Computational Neuroscience Introduction Day

- 14.00 Introduction
- 14.30 Computational Neuroscience Groups in Paris
- 15.00 Discussion of papers in groups: Questions
- 15.45 Discussion of papers in groups: Answers
- 16.30 Presentation of Answers

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

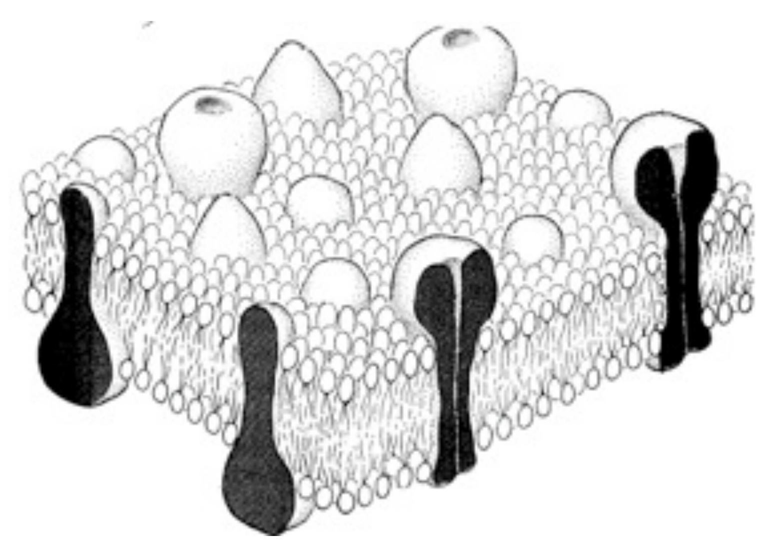
more complex brains generate a greater variety of behaviors

more complex brains can learn more behaviors

What's the brain made of?

Molecules

1 nm

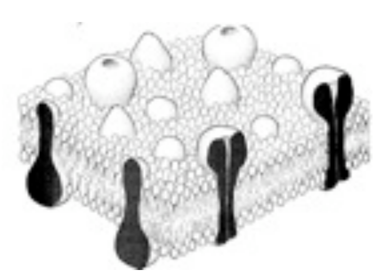


What's the brain made of?

Neurons — 100 µm

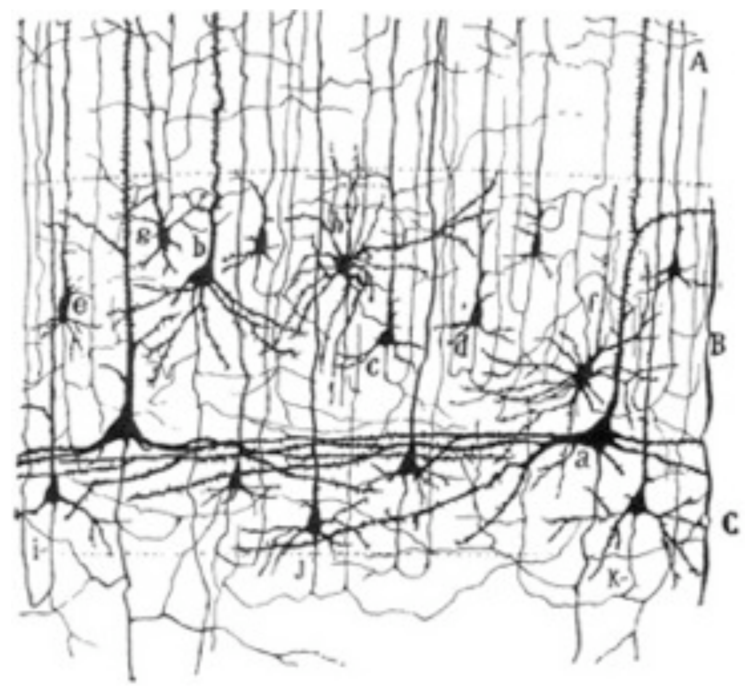
Synapses — 1 µm

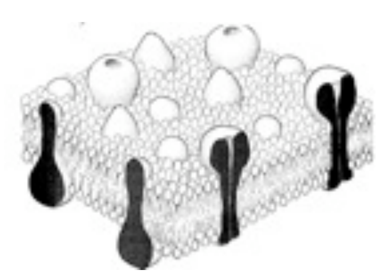
Molecules — 1 nm



What's the brain made of?

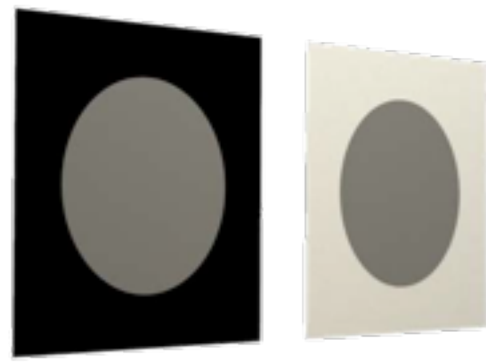
Maps	1 cm
Networks	1 mm
Neurons	100 µm
Synapses	1 µm
Molecules	1 nm

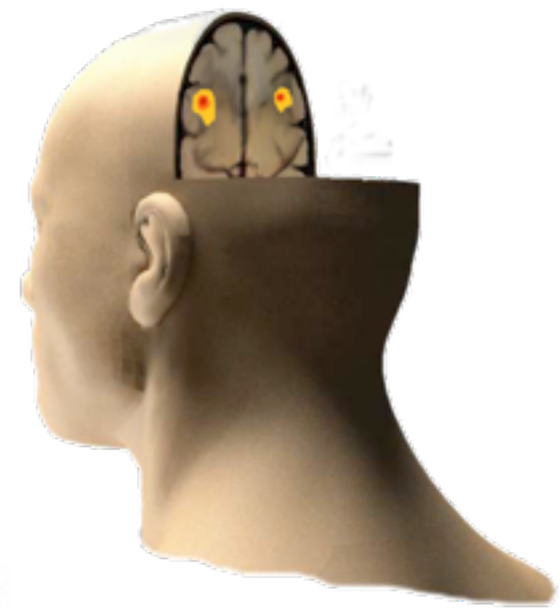


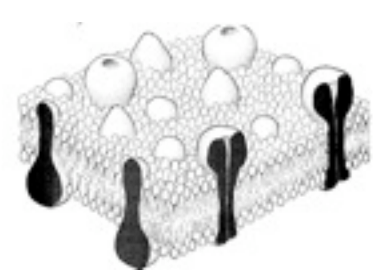


What's the brain made of?

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

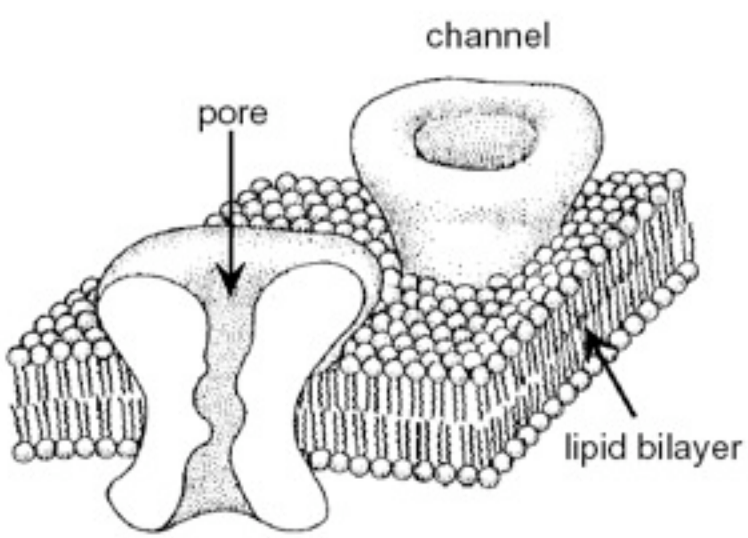
CNS	1 m
Systems	10 cm
Maps	1 cm
Networks	1 mm
Neurons	100 µm
Synapses	1 µm
Molecules	1 nm

