

Master 2

Computational Neuroscience and Neuroengineering (M2 CNN)

Facts & Figures

Degree: Master of Life Sciences and Health (MSc)

Duration: 1 year (60 EC), full time

Start month(s): september 2020

Language of instruction: English

Enrolled students: 30 students start the Master's programme per year

Classes hours: 15-20 hours per week

Master's legal tuition fee 2020-2021: *In 2019-2020, the total Tuition fees were 334 € per academic year for Master's studies for all students. Fees for academic year 2020-21 will be published early in 2020.*

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Master in Computational Neuroscience and Neuroengineering

One of the greatest challenges of modern science is to understand how the brain processes information in order to imitate its computing and learning capabilities (Artificial Intelligence, neuromorphic electronic circuits, machine learning,...) and to compensate the brain failures with computational and technological tools (Closed-Loop Neurosciences, Brain Computing Interface,...).

Thus, the Computational Neurosciences and Neuroengineering Master aims to train students to face problems raised by brain perception, processing and transmission of information. The training program is based on experimental, computational and theoretical approaches, combining neurosciences, physics, applied mathematics and computer sciences at different scales (cell, network, behaviour) and different organizational levels (micro, meso- and macroscopic scales).

Thanks to the reputation of the laboratories and research teams involved, the Master degree offers a very high level courses programme with a high international visibility.

Goals

The target of this Master program is to present the concepts, technological achievements, methodological approaches and research challenges in computational neurosciences and neuroengineering. It also aims to raise students' awareness of the theoretical, experimental, applicative, entrepreneurial and ethical themes of Neurosciences using the concepts of Physics and Engineering Sciences.

Students have access to an unique interdisciplinary training, enhancing their skills in research, analysis and scientific presentation and developing their ability to work as part of a multidisciplinary team.

Job opportunities

The CNN Master's degree trains future engineers, researchers and lecturers specialized in Computational Neuroscience and Neuroengineering with an interdisciplinary culture and approaches ranging from theory to experimentation by combining computational methodologies. Engineer jobs and Phd projects in academic, industrial laboratories, integration in R&D departments in France or abroad, represent the main opportunities.

Courses description

The CNN Master courses programme targets students with a range of backgrounds, including Life Sciences, Computing Science, Mathematics, Physics and Engineering. One part of the courses is focused on the theoretical approaches and the remainder is focused on a research project. Student will achieve the CNN Master with his own skills and interests.

During the first semester, lectures such as the physiological bases of neuroscience, the neural bases of perception, the techniques for measuring and stimulating neural activity, the processing and analysis of neural signals, the dynamical systems and computational neuroscience, will provide the necessary tools to understand the complex phenomena involved in processing and transmitting information in the brain. A supervised scientific project will complete the students' training during the semester one.

Semester two begins with an research internship of three to six months. This internship gives students real research experiences in computational neurosciences and neuroengineering. They will have the opportunity to work closely with a

leading research team in the academic laboratories and opportunities will be created to work on industry lead projects. They will benefit from the supervision of experienced researchers. The project can be carried out with a research group at University Paris-Saclay, with an industrial partner or with a research institut in France or worldwide.

S1 - Semester 1

Courses	EC*	Hours
Physiological bases of neuroscience	3	25
Neural bases of perception	3	25
Dynamical systems and computational neuroscience	3	25
Closed-loop neuroscience	3	25
Techniques for measuring and stimulating neural activity	3	25
Machine learning	3	25
Supervised project	12	50

S2 - Semester 2

	EC	CM	TD	TP
Internship	30	-	-	-

*EC: European Credits

Research environment

The Research institute involved in the Computational Neurosciences and Neuroengineering Master is the Paris-Saclay Institute of Neurosciences (NeuroPSI), a fundamental research institute in Neurosciences focused on the multi-scale approaches of the nervous system, from molecule to cognition and from embryo to adult. It is a Joint Research Unit of the CNRS and the University of Paris-Sud (UMR 9197). Together with NeuroSpin, which is entirely focused on the brain imaging and the study of cognitive processes, it forms the NeuroSaclay organization, which is the Neuroscience component of the Université Paris-Saclay. Students benefit from the emulation, intellectual stimulation, and various experimental and technological platforms of the NeuroPSI Institute and NeuroSpin.

