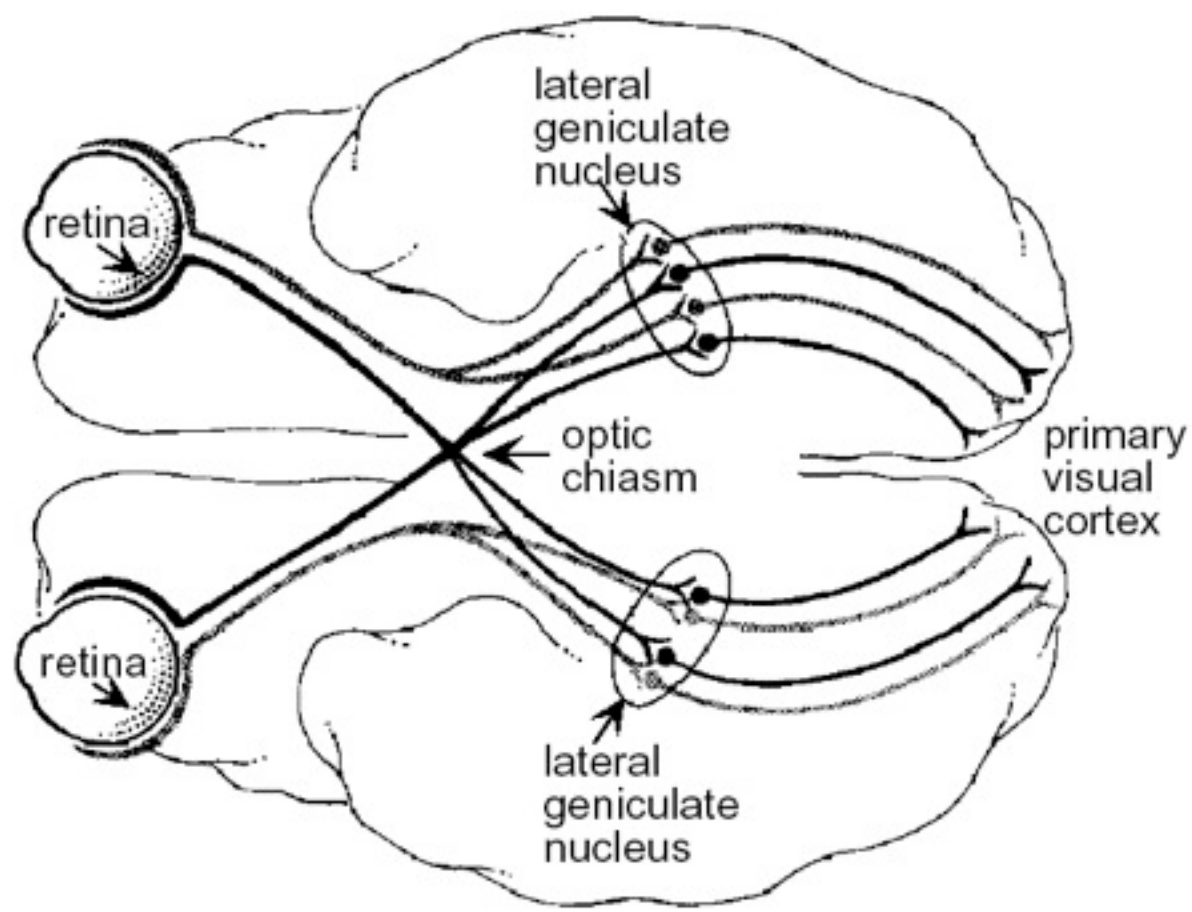
easy

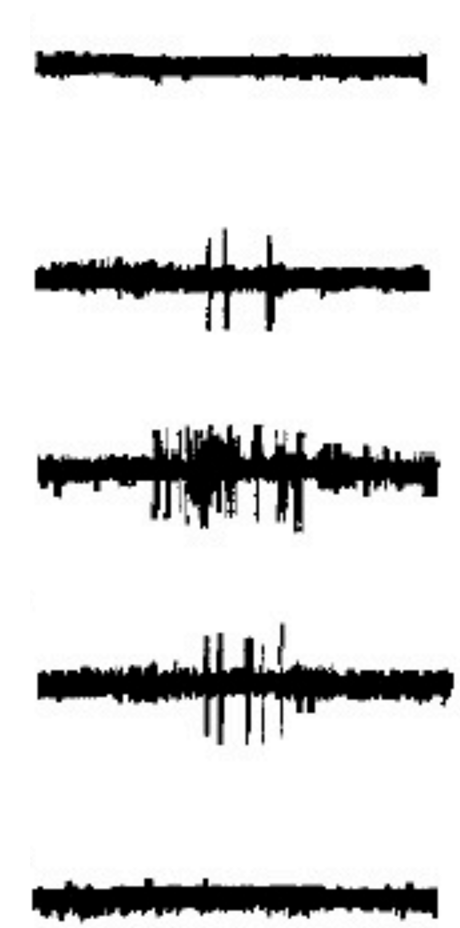
```
    XXIX
+ XXXIII
--------
```

difficult

Most famous example: “edge detectors” in visual system

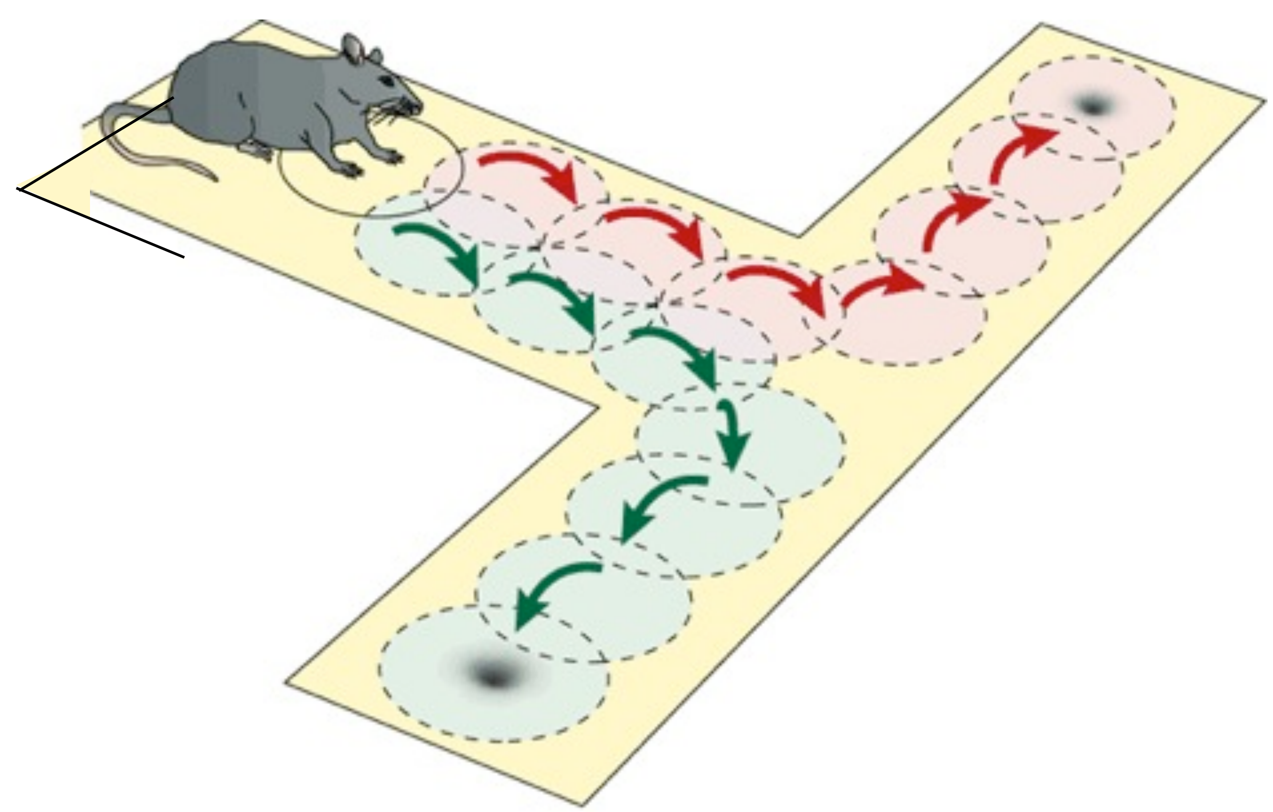
Stimulus:
black bar





Activity of
a neuron in V1

Another famous example: Place cells in the hippocampus



Studying representations in the brain

Experimental work

- perceptual representations:
  vision, audition, olfaction, etc.
- representation of motor variables
- "higher-order" representations:
  decisions
  short-term memory
  rewards
  dreams
  uncertainty
  ... you name it ...

Theoretical work

- Quantifying information content
  quest for the neural code,
  information theory, discriminability, ...
- Understanding the computational
  problems: object recognition, sound
  recognition, reward maximization

