

Advanced Course in Computational Neuroscience



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Sorbonne University



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Ecole Normale
Supérieure



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Ecole Normale
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Alain Destexhe
University Paris-
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Denis Sheynikhovich
Sorbonne University



Gisella Vetere
ESPCI



Boris Gutkin
Ecole Normale
Supérieure

For Master 2 and PhD students with computational background. The course presents biology, modelling, simulations, data analysis, signal processing, machine learning and clinical relevance.

Covered Topics

- Brain function and clinical issues
- Hearing and mechanical transduction in hair cells
- Vision and signal transduction in photoreceptors
- Neural coding in the retina and vision restoration
- Electrochemistry of synapses and dendritic spines
- Neuron-glial interactions and synaptic plasticity
- Emergence and interplay of brain rhythms
- Spatial memory and navigation
- Large scale brain activity in normal and pathological states
- Big data analysis applied to behavioral neuroscience
- Analysis and interpretation of EEG data
- Brain-Computer interface

Coordination: Jürgen Reingruber and David Holcman

Practical Information

- **12 courses**
- **When:** Wednesday, 17h15-19h30h
- **Where:** Salle 316, ENS, 46 rue d'Ulm, 75005 Paris
- **Link for streaming:**
<https://bbb.bio.ens.psl.eu/b/jur-yj7-fzc-rsb>
- **IBENS Teaching Webpage for additional information:**
<https://moodle.bio.ens.psl.eu/>
- **Recordings will be made available after each class at:**
<https://moodle.bio.ens.psl.eu/>
Homepages of D Holcman and J. Reingruber at IBENS
<https://www.ibens.bio.ens.psl.eu/spip.php?article465&lang=fr>
<https://bionewmetrics.org/open-lectures/>
- **Coordinators:** Jürgen Reingruber and David Holcman
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Validation

- **PhD students**
Proof of attendance
- **Master students (3 ECTS)**
Scientific/Engineering/Clinical projects [Nov-Dec]
 - 1-2 pages summary
 - 20min ppt presentation + 10min questions
 - **Exam:** Mid January

Context

- Understanding **multiscale organization and functioning** of the **brain** from **single neurons** up to the **level of networks** remain key challenges for modern neuroscience.
- Interaction between **experiment** and **theory** are necessary
- Computational approaches based on **modeling, simulations, data analysis, signal processing** and **machine learning** are crucial to reveal principles of brain functioning.
- **Quantitative approach** is fundamental for neurobiology and clinical applications

Goals

- Introduce **computational models** in neuroscience at different levels
- Present **mathematical methods** for analysis and simulations
- Identification of **features** from analysis of large datasets
- **Analysis and interpretation** of EEG recordings
- **Signal processing** and **machine learning** for brain computer interfaces
- Introduce clinical applications

Organization of the course

1. Brain function and clinical issues

Nathalie Kubis (Hôpital Lariboisière, Paris)

2. Sensory input to the brain (3 classes)

Pascal Martin (Institut Curie), Jürgen Reingruber (Ecole Normale Supérieure), Olivier Marre (Institut de la Vision)

3. Fundamental brain constituents (2 classes)

Thibault Lagache (Institut Pasteur), David Holcman (Ecole Normale Supérieure)

4. Neural Networks (3 classes)

Boris Gutkin (Ecole Normale Supérieure), Denis Sheynikhovich (Institut de la Vision)
Alain Destexhe (Paris-Saclay)

5. Large scale data analysis

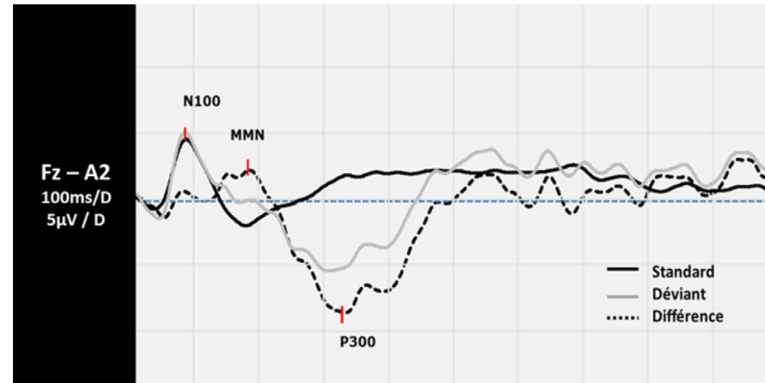
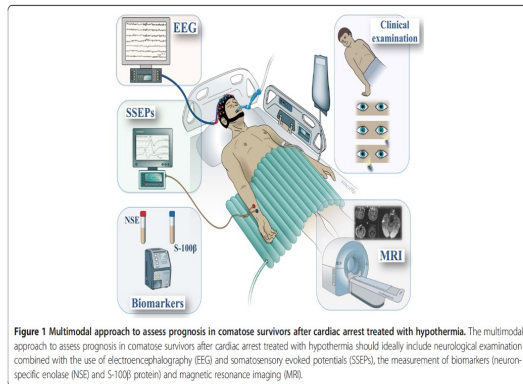
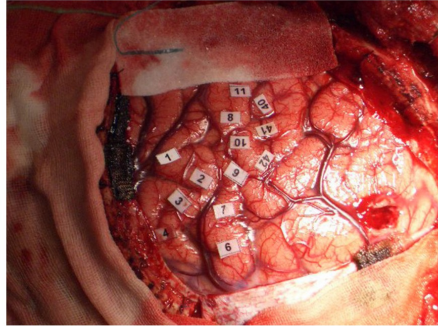
Gisella Vetere (ESPCI)