Two departments in particular of NeuroPSI will be involved in the training of students:

- The Cognitive Neurosciences Department, whose purpose is to understand the neural bases of cognitive functions such as perception, communication, decision-making, learning and memory, but also to identify the mechanisms involved in pathologies or alterations in these functions.
- The Department of Integrative & Computational Neurosciences (ICN), whose purpose is to study the brain at multiple scales to identify the computational principles and thalamocortico-cortical neurophysiological mechanisms that govern the emergence of higher brain functions, such as perception and learning. The ICN is also in charge of two international antennas, the French node of the International Coordination Facilities in Neuroinformatics (INCF) and the European Institute for Theoretical Neuroscience (EITN). The ICN is an active participant in the Human Brain Project. It is a major European scientific project that aims to better understand the brain and its pathologies by about 2024, using information science technics (computational neuroscience, neuroinformatics, neuromorphic computation, neuro-robotics, etc.).

CentraleSupélec, one of France's most prestigious engineering schools, as well as its research laboratories, in particular the Signals and Systems Laboratory (UMR8506), which brings together researchers of excellence in signal processing, statistics, machine learning and dynamical systems, is actively involved in the Master. The influence of the lecturers involved in the Master benefits the national and international visibility. The network of foreign collaborators also provides unique opportunities for M2 students in terms of international exchanges and internships abroad.

Admission requirements

Firstly, the application to the M2 CNN will be made through the submission of an application form on the website of the University of Paris-Saclay.

The applicant is requested to attach to the application form all mandatory supporting documents. He may also complete his application with additional documents that he wishes to bring to the attention of the M2 CNN admission committee.

In a second step, an interview will be proposed to the candidates according to the decision of the admission committee.

The admission to the M2 program concerns candidates with a very good academic record and a strong motivation for the Master CNN program.

Deadline for application

Applicants must submit a complete application form between 1st March and 31st August.

[Click here for details on the application process](#)

Mandatory supporting documents

- A Curriculum Vitae.
- A letter of application to the M2 CNN training.
- All transcripts of validated years/semesters until the date of application.
- Reference letters.

Scholarship application :

Master student can apply to the scholarship provided by the Université Paris-Saclay.

<https://www.universite-paris-saclay.fr/en/programme-de-bourses-internationales-de-master>

Potential laboratories for the internship :

Institut de Neurosciences Paris-Saclay (NeuroPSI), Université Paris-Saclay

Centre de recherches NeuroSpin du CEA

Laboratoire des Signaux et Systèmes de CentraleSupélec, Université Paris-Saclay

INRIA Sophia-Antipolis

Centre de Recherche Cerveau & Cognition, Université de Toulouse 3

Laboratoire Plasticité du Cerveau, ESPCI

Institut des Sciences Cognitives Marc Jeannerod, Université de Lyon 1

Institut de Neurobiologie de la Méditerranée, Université d'Aix-Marseille

Institut des Neurosciences de la Timone, Université d'Aix-Marseille

Laboratoire de Neurosciences Cognitives Computationnelles, ENS

Institut de la Vision, Université Pierre et Marie Curie

Laboratoire de Physique Statistique, ENS

Laboratoire des Systèmes Perceptifs, ENS

Institut du Cerveau et de la Moelle épinière, Université Pierre et Marie Curie

Centre Interdisciplinaire de Recherche en Biologie, Collège de France

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Contact

Do you have any questions about the Master CNN?

Please contact the Master's coordinator :

Professor Sabir Jacquir

Email : sabir.jacquir@u-psud.fr

Master 2

CNN: Computational Neuroscience and Neuro-Engineering

Description of teaching units

UE 1 : Physiological bases of neurosciences (CM : 19h, TD : 6h)

Coordinator : Sabir Jacquir

1) Goals

This course will focus on the study of the brain, its functions and its adaptability (brain plasticity) to the environment. The latest knowledge on the molecular and physiological basis of synapse and neuron function will be presented. At a more macroscopic level, the anatomy and structure of the brain will be addressed. The neural processes responsible for processing sensory information and perception, as well as their short- and long-term regulation through interaction with the environment, will be described.

2) Course program

● Chapter 1 : Issues and questions in neuroscience

In this chapter, the current challenges and issues in neuroscience will be presented.

● Chapter 2 : Development of the nervous system

This chapter will present the development of the nervous system from fertilization to brain formation, neurogenesis, axonal guidance, synaptogenesis and maturation of neural networks. It is about understanding the generation of large regions of the brain and the different brain functions associated with them.

● Chapter 3 : Nervous system organization: from neuron to network, transmission of the nervous signal

This chapter will present the general organization and cellular components of the nervous system. Excitation and inhibition circuits as well as the structure of neural networks are introduced and studied. It describes the elementary principles involved in the generation of an action potential and communication between neurons (soma, axon, dendrite, synapse, ion channels, rest potential).

● Chapter 4 : Synaptic transmission

This chapter presents the bases of synaptic transmission and homeostatic regulatory mechanisms. It describes the physical and biological principles underlying these behaviours.