What we understand now

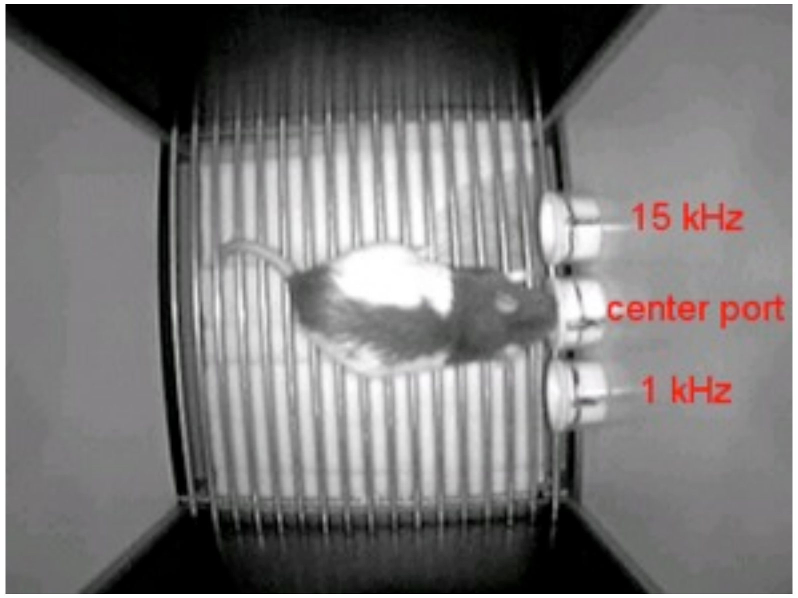
very little

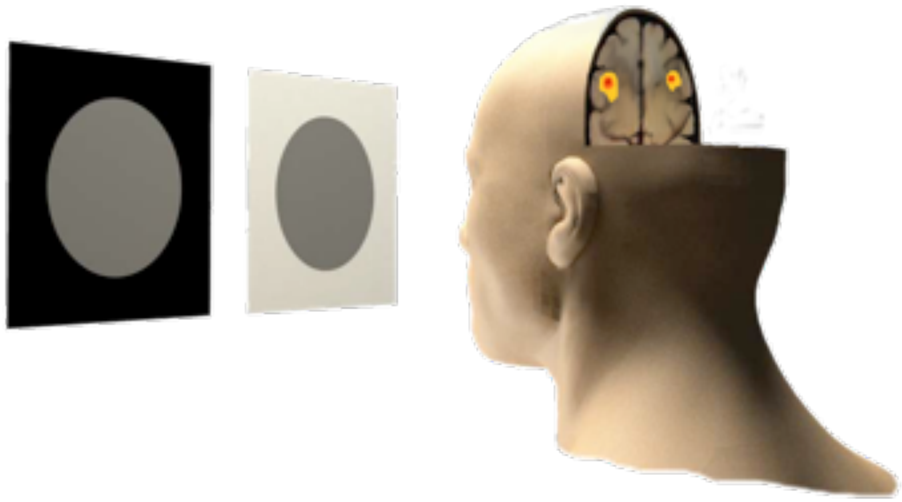
What we understand now

very little

What we need

- biologists
- psychologists

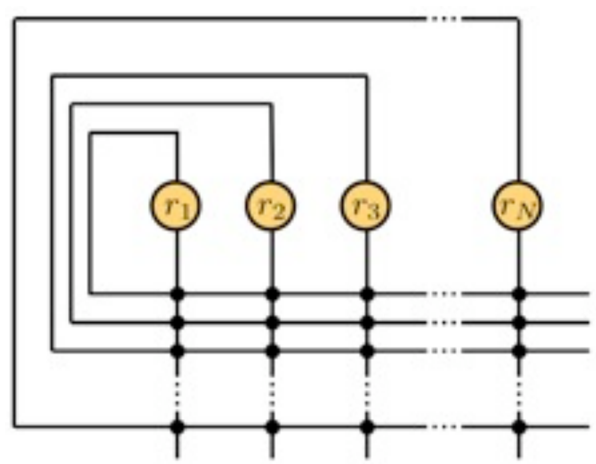




- to probe the brains of animals and humans
- to design and carry out clever experiments
- to investigate and quantify human and animal behavior

What we need

- physicists, computer scientists, engineers, etc.



$$\dot{r}_1 = -r_1 + f\Big(\sum_{j=1}^{N} w_{1j} r_j + E_1\Big)$$

$$\dot{r}_2 = -r_2 + f\Big(\sum_{j=1}^{N} w_{2j} r_j + E_2\Big)$$

- to formulate mathematical theories of information processing
- to create biophysical models of neural networks

Teaching in the Cogmaster

Computational Neuroscience

Core Classes

S1

CA6(a) Theoretical Neuroscience

JP Nadal, N Brunel, R Brette, G Mongillo
Thursday, 14-17, ???,

START:

CA6(b) Seminar in Quantitative Neuroscience

R Brette, R da Silveira, S Deneve, B Gutkin, V Hakim, C Machens
Tuesday, 17-18.30, Salle Seminaire DEC (29, rue d'Ulm, RdC)

START: 5 Oct

S2

CO6 Introduction to Comput. Neuroscience

V Benichoux, R Brette, C Machens
Tuesday, 17-19

AT2 Atelier Comput. Neuroscience

C Machens
Monday, 10-12

Many more classes available!!

see cogmaster website!!
contact us!!

Computational Neuroscience Research in the Cogmaster and Beyond

ENS: Group for Neural Theory
(Sophie Deneve, Boris Gutkin, Christian Machens, ...)
ENS: Equipe Audition
(Romain Brette, Victor Benichoux, ...)
ENS: Laboratoire de Physique Statistique
(Jean-Pierre Nadal, Vincent Hakim, ...)
Paris V: Laboratoire de Neurophysique et Physiologie
(Nicolas Brunel, David Hansel, ...)

you can find more labs under:

http://cogmaster.net
http://neurocomp.risc.cnrs.fr

for internship / stages / Master's thesis: contact the faculty! (email etc.)

The articles you have read:

Neural coding

WT Newsome, KH Britten, JA Movshon
Neuronal correlates of a perceptual decision

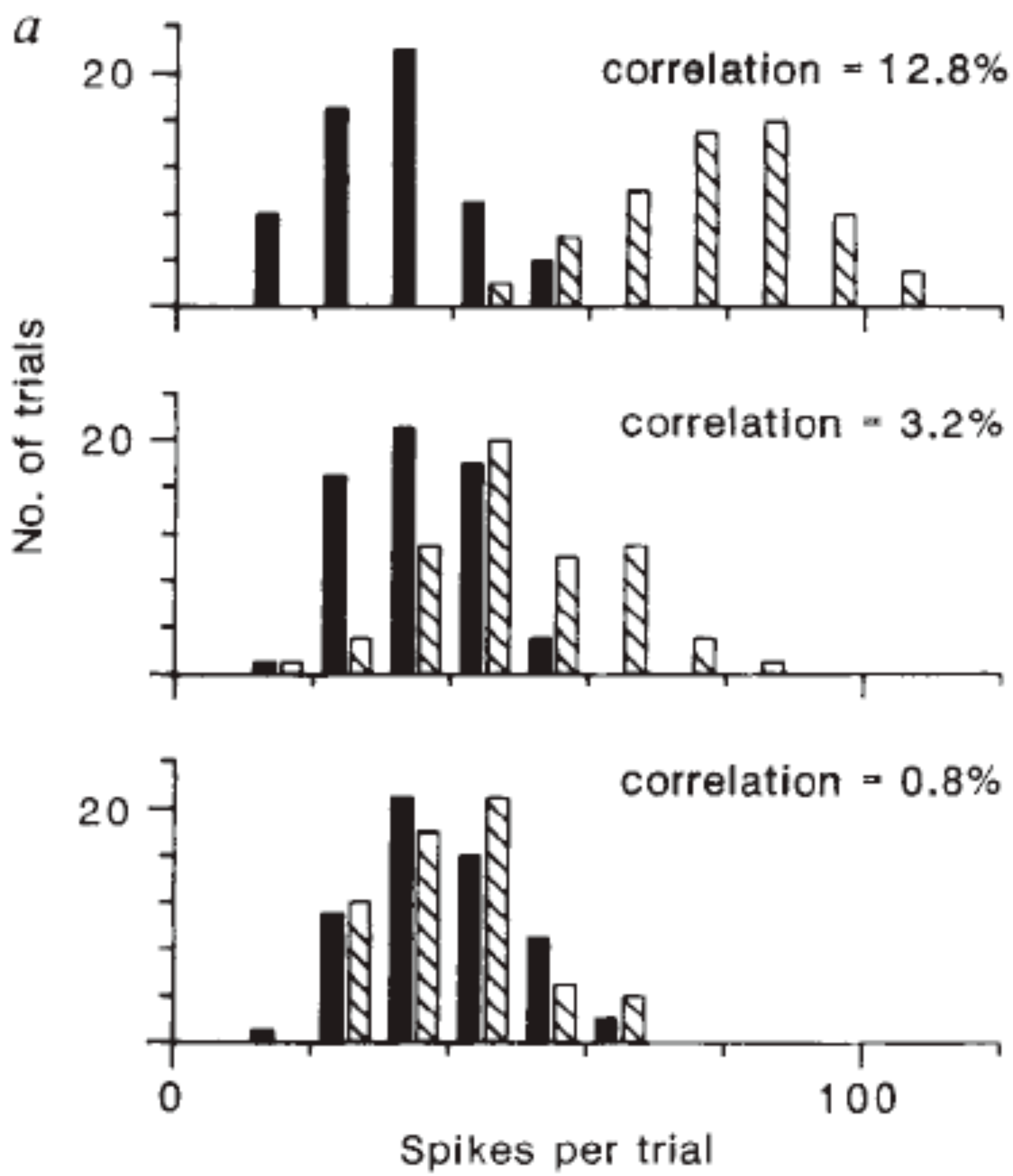
Reinforcement Learning

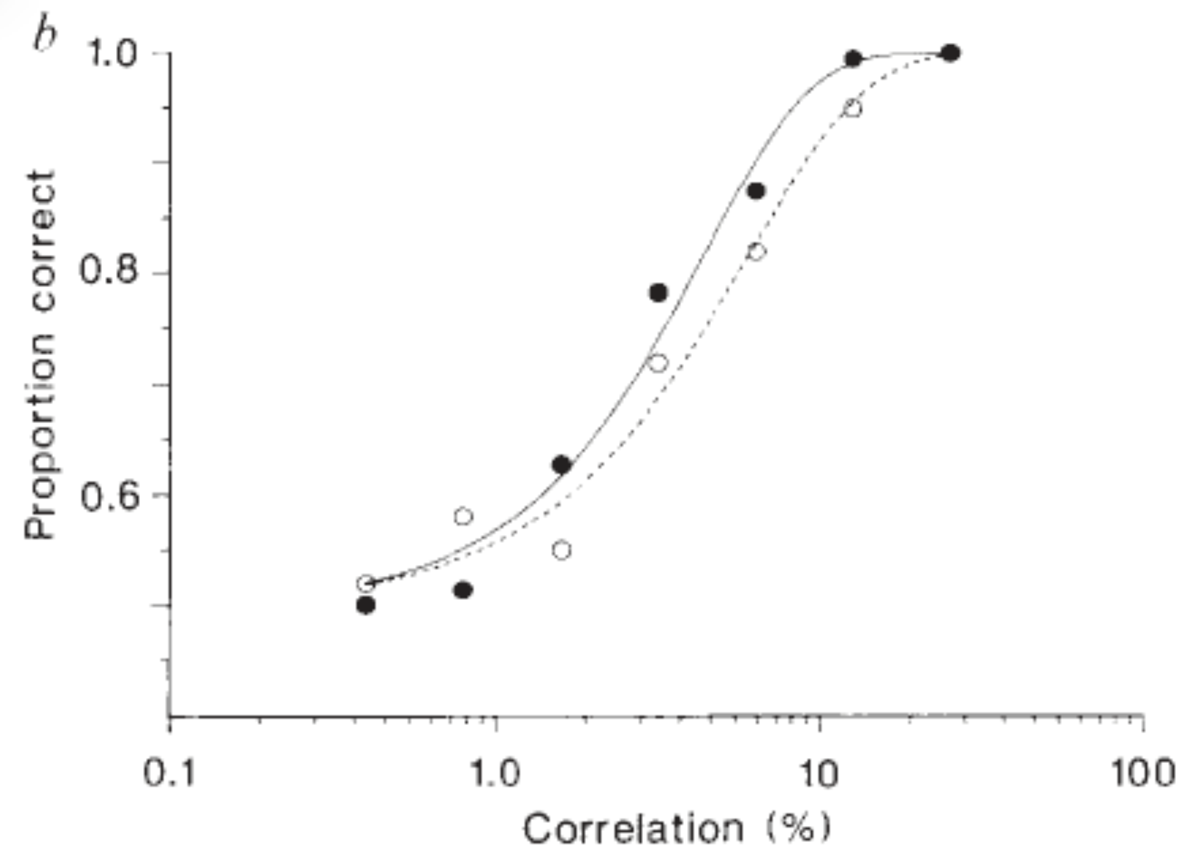
W Schultz, P Dayan, PR Montague
A neural substrate of prediction and reward