6. EEG analysis and Brain-Computer Interfaces (2 classes)

Michel Le Van Quyen (Sorbonne University), Theodore Papadopoulos (INRIA Nice)

Course 1: Brain function and clinical issues, examples

Nathalie Kubis (*Hôpital Lariboisière, Paris*)

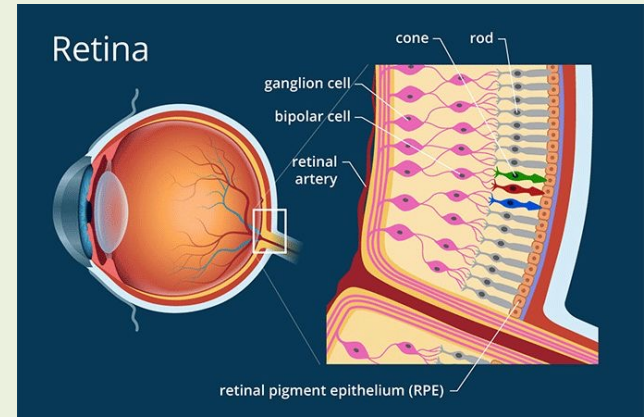
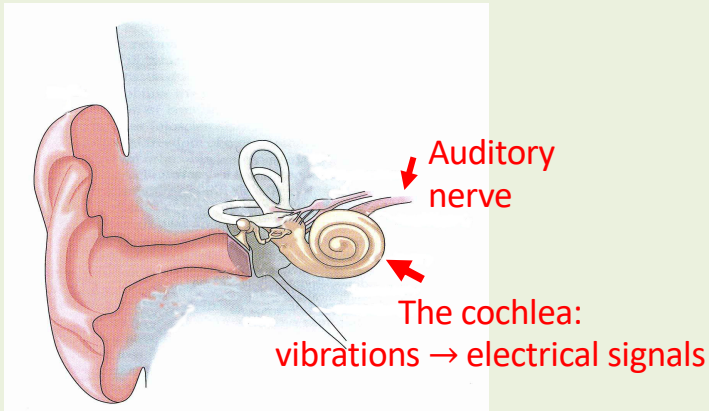


What is the anatomy of the brain ? What is consciousness and lack of it (coma) ? Can we prognose the outcome of patients in coma ?

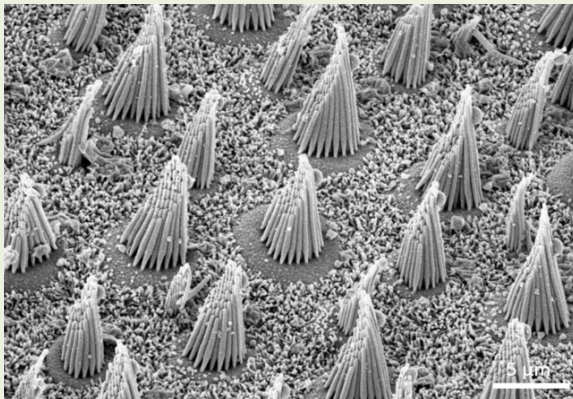
Course 2 and 3: **Modelling hair cells and photoreceptor sensory neurons**

Pascal Martin (*Institut Curie, Paris*)

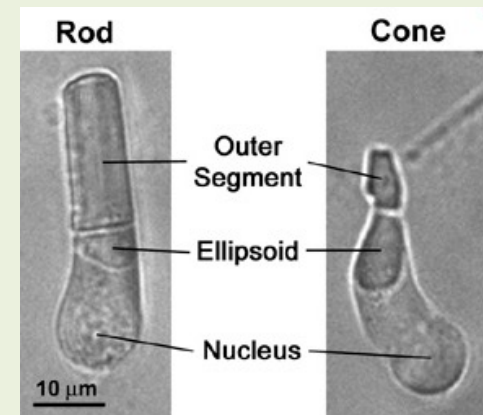
Jürgen Reingruber (*ENS, Paris*)