● Chapter 5 : Synaptic plasticity, functional plasticity

This chapter will be devoted to the plasticity and the learning of the perceptual-motor function.

3) Skills acquired

At the end of this course, the student will be able to:

- Understand neural communication processes at the physiological level.
- Have a global vision of the complexity of the nervous system and the interactions between the different components of the brain.
- Be able to identify the neural processes responsible for processing sensory and motor information.

4) Teaching team

- Christophe Bernard (INSERM, Institut de Neurosciences des Systèmes)
- Daniel E. Shulz (CNRS, NeuroPSI)

UE 2 : Neural bases of perception (CM : 25h)

Coordinator : Jean-Marc Edeline

1) Goals

This course will present the neural bases of perception in the auditory, vision, somatosensory and olfactory modality. It will give a focus on the neural plasticity that constantly operates and biases our perception.

2) Course program

- Chapter 1 : Anatomy and Physiology of the auditory system
- Chapter 2 : Functional properties of visual cortex neurons assessed by electrophysiology and in vivo imaging
- Chapter 3 : Visual system modeling
- Chapitre 4 : Fonctionnal organization in the somatosensory system
- Chapter 5 : Olfactory system
- Chapter 6 : Neuronal coding of communication sounds in song birds
- Chapter 7 : Multisensory Interactions (B Bathellier, CM 3h)

3) Skills acquired

At the end of this course, the student will be able to:

- Understanding the anatomy and physiology of the main sensory systems.
- Understanding the neural bases of the sensory code.
- Understanding the main techniques and methodologies to study the sensory systems.

4) Teaching team

- Brice Bathellier (CNRS, Institut de l'audition)
- Cathérine Del Negro (Univ ParisX, NeuroPSI)
- Jean-Marc Edeline (CNRS, NeuroPSI)
- Frédéric Chavane (CNRS, INT Marseille)
- Luc Esténabez (CNRS, NeuroPSI)
- Sabir Jacquir (Univ Paris-Saclay, NeuroPSI)
- Marc Pananceau (Univ Paris-Saclay, NeuroPSI)

UE 3 : Dynamical systems and computational neuroscience (CM : 17h, TD-TP : 8h)

Coordinator : Antoine Chaillet

1) Goals

This course constitutes an introduction to tools for the analysis of dynamical processes involved in brain functioning. Despite their huge complexity, brain functions are indeed based on elementary dynamics, some of which can be apprehended by a mathematical approach. Mastering these techniques is fundamental to progress in our understanding of brain functioning, to optimize instrumentation for brain activity measurements (brain imaging, electrophysiological recordings...), to improve brain machine interfaces, to build up neuro-inspired computational units, and to understand the mechanisms involved in some brain diseases and thus improve their treatment.

2) Course program

- Chapter 1 : Mathematical models of neurons

This chapter presents well-known neuron models. It introduces conductance-based models through the famous Hodgkin-Huxley model and underlines its electronic analogy. It then presents simplified models, such as integrate & fire or FitzHug-Nagumo models, as well as simple models of synapses and neuronal plasticity. Numerical simulation of these models is also introduced.

- Chapter 2 : Analysis of neuron models

This chapter present mathematical tools to study neuronal behavior. It introduces the notion of phase diagram and

bifurcation. These notions are first given for one-dimensional systems, and then for planar systems. The chapter establishes a link between these bifurcations and the qualitative behavior of the neuron. It also shows how to simplify a neuron model based on singular perturbation theory. It finally introduces the notion of “phase response curve”, which helps simplifying complex oscillatory behaviors to the mere time evolution of its phase, and shows how to use this technique in practice for the prediction of neuronal synchronization.

- Chapter 3 : Biophysical neuron model

This chapter presents a realistic neuron model based on dendritic modeling.

- Chapter 4 : Neuronal populations “Mean field model”

This chapter addresses the dynamics of a whole population of neurons or a cerebral structure. It presents simplified models of the activity of a population based on a mean field theory.

- Chapter 5 : Neuronal populations “Neural field model”

This chapter addresses the dynamics of a whole population of neurons or a cerebral structure. It presents simplified models of the activity of a population, such as the Wilson-Cowan model or neural fields. It shows how to predict the behavior of such models by stability or bifurcation analysis. It also provides tools to identify such models based on experimental data.

- Chapter 6 : Synapse modeling and plasticity

This chapter focuses on synaptic modeling and the exploration of synaptic plasticity.

- Chapter 7 : Neuromorphic computing

This chapter focuses on computing units and processors inspired by the processing of information by the brain.