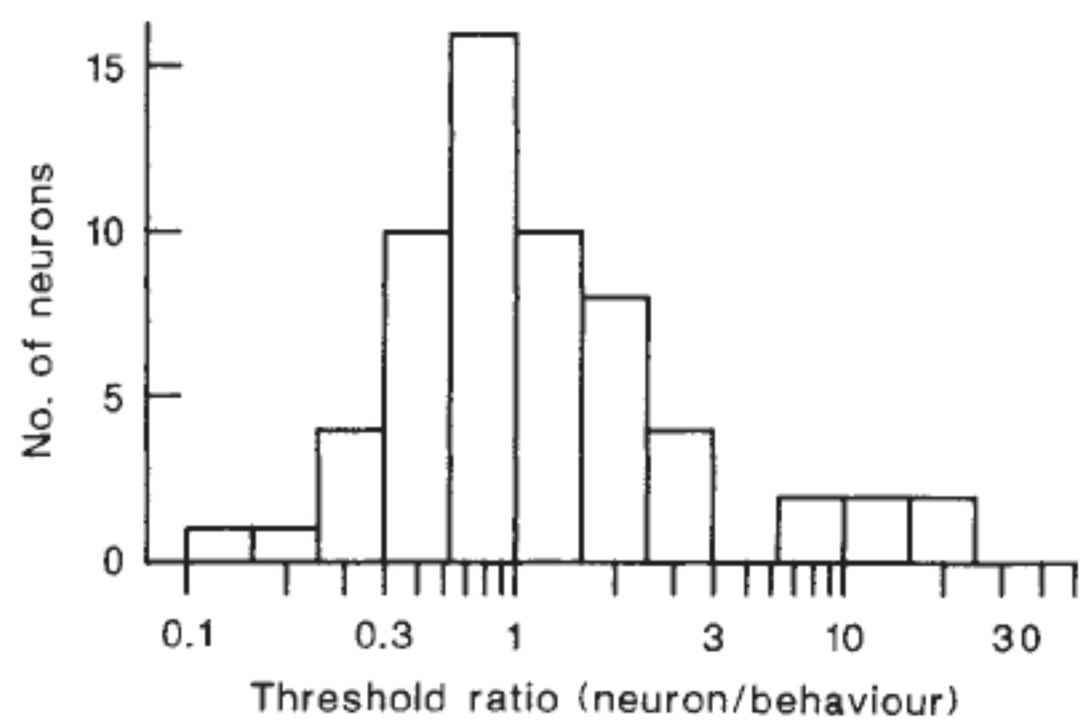
Neuronal correlates of a perceptual decision

**William T. Newsome*†, Kenneth H. Britten*†
& J. Anthony Movshon‡**

* Department of Neurobiology and Behavior, State University of New York, Stony Brook, New York 11794, USA
‡ Department of Psychology and Center for Neural Science, New York University, New York 10003, USA