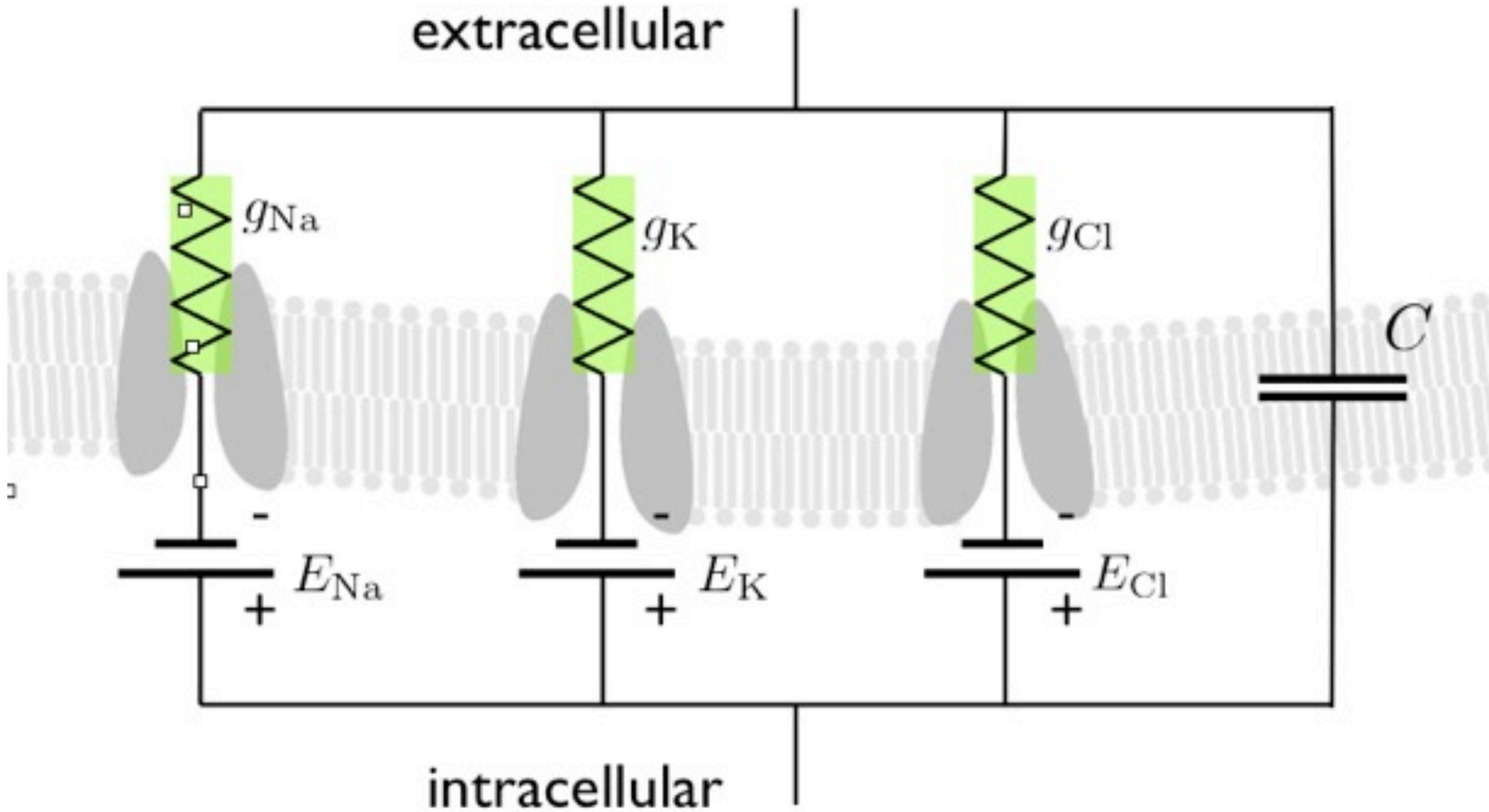
The quest for mechanisms: Constructing systems from parts

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

Biophysics of the membrane voltage:

The Hodgkin-Huxley Model



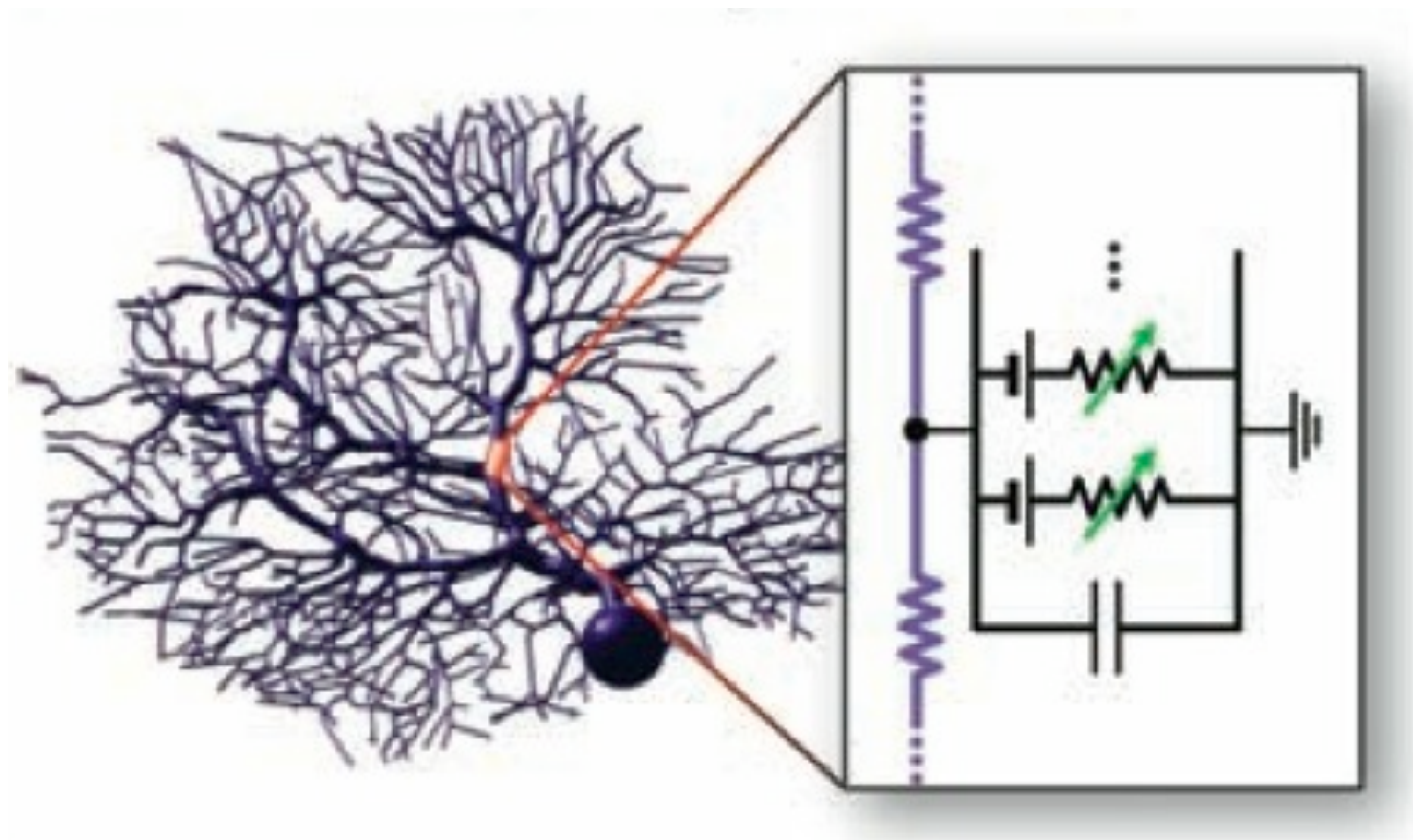


voltage

time

Reconstructing neurons:

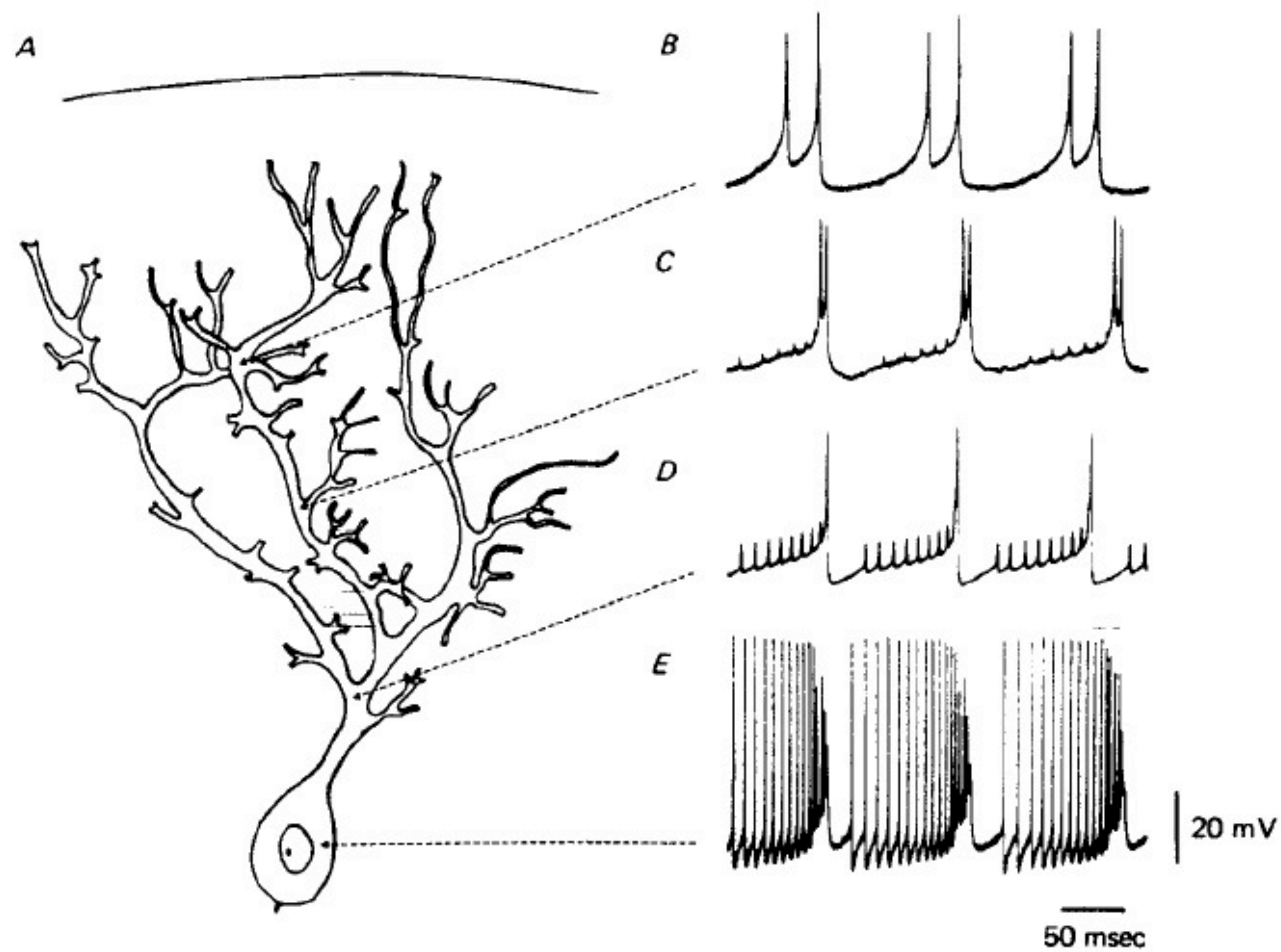
Ralls' cable theory and compartmental modeling