Hair cells: sensory cells of the inner ear



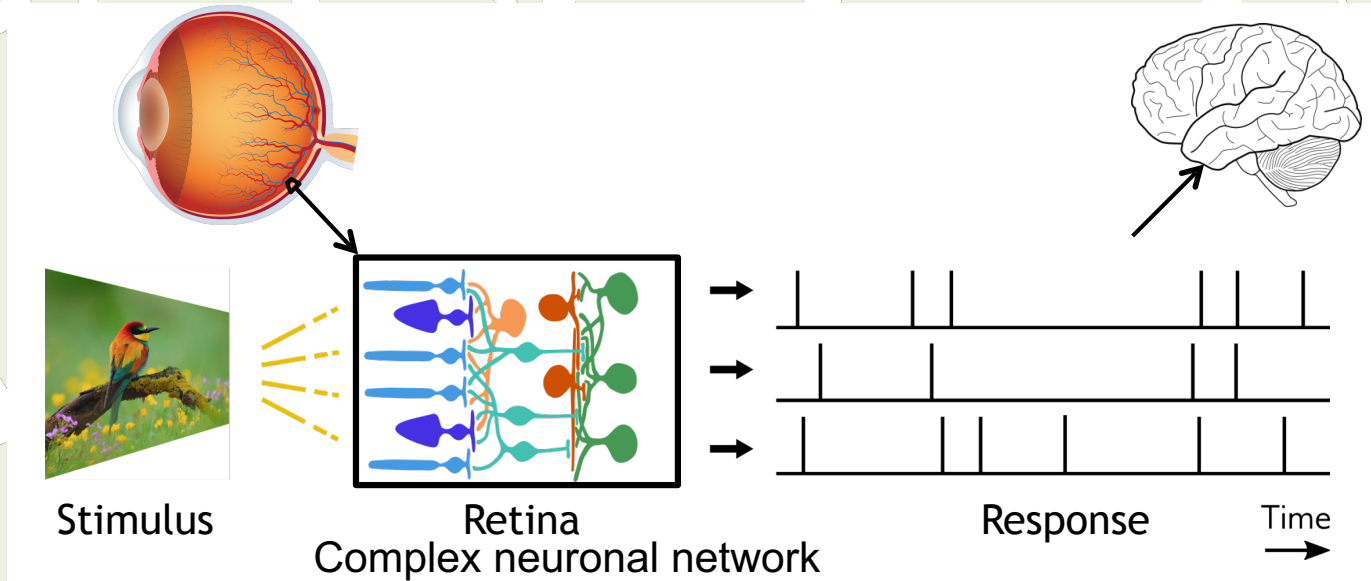
Photoreceptors: sensory cells of the retina



How do hair cells and photoreceptors function ? How do they determine the auditory and visual perception ?

Course 4: Neural coding in the retina and vision restoration

Olivier Marre (*Institut de la Vision, Paris*)

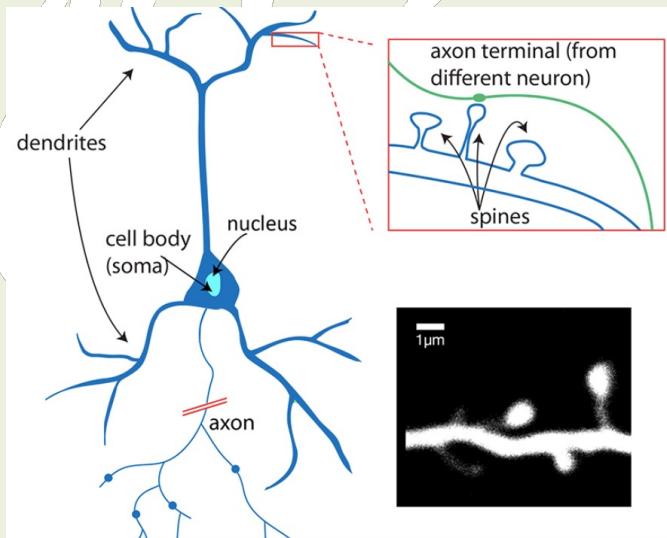


How is the visual stimulus processed in the retina ?

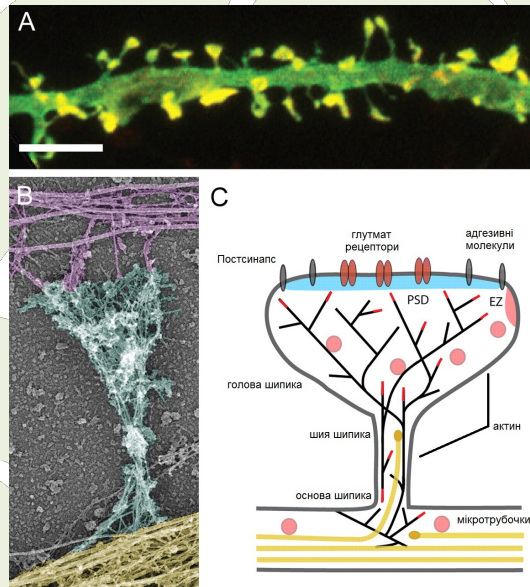
How can we apply retinal models to develop new strategies for vision restoration in blind patients ?

Course 5: Electrodiffusion model for synapses and dendritic spines

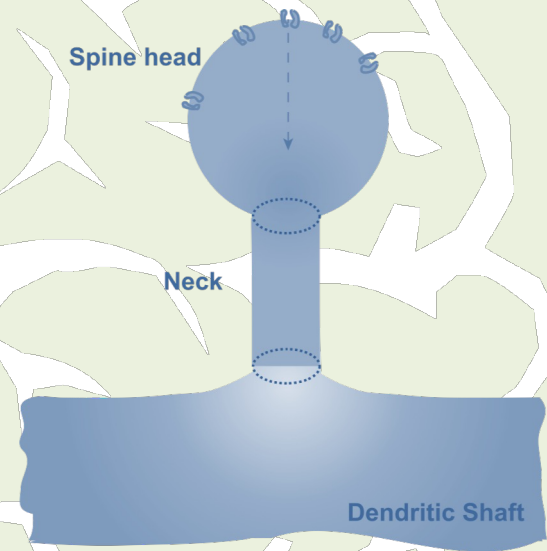
Thibault Lagache (*Institut Pasteur, Paris*)



Dendritic spines are the primary sites of synaptic integration



Spines have complex and dynamic shape



What is the role of the spine geometry ?