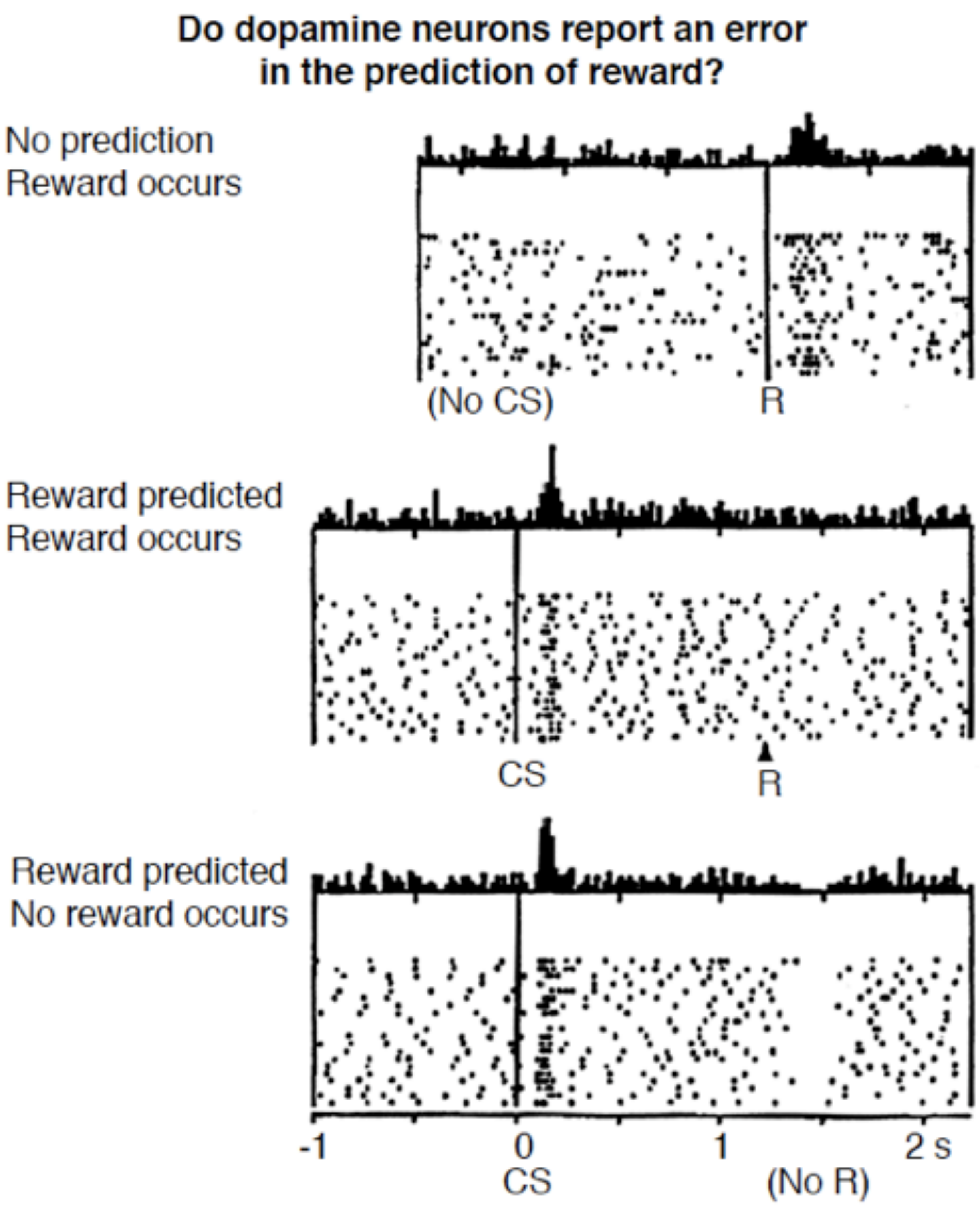


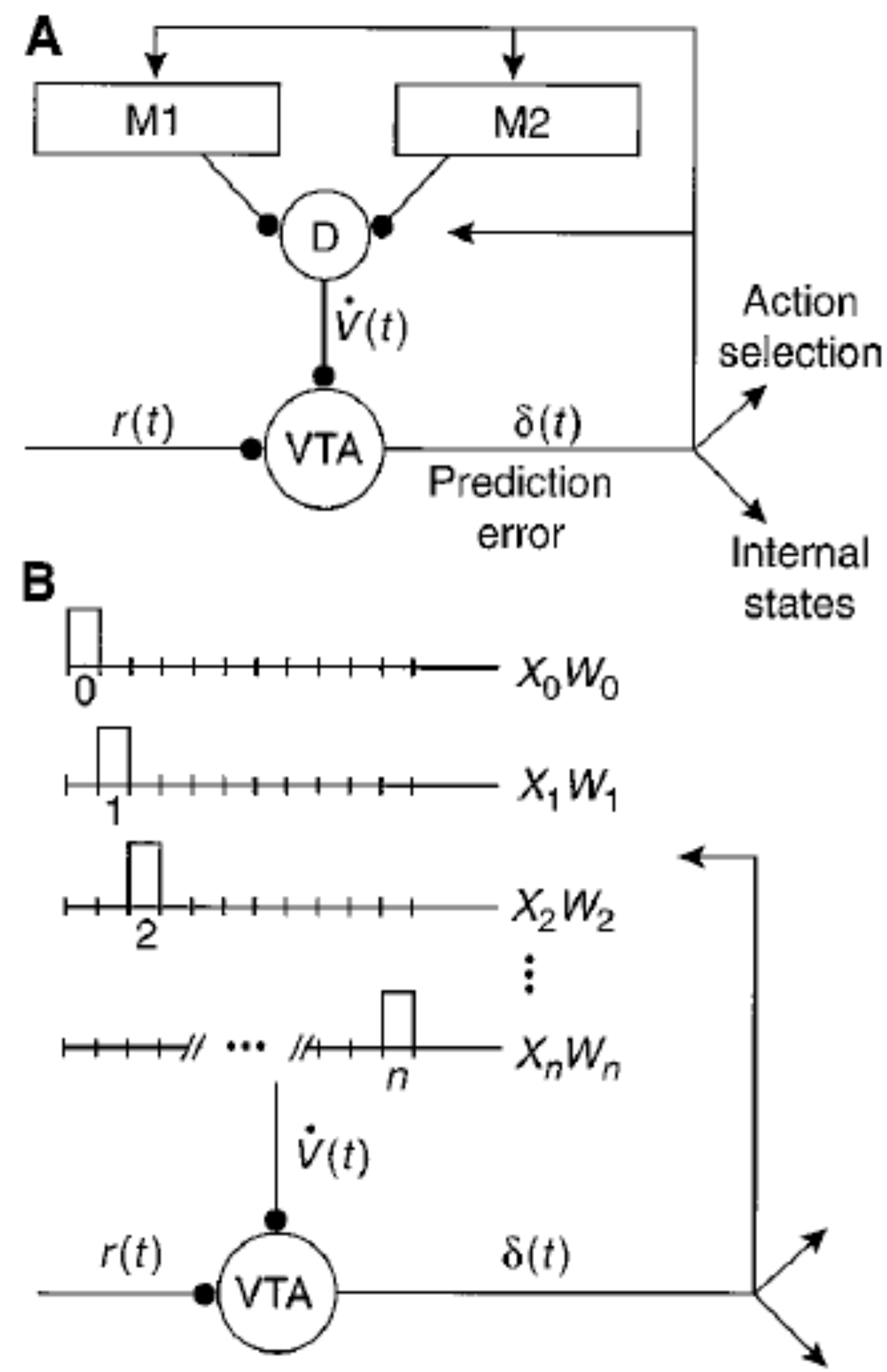




A Neural Substrate of Prediction and Reward