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
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Networks	1 mm
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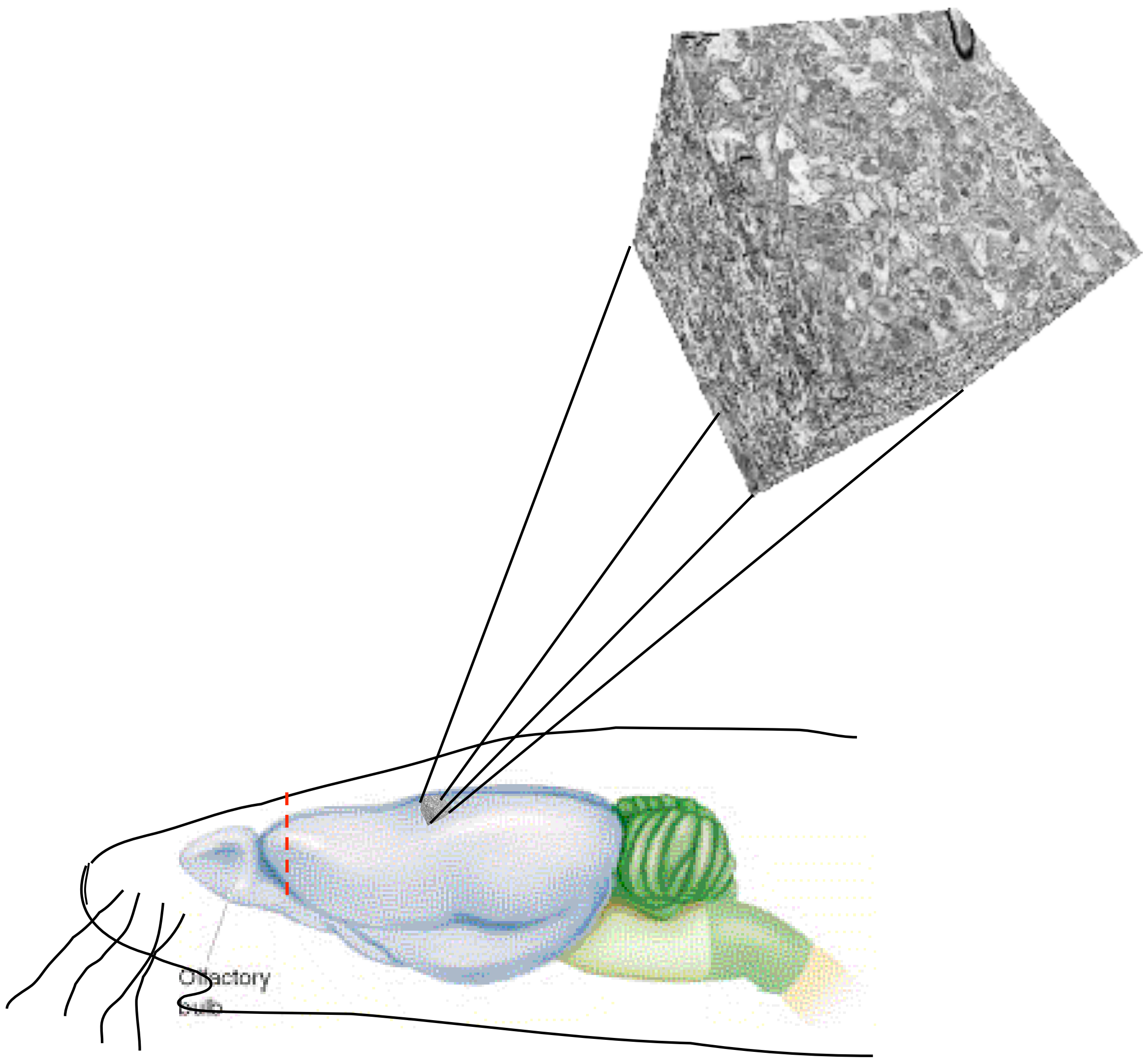
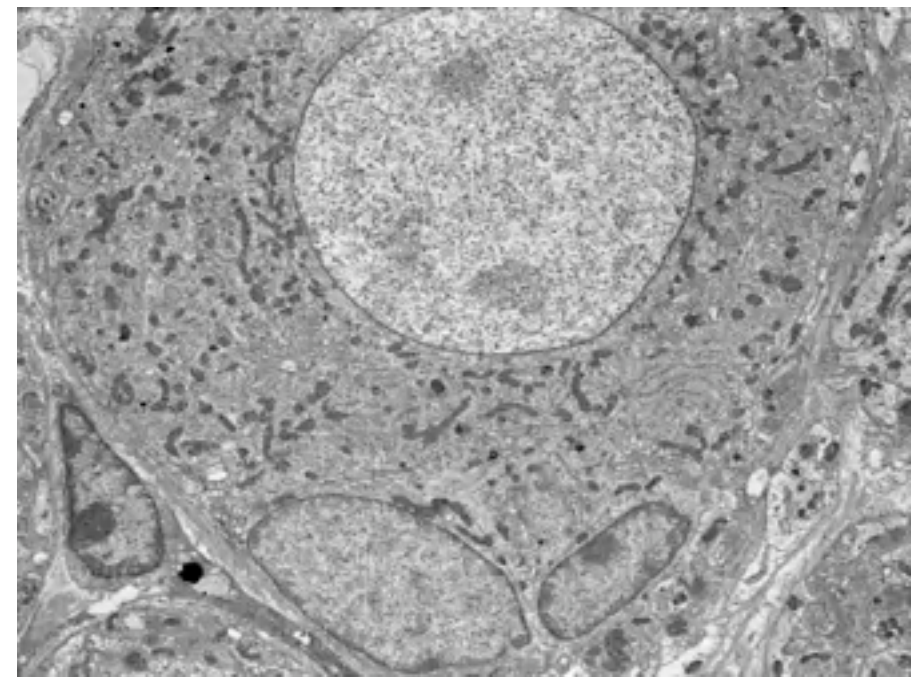
Reconstructing circuits

Serial Blockface Scanning Electron Microscopy





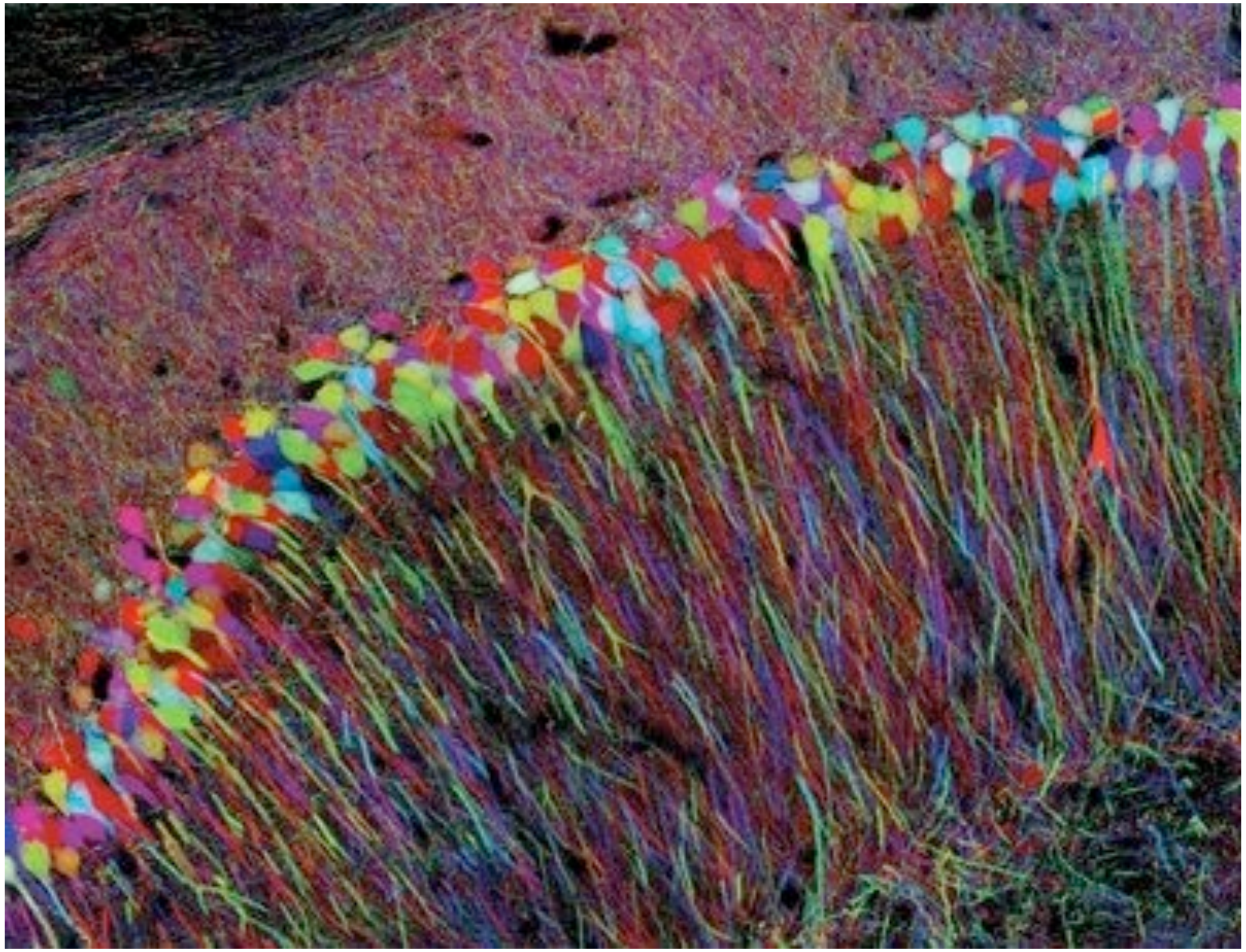
courtesy of W.Denk

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!