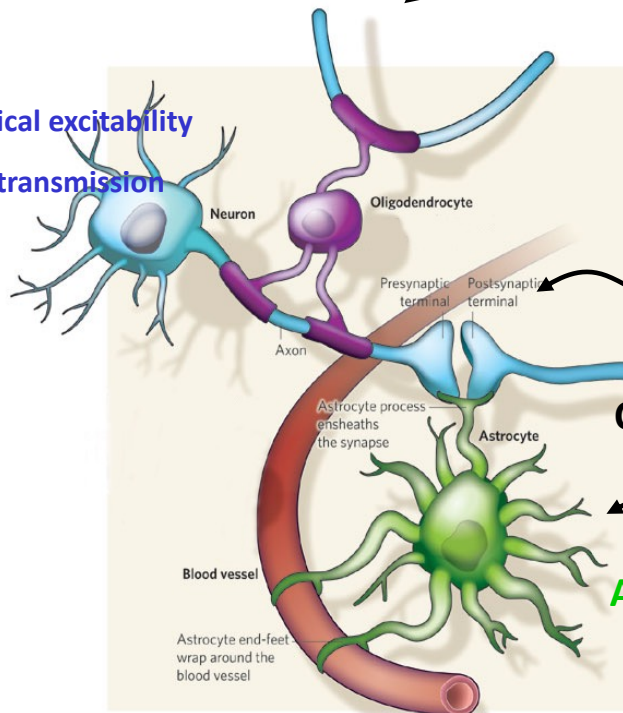
How do we apply the Poisson-Nernst-Planck formalism to model the voltage and ion dynamics in dendritic spines ?

Course 6: Modelling Neuron-Glial interactions and synaptic plasticity

David Holcman (*ENS, Paris*)

Neuronal networks

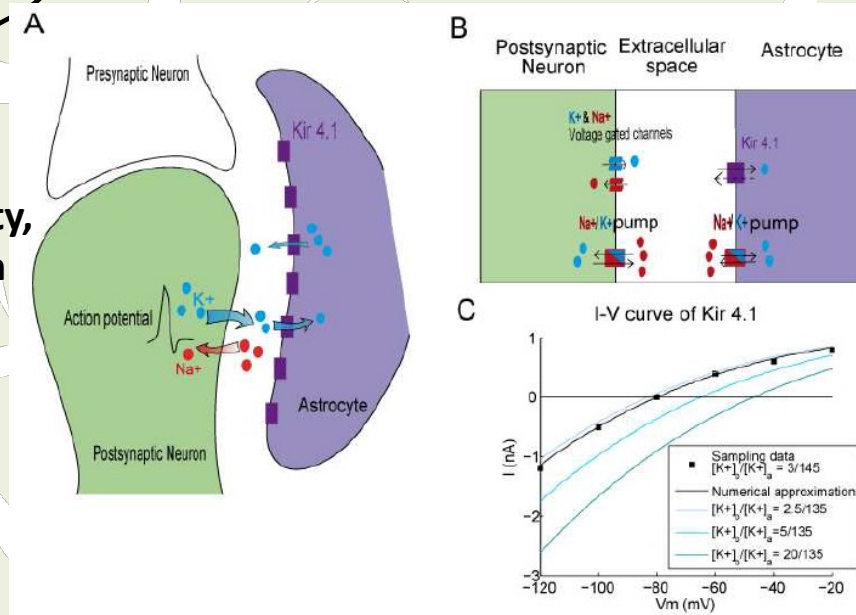
- Electrical excitability
- Neurotransmission



Classic concept:
Structural, metabolic and trophic support

New concept:
Calcium excitability, Gliotransmission

Astrocyte



Allen & Barres 2009, Nature

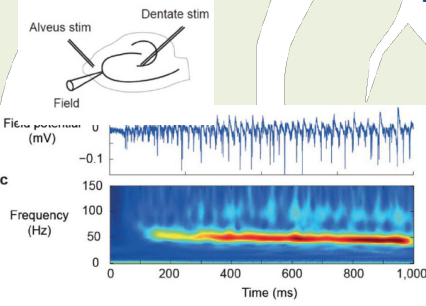
How does the neuron-glia interaction determine the brain functioning ?