Wolfram Schultz, Peter Dayan, P. Read Montague*





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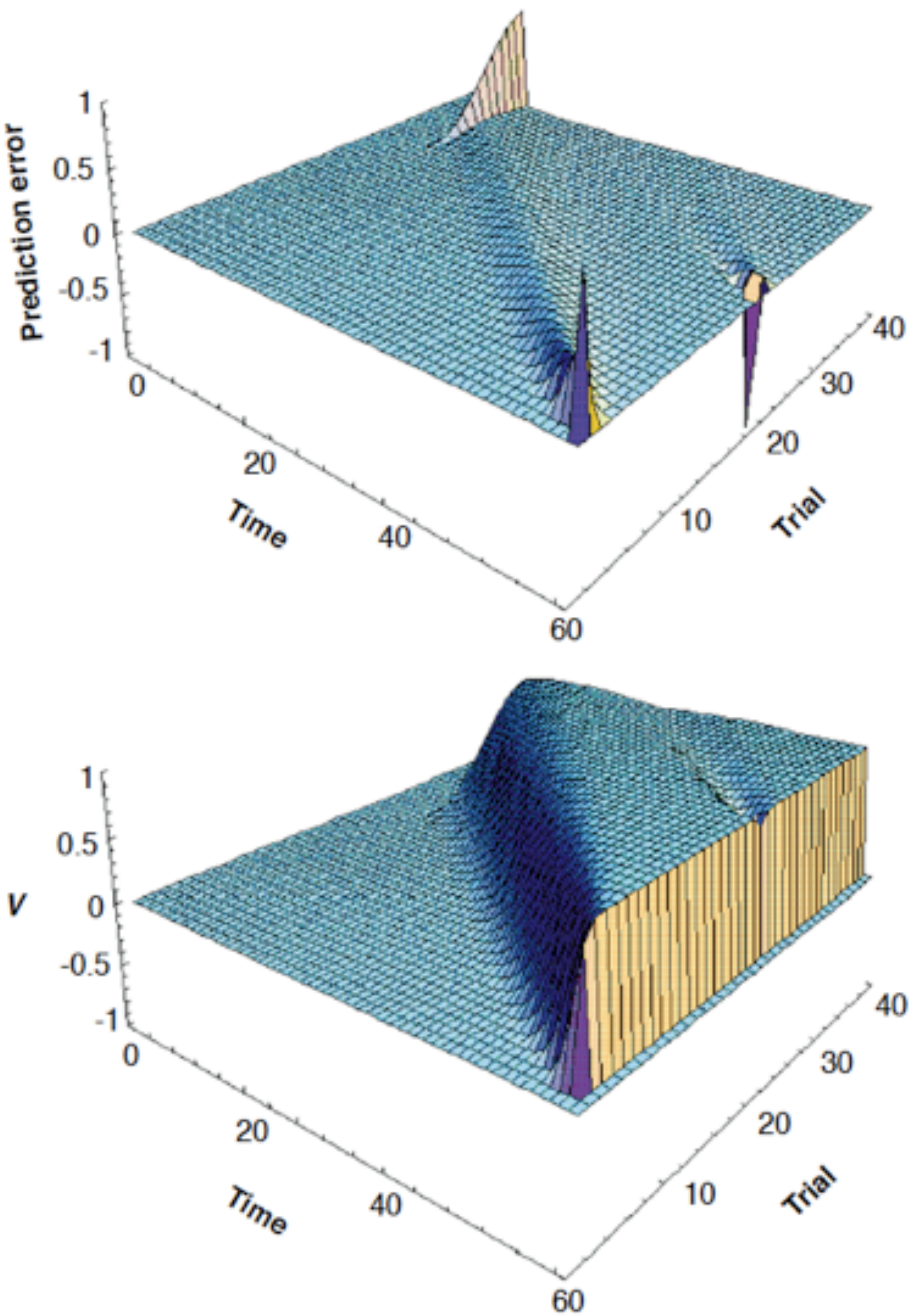