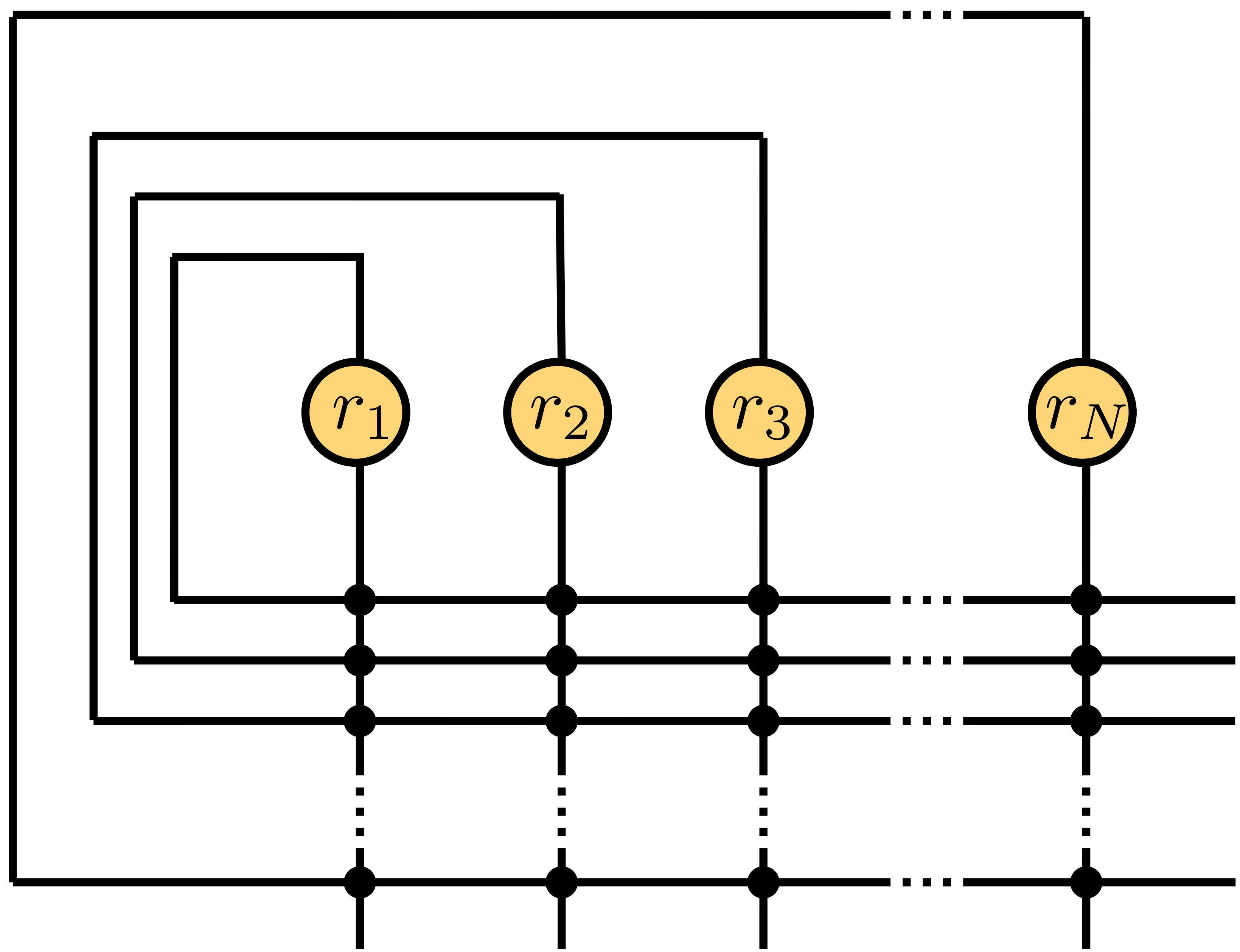


http://connectomes.org/

Theory of neural networks

Neurons, synapses → network activity

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

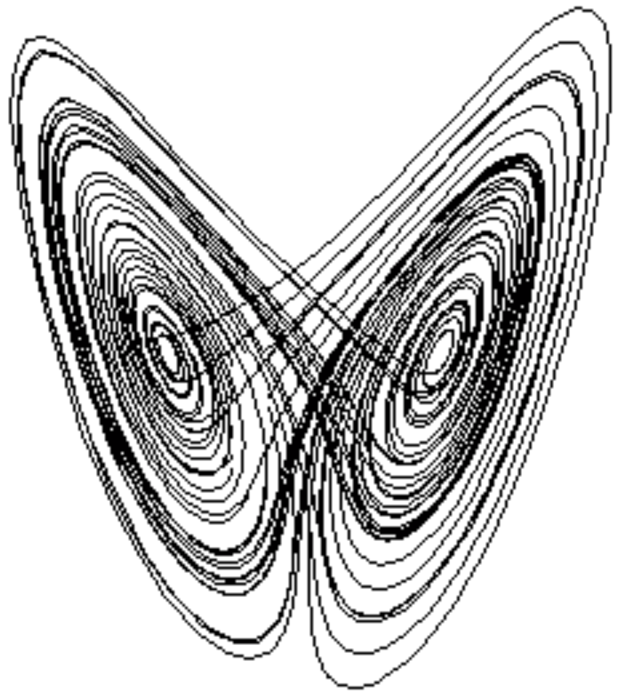


Network dynamics largely determined by connectivity

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

Possible dynamics:

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



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

For $N \rightarrow \infty$

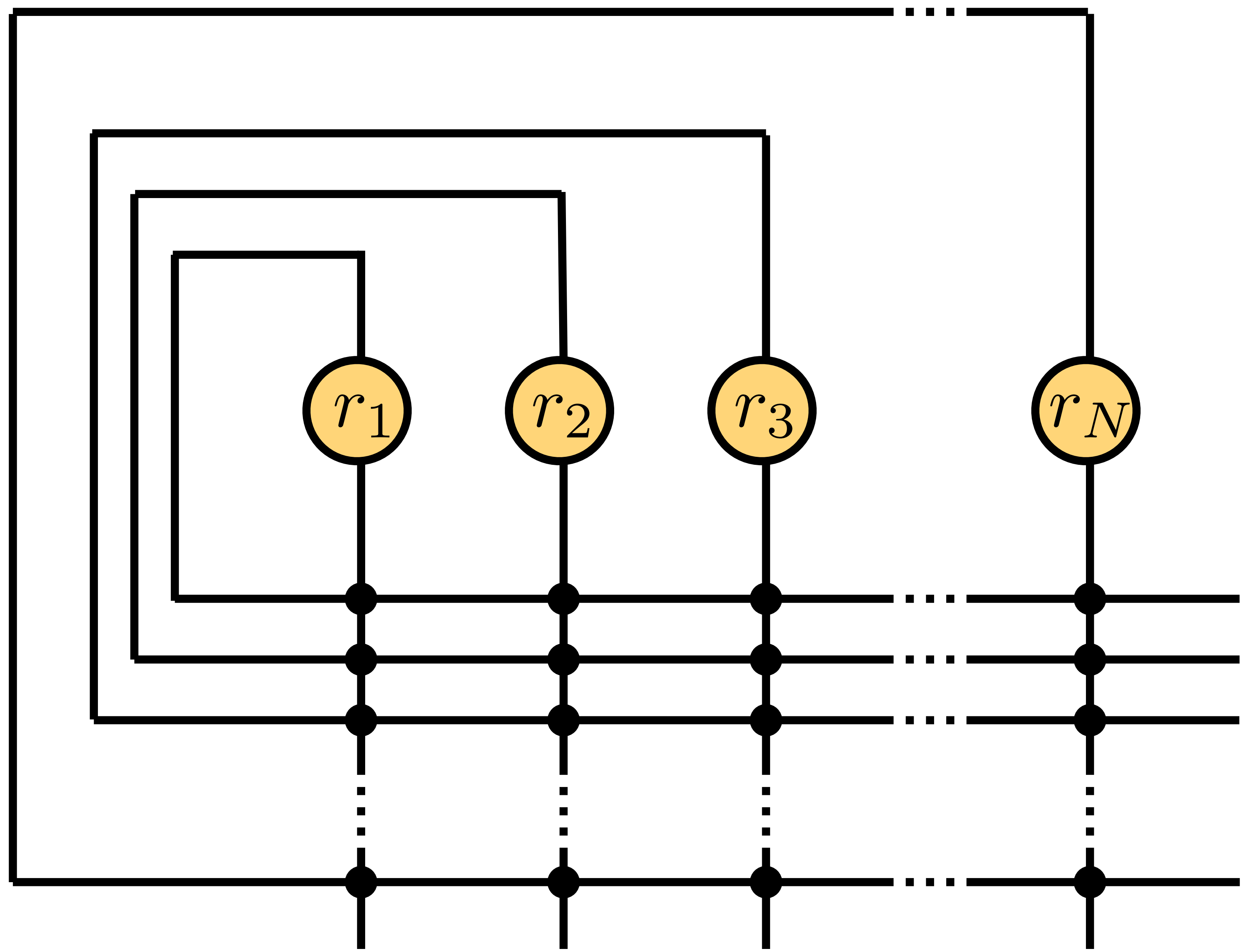
- neural networks can compute anything

(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
Systems	10 cm
Maps	1 cm
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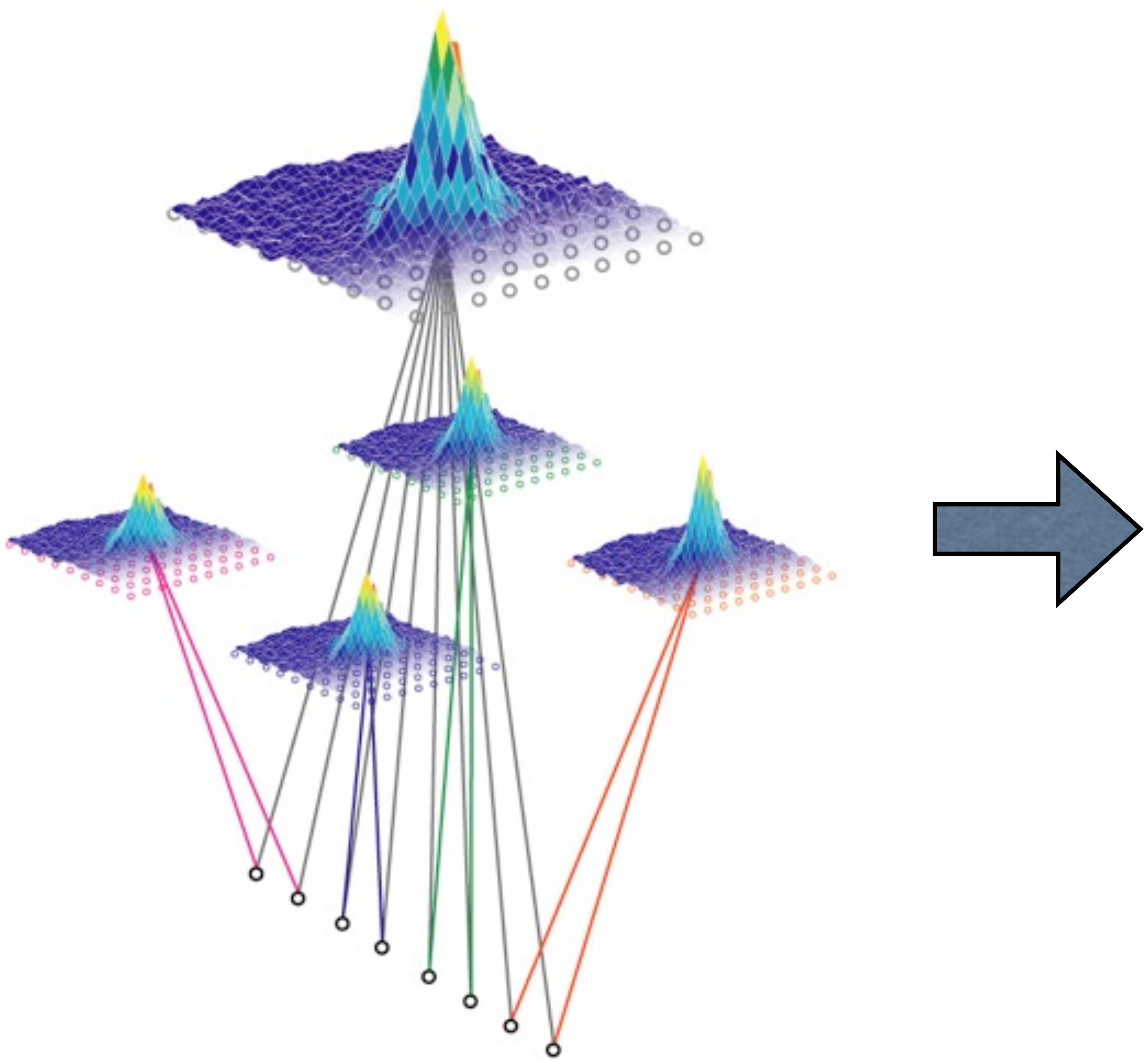
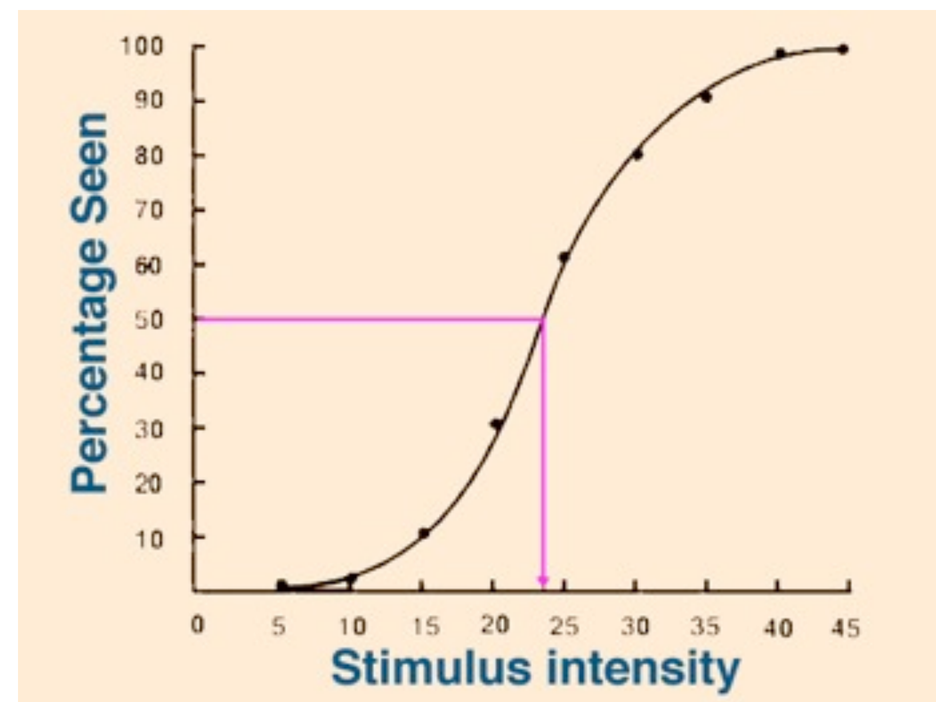
Molecules	1 nm