Course 7: Modelling and analysis of neural circuit dynamics: emergent rhythms and their interplay

Boris Gutkin (*ENS, Paris*)

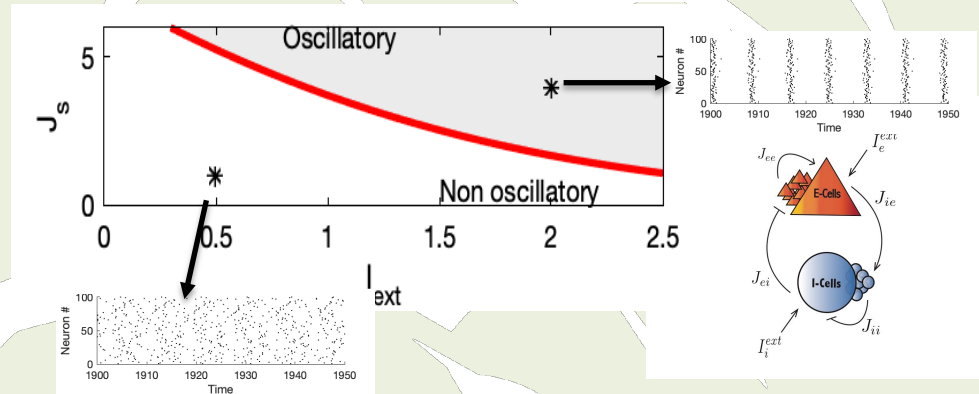
Oscillations are ubiquitous in the cortex

Gamma –oscillations in the hippocampal slice



Akam et al 2012

Oscillations arise through bifurcations



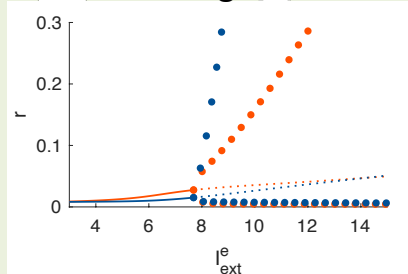
Theory can be developed using low-dimensional reduced models

$$\tau \frac{d}{dt} v(t) = \eta + v^2(t) + I(t)$$

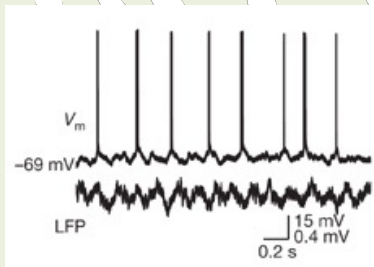
Mean field

$$\tau \frac{\partial}{\partial t} p(t, v | \eta) + \frac{\partial}{\partial v} \left[(\eta + v^2 + I(t)) p(t, v | \eta) \right] = 0$$

Gamma through subcritical Hopf



Rhythms arise from Spike synchronization

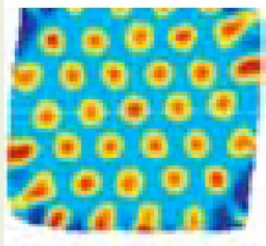
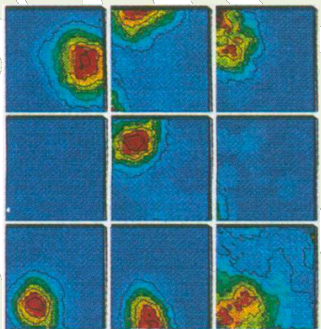
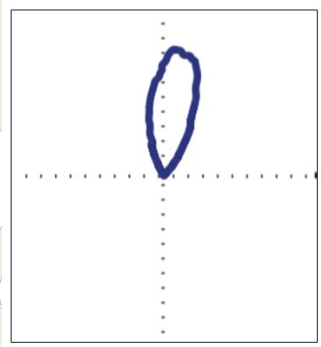


How do we model the dynamics and interaction of neural circuits and networks ? How do brain rhythms arise ?

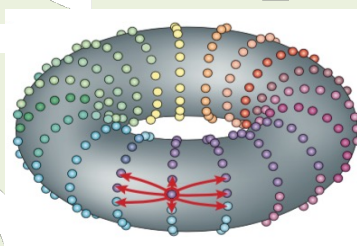
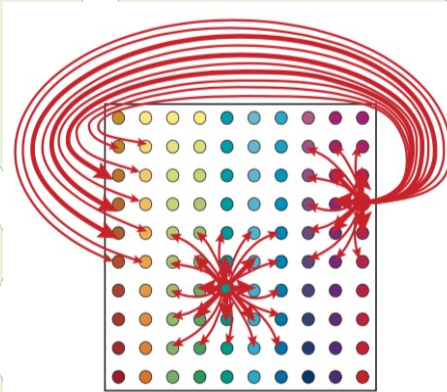
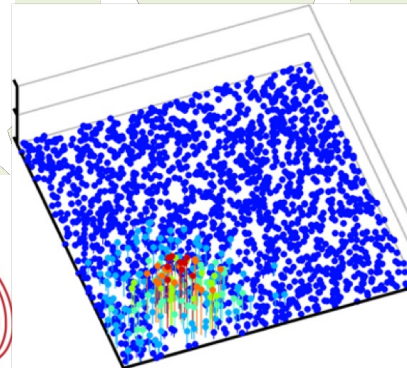
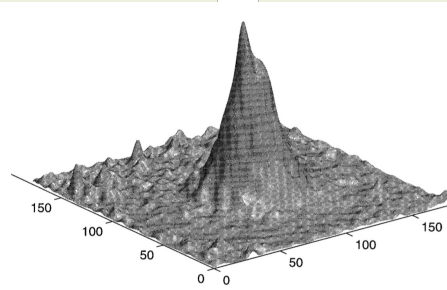
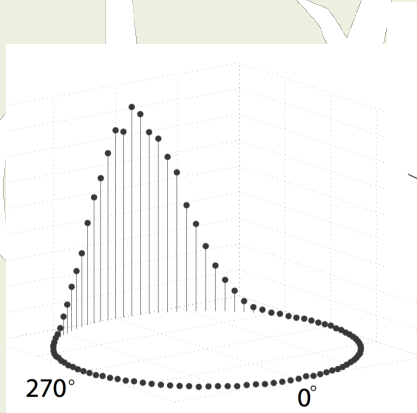
Course 8: Modeling spatial memory and navigation