3) Skills acquired

By the end of this course, students will be able to:

- Understand neuroscience fundamentals, for possible interaction with professionals of the field (neurosurgeons, computational neuroscientists, experimenters).
- Model the activity of a neuron or a whole neuronal population.
- Predict their behavior both analytically and numerically.

4) Teaching team

- Antoine Chaillet (CentraleSupélec, Laboratoire Signaux Systèmes)
- Andrew Davidson (CNRS, NeuroPSI)
- Alain Destexhe (CNRS, NeuroPSI)
- Sabir Jacquir (Univ Paris-Saclay, NeuroPSI)

UE 4 : Closed-loop neuroscience (CM : 25h)

Coordinator : Valérie Ego-Stengel

1) Goals

This course addresses the specific problems of the closed loop in neuroscience. Such loops arise from the bidirectional interaction between a biological system and a technological device. In the case of brain-machine interfaces, for example, it exists an interaction between a brain structure and a computer or robot. This course presents various techniques for influencing neural activity in real time, such as electrical, magnetic or optogenetic stimulation. It then focuses on brain-machine interface techniques by interpreting user intentions from EEG signals, as well as more recent techniques exploiting brain plasticity.

Finally, neuro-robotics techniques are described, focusing in particular on neuro-inspired robotics (in which the robot is programmed based on knowledge of brain function) and on robotic prostheses or orthoses.

2) Course program

- Chapter 1: Closed-loop Neuroscience and Brain Machine Interfaces

Description of the different types of brain-machine interfaces, the different components (recording, stimulation, algorithms...).

Sensory neuroprostheses (and sensory substitution), EEG-based interfaces, invasive interfaces, Neurofeedback.

Brain plasticity underlying learning.

- Chapter 2: Closed-loop neuroscience

Dynamic clamp, application to the manipulation of oscillatory rhythms of sleep and epilepsy.

- Chapter 3: Retinal neuroprosthesis for vision restoration
- Chapter 4: BCI Handling of attention in non-human primates by ICM

Decoding the focal point of attention in monkeys in the prefrontal cortex.

- Chapter 5: Learning and memory in the rodent space navigation system
- Chapter 6: Brain-Computer Interfaces

EEG-based interfaces in humans. Medical applications.

- Chapter 7: Real and neuro-inspired learning

Courses on different types of learning (with reinforcement, supervised, unsupervised...) in animals and in neural networks (deep learning...)+ demo of the learning robot.

- Chapter 8: Neurorobotic

Closed-loop retinal stimulation to understand neuronal coding.

3) Skills acquired

- To know the techniques for artificially influencing neural activity for therapeutic or experimental purposes.
- To know the components of a brain-machine interface device.
- To know the techniques of neuro-inspired robotics.

4) Teaching team

- Valerie Ego-Stengel (CNRS, NeuroPSI)
- Thierry Bal/Alain Destexhe (CNRS, NeuroPSI)
- Olivier Marre (Institut de la Vision)
- Suliann Ben Hamed (CNRS, Institut Jeannerod, Lyon)
- Karim Benchenane (ESPCI, CNRS)
- Fabrizio de Vico Fallani (ICM)
- Thomas Deneux (CNRS, NeuroPSI)
- Mehdi Khamassi (ISIR, UPMC)

UE 5: Methods for measuring and stimulating neuronal activity (CM : 25h)

Coordinator : Isabelle Férézou

1) Goals

The aim of this EU is to present methods for exploring neuronal activity (electrical, metabolic) as a means to access the organization and functioning of the brain. It will cover the principles and main applications of cellular (unit or multiple activity) and network (EEG, ECoG, LFP) electrophysiological approaches as well as invasive (calcium or potential-sensitive imaging in conventional or multi-photon microscopy) and non-invasive (PET, fMRI, MEG) brain imaging approaches. Methods to stimulate neural activity at different spatial and temporal scales will also be presented. We will see how these methods make it possible to establish causal links between patterns of neural activity and cognitive functions.

2) Course program

- Chapter 1: Introduction to the different scales of neural activity reading, what are the main issues and challenges to be addressed?

This introductory chapter provides an overview of the challenges faced in the recording of neural activity. Nowadays, the diversity of experimental approaches available in Neuroscience allows us to read neural dynamics at different spatial and temporal scales. Before going deeper into the principles of the different methodologies, this course aims to highlight the complementarity of these approaches, their respective interests, and the challenges that remain to be overcome to better understand the neural bases of behavior.

- Chapter 2: Non-invasive neural recording methods used in humans

In this chapter, we will present the principles and applications of the main methods commonly used in humans (EEG, MEG, MRI, PET, TMS) to study the neural correlates of cognitive activity.