Connectionist models: From networks to behavior



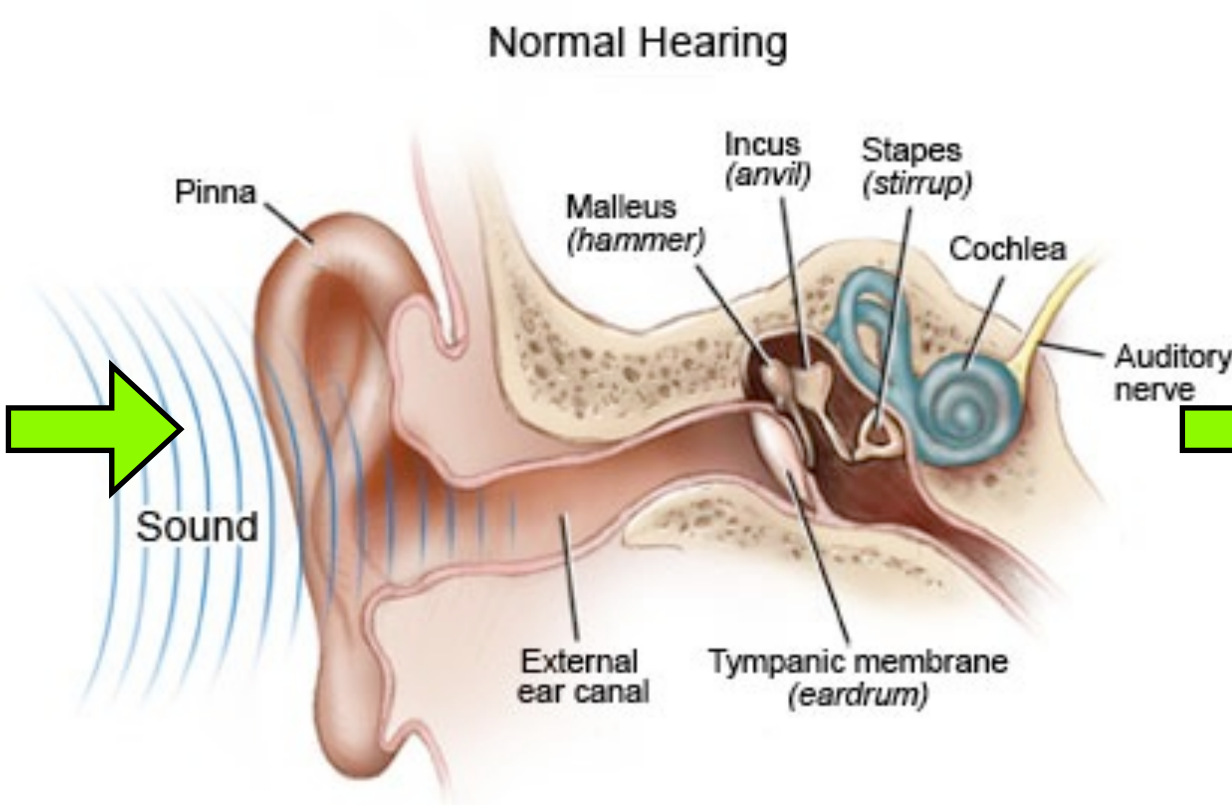


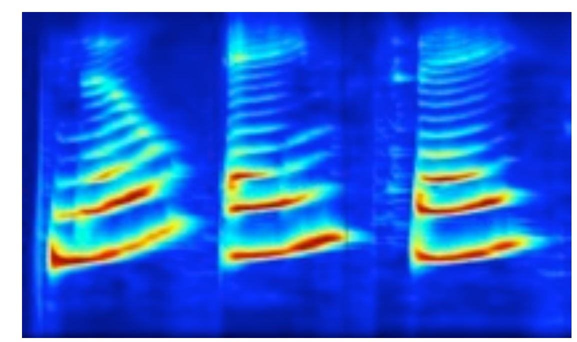
A computer science approach

Study the computational problems

Computation: manipulating information

sound pressure wave





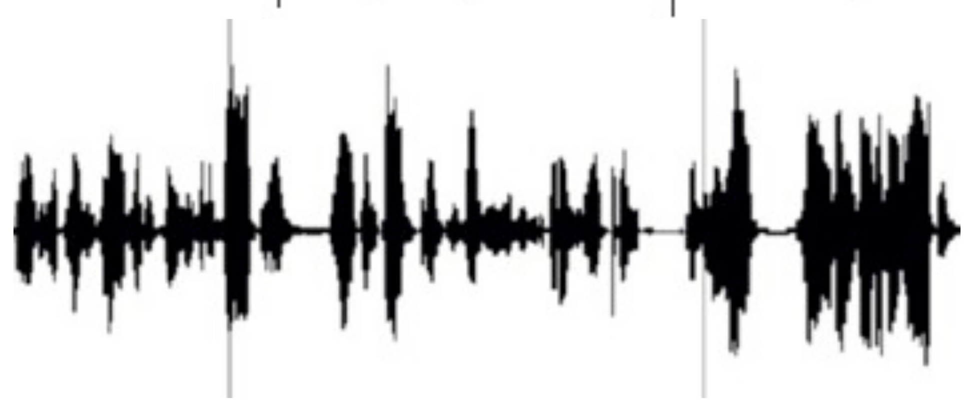
cochleogram
(time-frequency
representation of sound)

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`	in ...?
`23`	in multiples of 10
`00010111`	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:

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

Can you add these numbers?

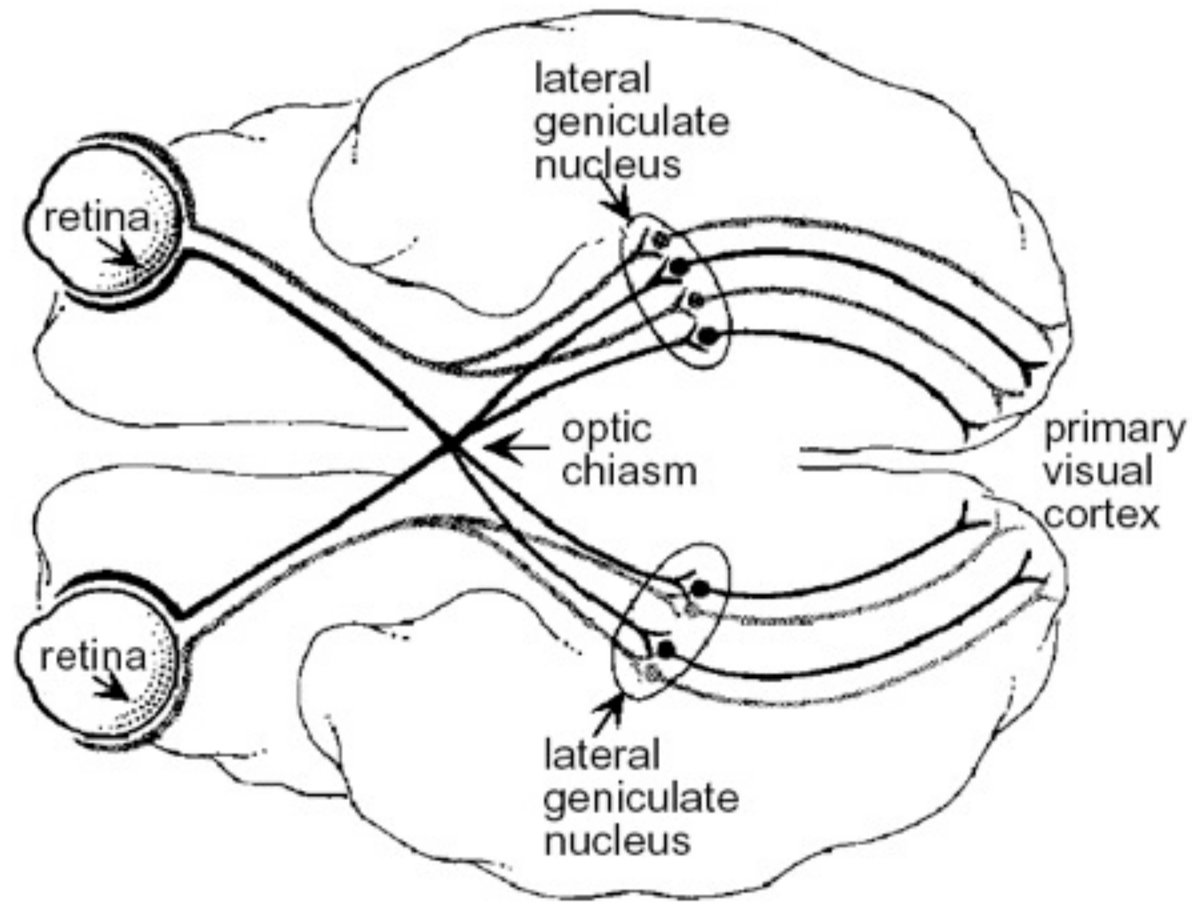
```
   29
+  33
-----
   62
```
easy

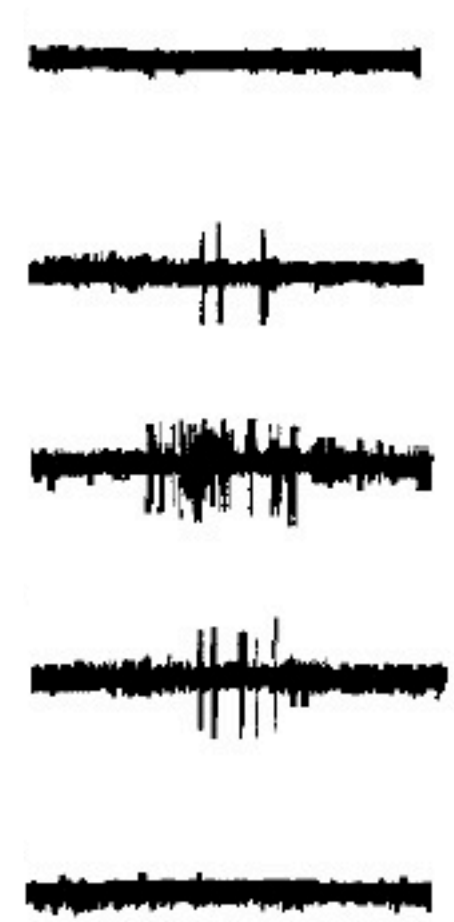
```
  00011101
+ 00100001
----------
  00111110
```
easy