Denis Sheynikhovich (Institut de la Vision)

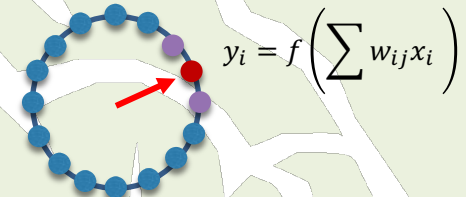
Neural activity



Computational models



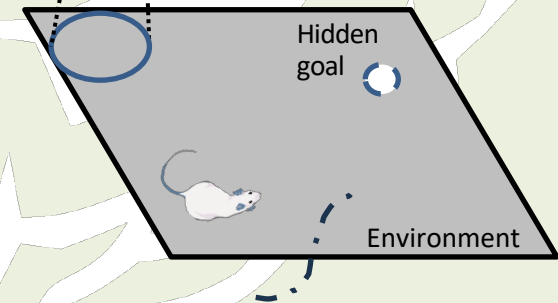
Behavior



$$y_i = f\left(\sum w_{ij}x_i\right)$$

w_{ij}

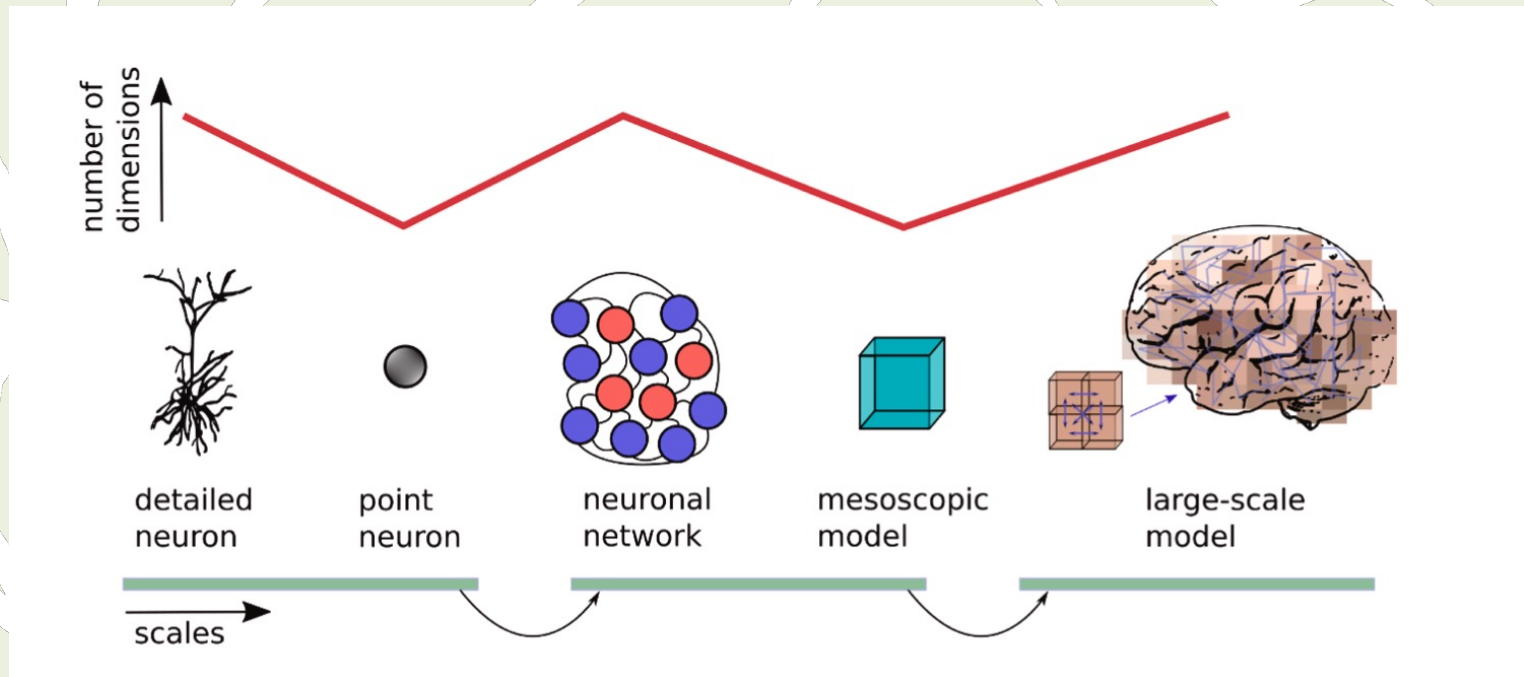
x_i



How do we orient in space ? What is the navigation network in the brain ? How to model to spatial memory and navigation ?