- Chapter 3: In vitro electrophysiology

This chapter presents the main electrophysiological recording methods applied to in vitro preparations for synaptic and cellular recording of neuronal activity (neuronal membrane potential, patch clamp and its different configurations).

- Chapter 4: In vivo electrophysiology

This chapter is dedicated to the presentation of electrophysiological recording techniques performed in vivo, which can range from single-cell membrane potential (intracellular recording, blind or targeted patch-clamp), or action potentials recording (juxta, extra, tetrodes, Utah arrays, NeuroPixels) to more global recording methods (field potential, ECoG).

- Chapter 5: Optical recording of the membrane potential

This chapter will cover optical methods for real-time visualization of membrane potential variations using voltage-sensitive probes, either at the scale of the single neuron in vitro, or at the scale of the neural network in vivo, in anesthetized or behaving animals.

- Chapter 6: Optical recording of intracellular calcium concentration changes

This chapter will present optical methods to visualize variations in intracellular calcium concentration that are correlated with the emission of action potentials by neurons. Among these, the most commonly used method, biphotonic calcium imaging, will be more particularly detailed, as well as mono and triphotonic imaging and their respective uses in vivo, in anesthetized or behaving animals.

- Chapter 7: Targeted neural stimulation methods

In this chapter, we will present the tools available nowadays to Neuroscientists (electrical microstimulation, transcranial magnetic stimulation, optogenetics) to stimulate neuronal activity and thus establish correlates between activation of specific neuronal populations at different scales and behavior.

3) Skills acquired

At the end of this course, students will be able to:

- have a comprehensive overview of the technological arsenal available nowadays to neuroscientists.
- Assess the relevance of using one method over another based on the scientific questions addressed.
- Identify the limitations of the different methods for a well-versed interpretation of the experimental results described in the literature of the field.

4) Teaching team

- Thierry Bal (CNRS, NeuroPSI)
- Laurent Boudieu (CNRS, IBENS)
- Glenn Dallerac (CNRS, NeuroPSI)
- Isabelle Ferezou (CNRS, NeuroPSI)
- Nicolas Giret (CNRS, NeuroPSI)
- Florent Haiss (Institut Pasteur)
- Sabir Jacquir (Univ Paris-Saclay, NeuroPSI)
- Gilles Ouanounou (CNRS, NeuroPSI)
- Marc Pananceau (Univ Paris-Saclay, NeuroPSI)

- German Sumbre (CNRS, IBENS)
- Bertrand Thirion (INRIA, NeuroSPIN)
- Virginie Van Wassenhove (INSERM, NeuroSPIN)

UE 6 : Machine learning (CM : 17h, TD-TP : 8h)

Coordinator : Arthur Tenenhaus

1) Goals

Neuroscience is a field where very large data are generated ("Big Data", several tens of GB per session in fMRI, EEG, high temporal and spatial resolution optical recordings, or multi-electrode electrophysiology). The analysis of these data requires very specific analytical methods, which are themselves the subject of advanced research. This course presents an overview of machine learning methods as well as examples of the application of the different approaches developed.

2) Course program

Chapter 1: Regression and classification (Ridge Regression, Generalized Linear Model -including logistic regression, Support Vector Machines). Extensions to core methods.

Chapter 2: Generalized Linear Model and Selection of Variables (Sparsity Constraints).

Chapter 3: Aggregation methods (Boosting, Random Forrest)

Chapter 4: Statistical tools for the analysis of large data.

Chapter 5: Model of mixtures

Chapter 6: Dimension reduction (Analysis in Principal Components).

Chapter 7: K-means / Hierarchical clustering.

3) Skills acquired

At the end of this course, students will be able to define, understand and choose a machine learning method and to implement it in line with the specific problem.

4) Teaching team

- Arthur Tenenhaus (CentraleSupélec)
- Thomas Deneux (CNRS, NeuroPSI)
- Sabir Jacquir (Univ Paris-Saclay, NeuroPSI)

UE 7 : Supervised scientific project

Responsable : Sabir Jacquir

Goal

A supervised scientific project will complete the students' training during the semester one. This project is focused on a scientific issue including a bibliographic and/or experimental and/or simulation works.

UE 8 : Internship

Responsable : Sabir Jacquir

Goal

Semester two begins with an research internship of three to six months. This internship gives students real research experiences in computational neurosciences and neuroengineering. They will have the opportunity to work closely with a leading research team in the academic laboratories and opportunities will be created to work on industry lead projects. They will benefit from the supervision of experienced researchers. The project can be carried out with a research group at University Paris-Saclay, with an industrial partner or with a research institut in France or worldwide.