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

Most famous example: “edge detectors” in visual system

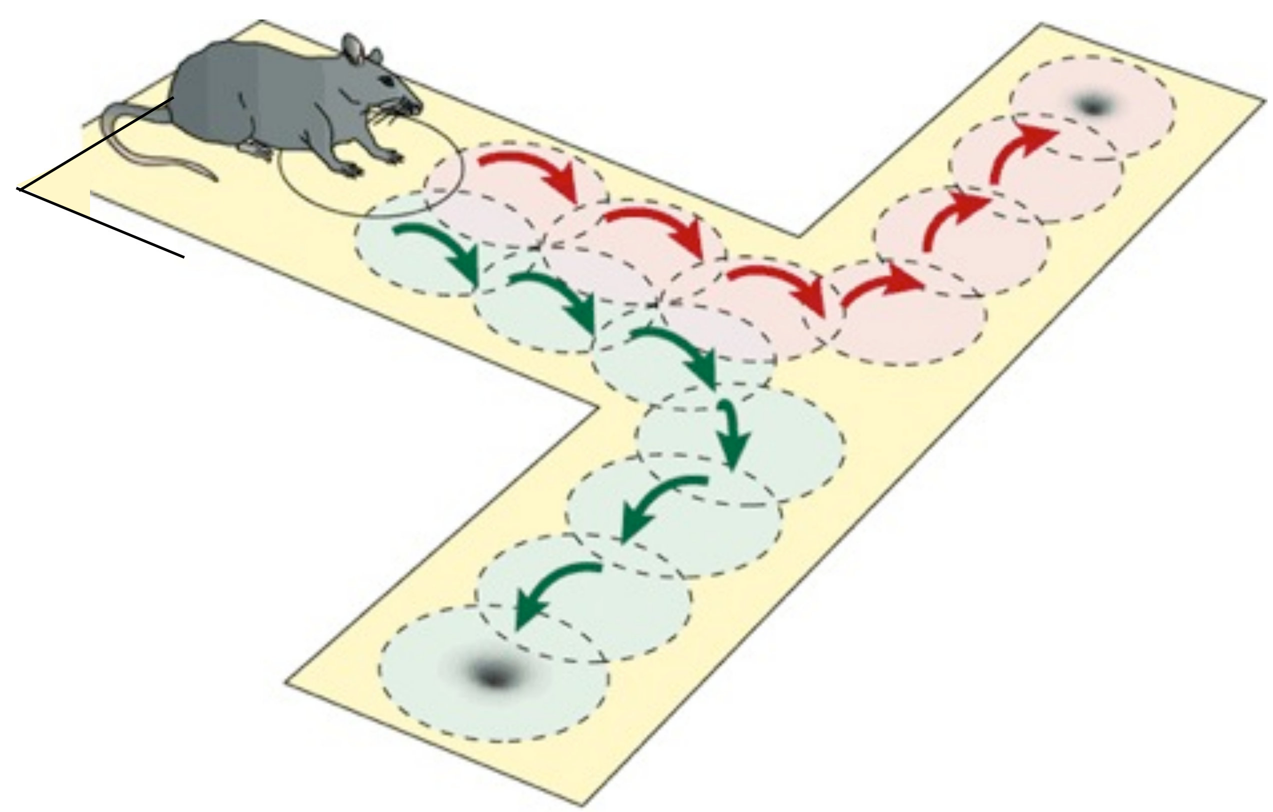
Stimulus:
black bar





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

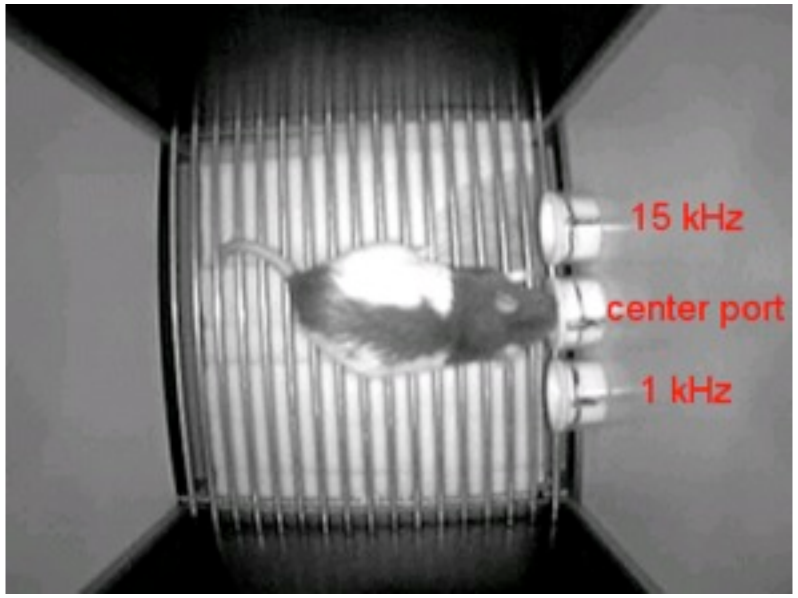
very little

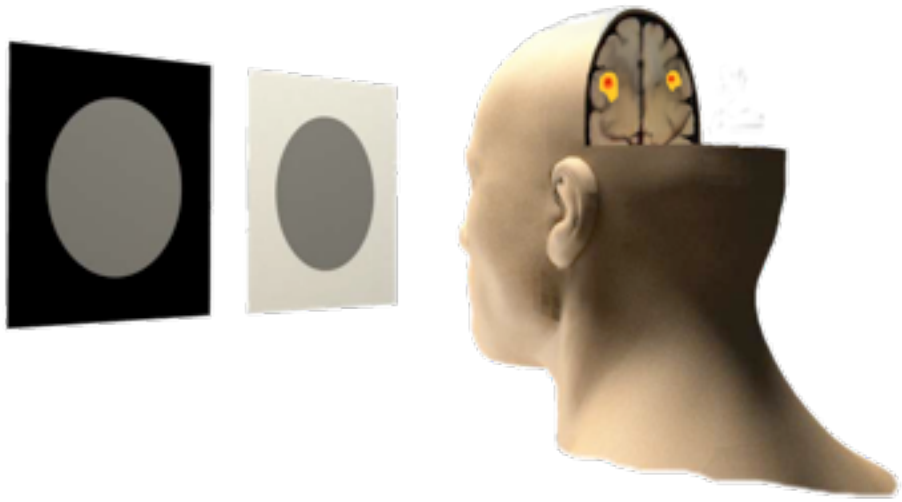
What we understand now

very little

What we need

- biologists
- psychologists

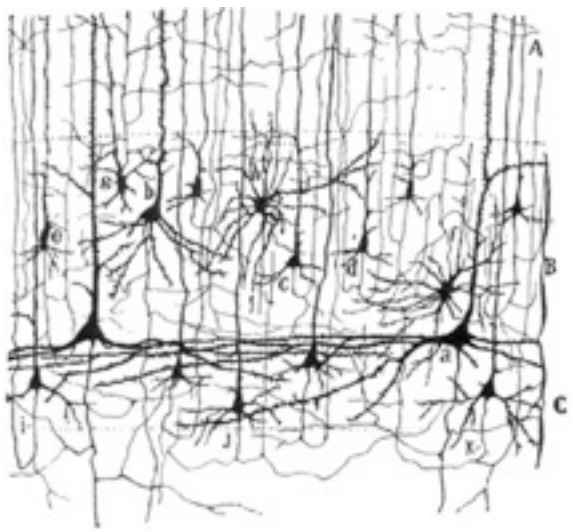


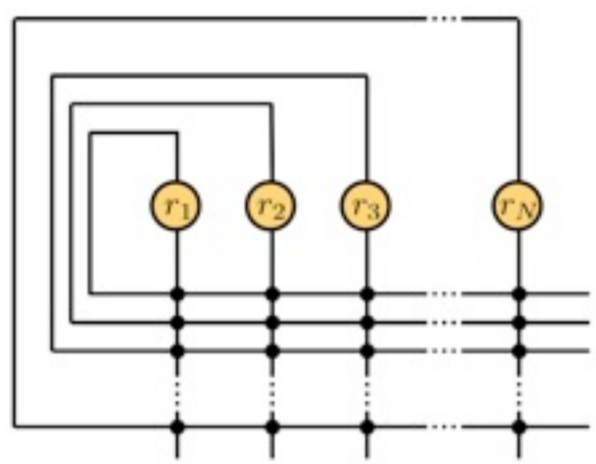


- to probe the brains of animals and humans
- to design and carry out clever experiments
- to investigate and quantify human and animal behavior

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

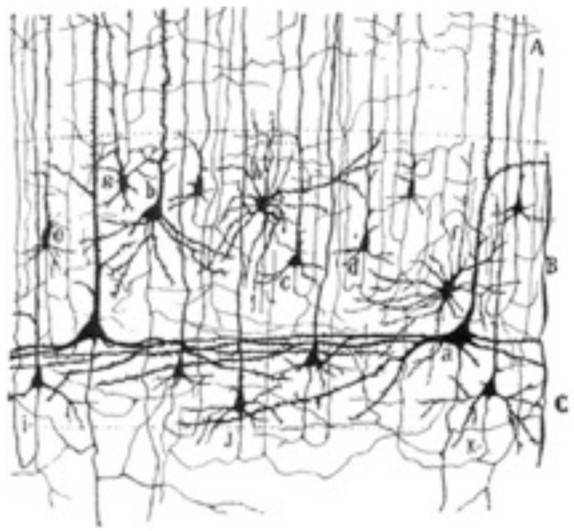
L3/M1

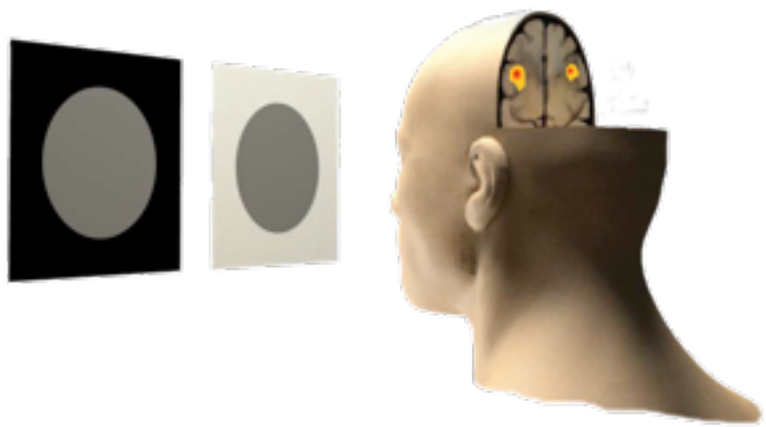
CO6

Introduction aux neurosciences computationnels

Christian Machens

S2, Wed, 17-19





Neurons

- Membrane voltage
- Action potentials
- Computations

Networks

- Attractors
- Associative memory
- Decision-making
- Sensory processing

Behavior

- Psychophysics
- Reinforcement Learning
- Neuroeconomics

L3/M1

CO6 Introduction aux neurosciences computationnels

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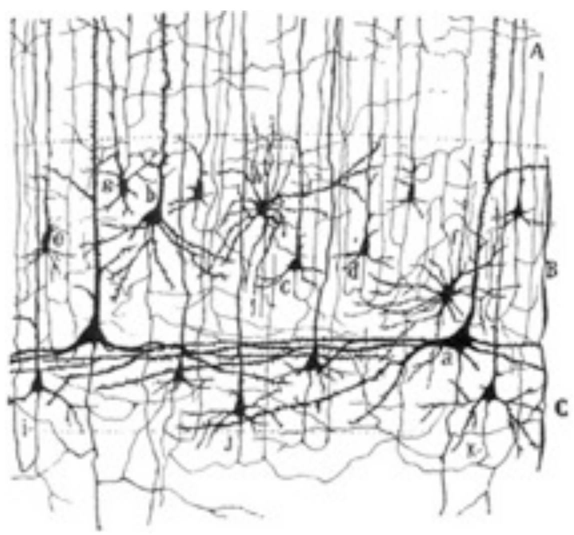