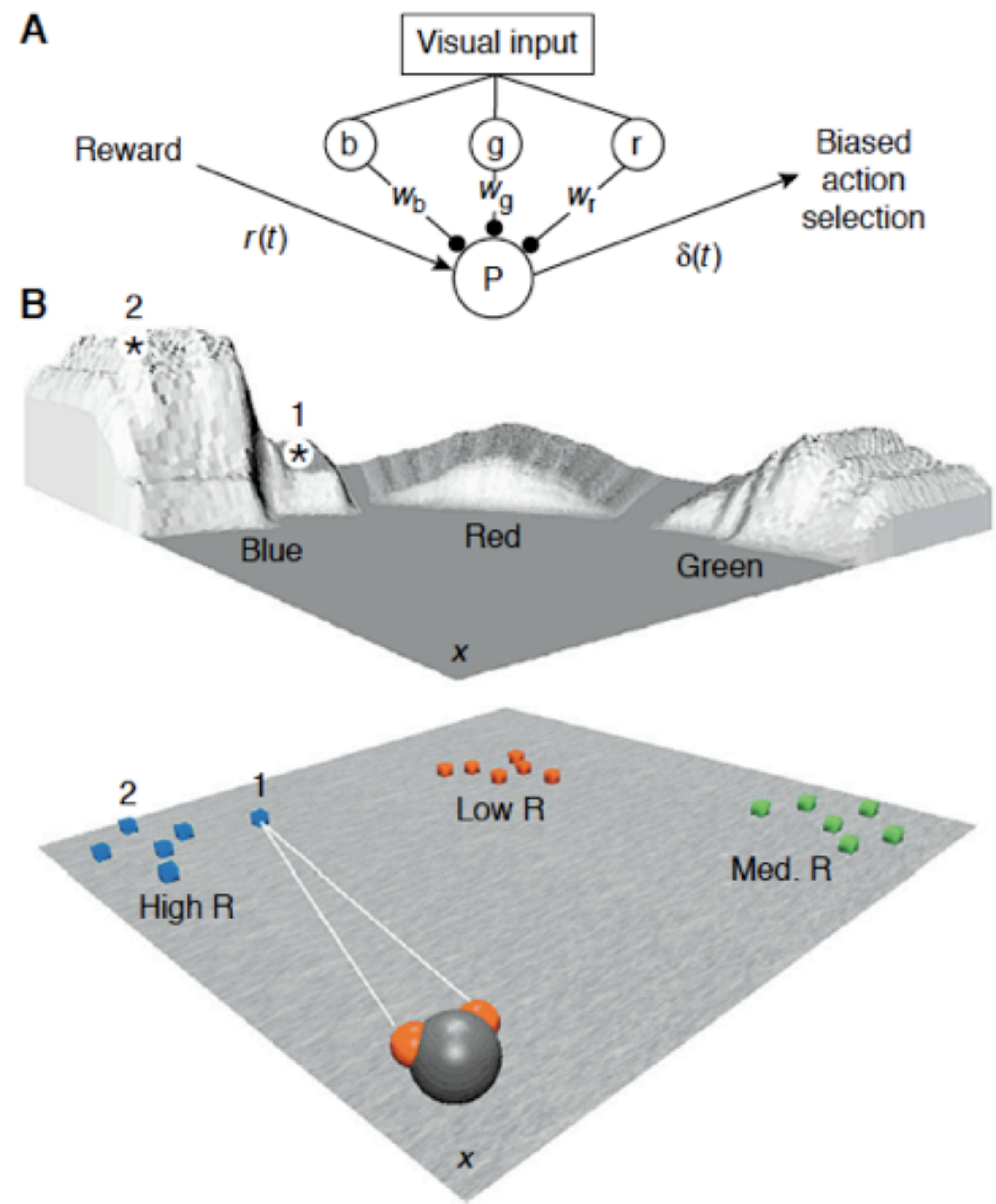

The Quest for the Neural Code

Neuronal correlates of a perceptual decision

William T. Newsome*†, Kenneth H. Britten*† & J. Anthony Movshon‡

* Department of Neurobiology and Behavior, State University of New York, Stony Brook, New York 11794, USA
‡ Department of Psychology and Center for Neural Science, New York University, New York 10003, USA

how is information represented in the brain?

Maybe it's the timing of spikes, rather than their average count (firing rate) that actually carries the information!

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how much information does the population contain?

Population codes are complicated because you cannot just add the information from different neurons if these are correlated (if they carry redundant information)

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on what time scales is information represented?

In the article, stimuli are 2 sec long! But monkeys (and humans) integrate motion over much shorter time scales (100s of millisec) - then each neuron contributes less info!

How behaviors are learned

A Neural Substrate of Prediction and Reward

Wolfram Schultz, Peter Dayan, P. Read Montague*

Edward Thorndike (1874-1949)

Psychology of Animal Learning

How behaviors are learned

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(1874-1949)

Psychology of Animal Learning

Optimal Control Theory

Richard Bellman
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Marvin Minsky
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Harry Klopf
(1927-???)

Artificial Intelligence (Machine Learning)

How behaviors are learned

Edward Thorndike
(1874-1949)

Psychology of Animal Learning

Optimal Control Theory

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(1920-1984)

Reinforcement Learning

Richard Sutton
(1956-???)

Andrew Barto
(1948-???)

Marvin Minsky
(1927-???)

Harry Klopf
(1927-???)

Artificial Intelligence (Machine Learning)

In case you are interested...

9th Computational Neuroscience Day, Wed

"Modeling Network Dynamics"

Salle Fessard
Institut de Neurobiologie Alfred Fessard
CNRS, Bat 33
1 Avenue de la Terrasse,
91190 Gif sur Yvette