Course 9: Mesoscopic models: from neural circuits to large-scale activity, in normal and pathological states

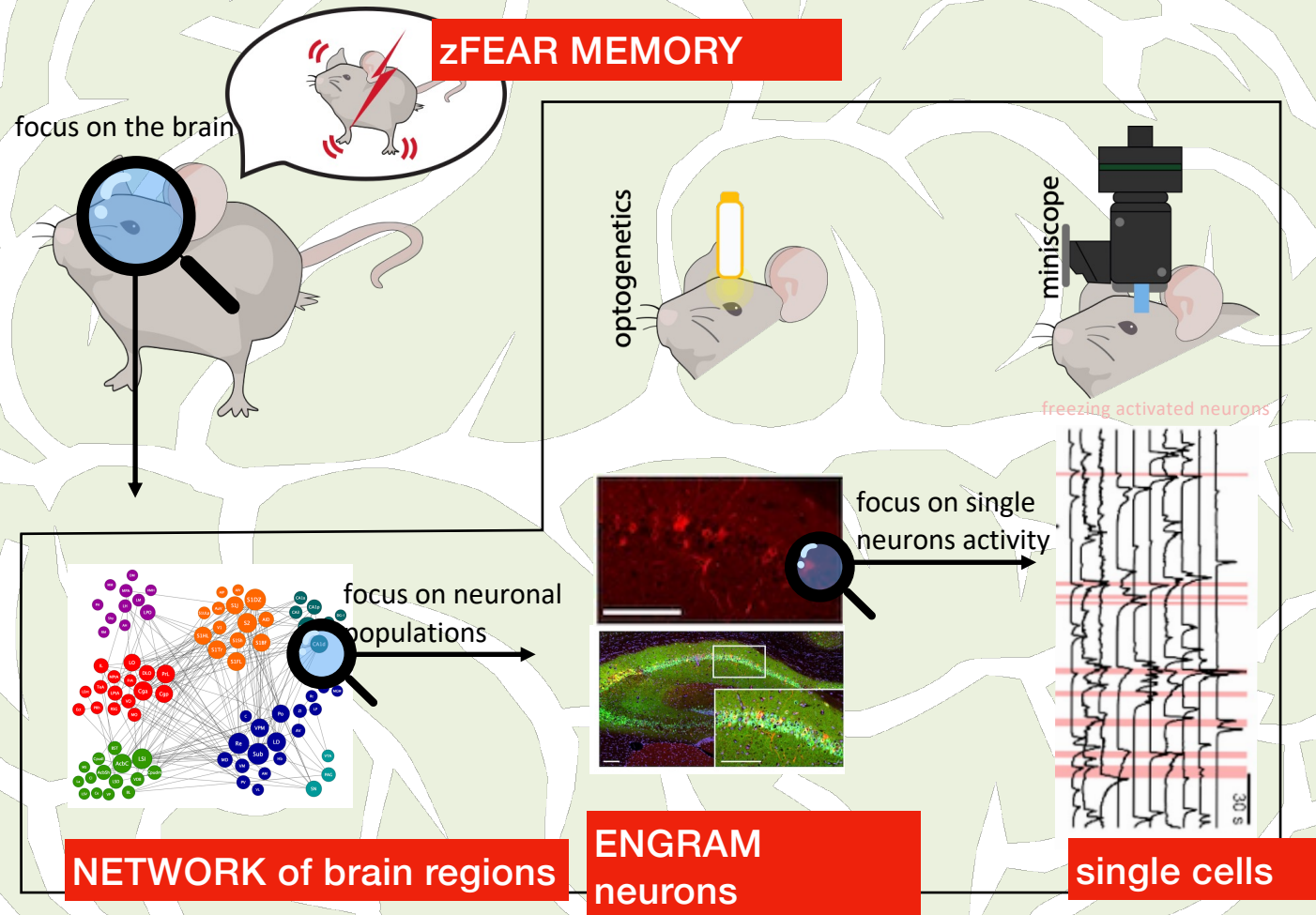
Alain Destexhe (*University Paris-Saclay*)



How do we model brain function from neuronal level to circuit level to whole-brain activity ? How to derive effective models at different scales ?

Course 10: Big Data analysis applied to behavioral neuroscience

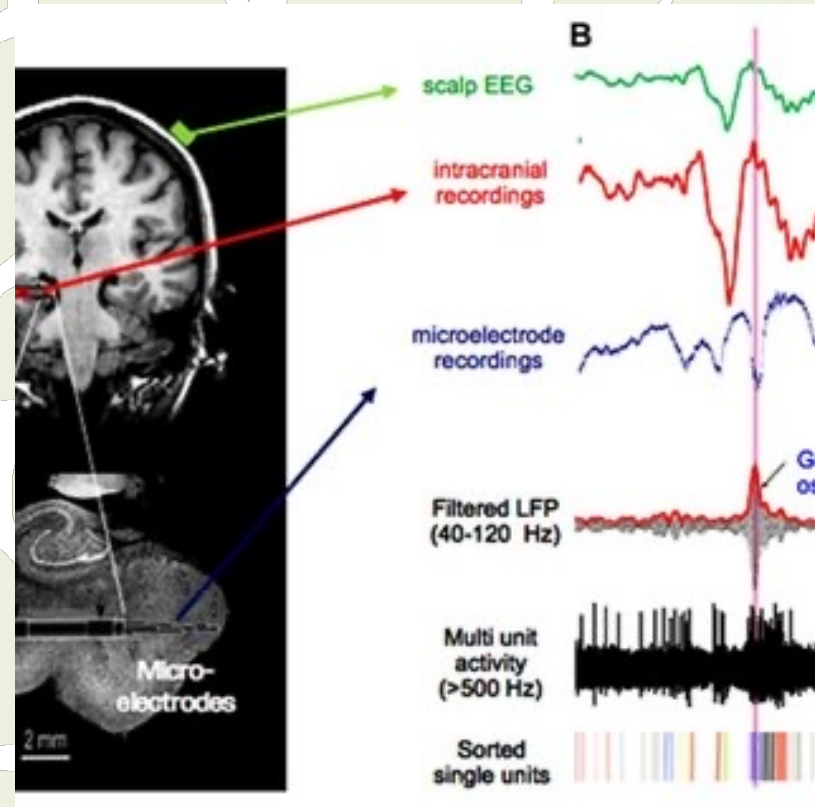
Gisella Vetere (*ESPCI*)