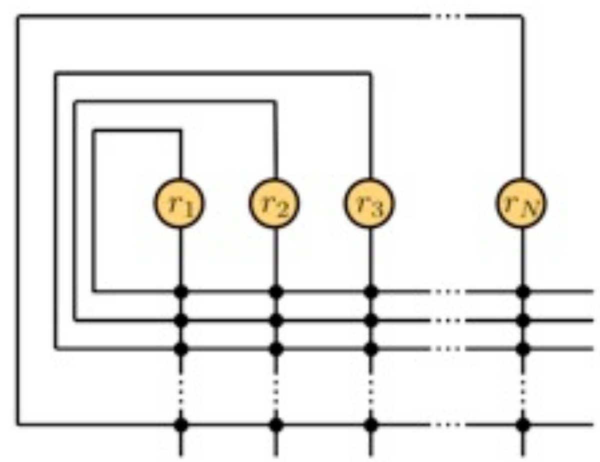

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$$\dot{r}_2 = -r_2 + f\Big(\sum_{j=1}^{N} w_{2j} r_j + E_2\Big)$$

What you need

- Basic math skills,
  High-School Level
  (ask if you are uncertain!)

What you get

- Foundations of Comp Neurosci
- 4 ECTS

Validation

- 100% exam

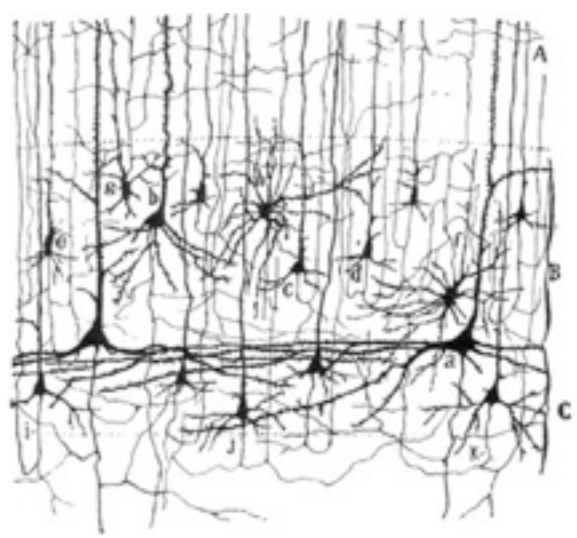
L3/M1

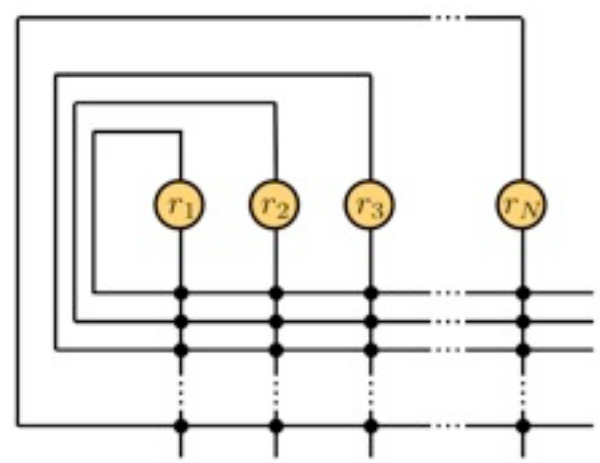
AT2

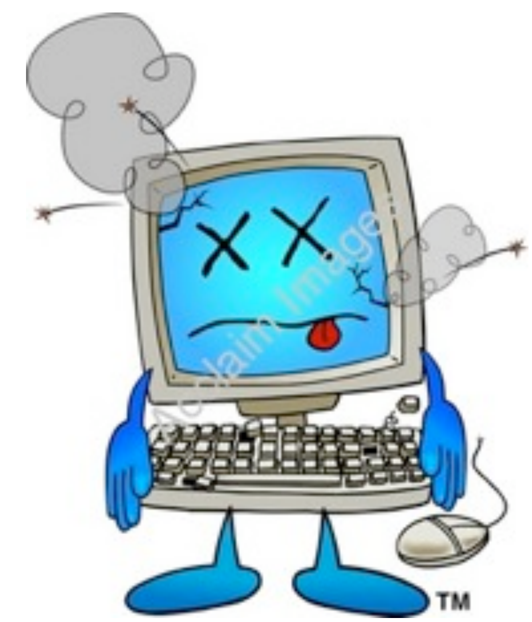
Atelier théorique neuromodélisation

Christian Machens

S2, Wed, 14-16







What you need

- Basic math skills
  High School Level

What you get

- Putting models into the computer!
- 4 ECTS

Validation

- 100% course exercises

M1/M2

CA6a

Theoretical Neuroscience

S3

Rava da Silveira, Vincent Hakim, Nicolas Brunel, Jean-Pierre Nadal

2 Classes:	Single neurons, Hodgkin-Huxley, Integrate-and-Fire
3 Classes:	Single Synapses: dynamics, plasticity, learning
2 Classes:	Rate models of Neural Networks
3 Classes:	Network anatomy, spiking networks
1 Class:	Learning and Memory in Neural Networks
2 Classes:	Neural Coding, Population Coding

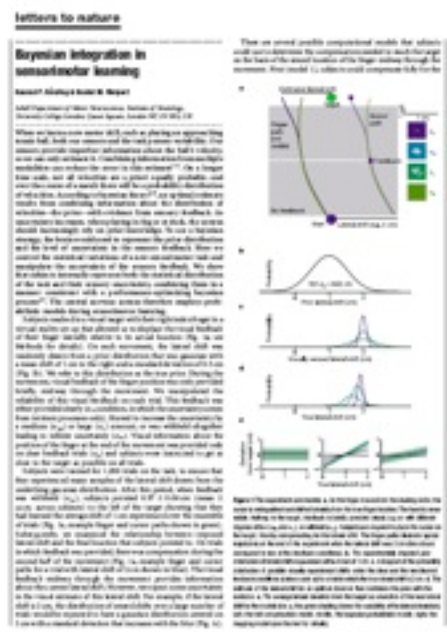
Start: October 1st
Salle T15, physics

M1/M2

CA6b Seminar / Journal Club Quantitative Neuroscience

Rava da Silveira, Vincent Hakim,
Christian Machens

S3, Tue, 17.30-19


letters to nature

Bayesian integration in sensorimotor learning

What you need

- Basic knowledge of computational neuroscience (ask if you are uncertain!)

What you get

- Learn about recent research
- Learn how to give a talk
- 3 ECTS

Validation

- 50% talk
- 50 % course participation

Talks in French or English

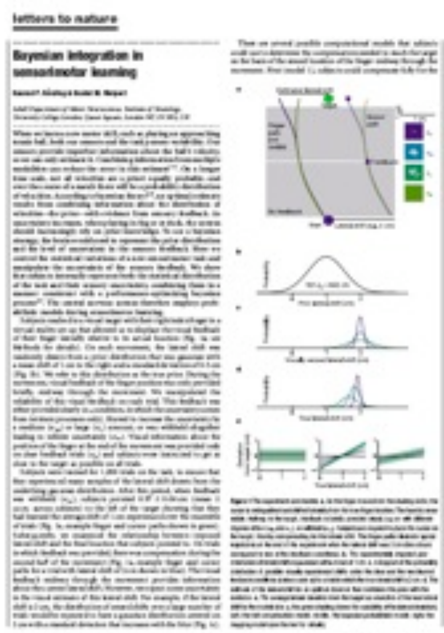
M1/M2 CA6b Seminar / Journal Club Quantitative Neuroscience

Rava da Silveira, Vincent Hakim, Christian Machens

S3, Tue, 17.30-19

Start: Sep 29th

Salle 235b, 29, rue d'Ulm



What you need

- Basic knowledge of computational neuroscience (ask if you are uncertain!)

What you get

- Learn about recent research
- Learn how to give a talk
- 3 ECTS

Validation

- 50% talk
- 50 % course participation

Talks in French or English

Many more classes available!!

see cogmaster website!!
contact us!!

Computational Neuroscience Research in the Cogmaster and Beyond

ENS: Group for Neural Theory
(Sophie Deneve, Christian Machens, ...)
ENS: Laboratoire de Physique Statistique
(Jean-Pierre Nadal, Vincent Hakim ...)
Paris V: Laboratoire de Neurophysique et Physiologie
(Nicolas Brunel, ...)

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

Computational Neuroscience Introduction Day

- 14.00 Introduction
- 14.30 Computational Neuroscience Groups in Paris
- 15.00 Discussion of papers in groups: Questions
- 15.45 Discussion of papers in groups: Answers
- 16.30 Presentation of Answers

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