How do we analyze big data sets of neuronal response in behaving animals ?
What underlies the formation and consolidation of memories ?

Course 11: Analyse des signaux électrophysiologiques: des cycles lents aux oscillations rapides

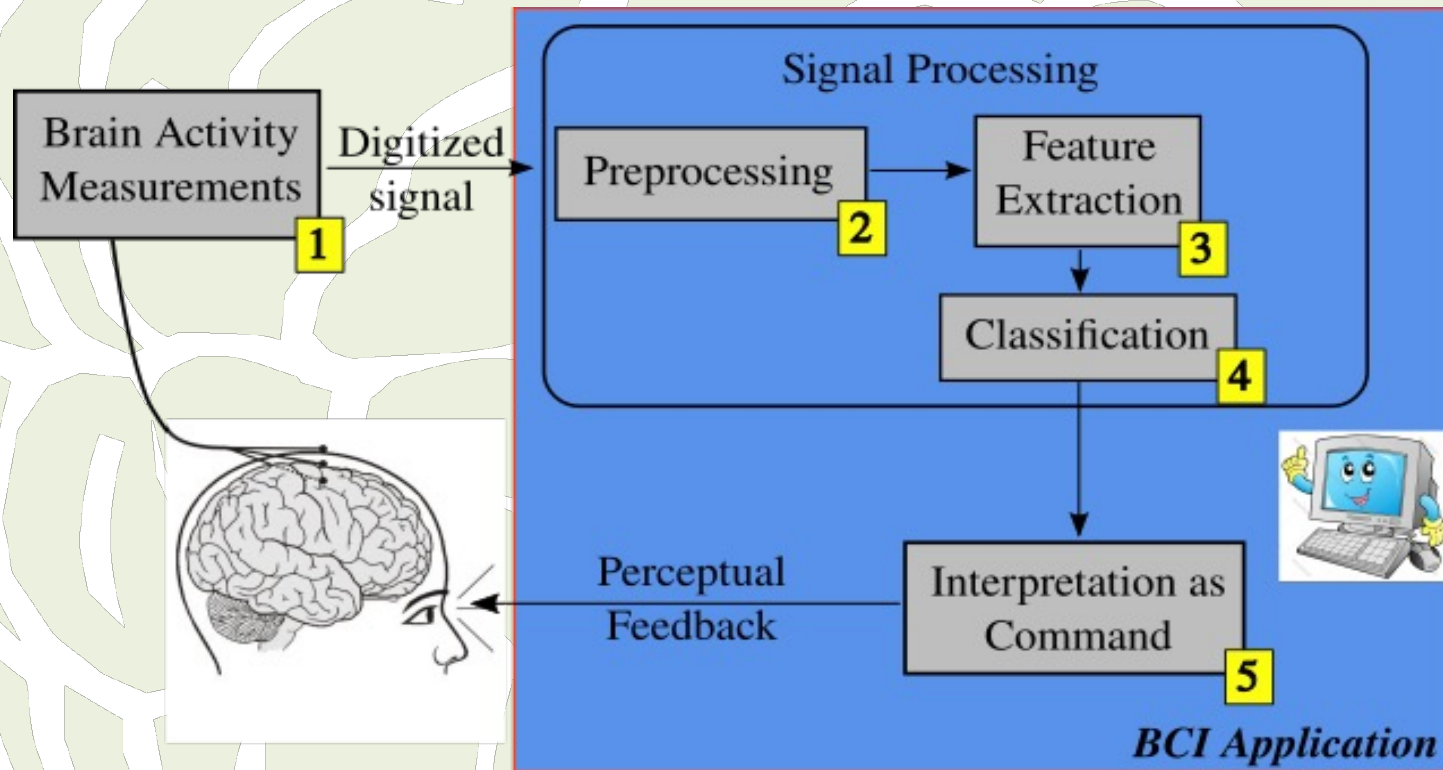
Michel Le Van Quyen, (*Sorbonne University*)



What can we learn about brain functioning by analyzing EEG signals ? How can we apply this to anaesthesia ?

Course 12: Signal processing and machine learning for Brain-Computer Interfaces

Theodore Papadopoulos (*INRIA, Nice*)



How can we use measured brain signals to create Brain-Computer interfaces (BCIs) ?