A.Y. 2023/2024
TEACHING OFFER

The teaching offer of Basic course, Soft Skills and Advanced Courses and the format of Journal Club are described as follows.

BASIC COURSES (in person)

PhD students are required to choose minimum 2 out of three macro topics, OR SPECIFIC COURSES across the three macro topics (for minimum 70 hours). Course choices are binding. The Basic Courses will be held in person (minimum: 70% of attendance) and only PhD students who are abroad can attend the courses online.

TOPIC 1: STATISTICS (38 hours)

I module: Dr. Angela Andreella; 8 hours (1st year)
The first module will cover three main topics:

1. **Introduction to the programming language R and notebooks**, i.e., a solution for having reproducible results: basic R commands and basics of R markdown (optional)
2. **Exploratory Data Analysis** (EDA), i.e., how to start with data analysis. It can be roughly summarized in 3 parts: (a) Structure and summary of data (type of variables, location indices); (b) Exploratory plots (histograms, box-plots, correlograms, scatterplots..); (c) Preprocessing step (transformation of variables, dealing with missing values, outliers). This part will be developed from a theoretical and practical (using R) point of view with simulated data and real data applications.
3. **Introduction to Statistical Inference**, i.e., how to start to make conclusions about research questions. It introduces the concept of (a) Point estimator, (b) Confidence interval, and (c) Hypothesis Testing, using practical examples in R.

Final evaluation: TBA

II module: Dr. Anna Vesely; 8 hours (1st year)
The second module will cover two main topics:

1. Before modeling, i.e. how to plan a good experimental design: main concepts, the difference between randomized experiments and observational studies, type of randomization, the concept of replication, and why “correlation does not imply causation”.
2. Modeling: Linear regression, the concept of contrasts, the interaction between variables,

analysis of confounders, how to deal with nested variation, and how to apply these elements from a theoretical and practical (using R) point of view with real data applications.

Final evaluation: None.

III module: Graph theory and null models, Prof. Samir Suweis; 6 hours (1st year)

This course covers some basic concepts of graph theory including connectivity, centralities, assortativity and clustering. Applications on some real networks are also shown. The second part of the course introduces some more advanced topics, such as the use of random graphs (Erdos-Reny, Small-World and Barabasi) as null models, to actually infer biological information from data on brain networks. Upon completion of the course, students will be able to: (1) Calculate the main structural properties of graphs (2) understand the fundamental properties of some families of random graphs; (3) Use random graphs as null models to test different properties of real networks.

Final evaluation: TBA

IV module: Repeated Measures and Generalized Linear Mixed Models, Prof. Livio Finos; 8 hours (2nd year)

- Parametric Linear models for repeated measures
- Linear Mixed Models and its generalization
- Data visualization
- Practice with R software

Final evaluation: Brief homework assigned after each class.

V module: Permutation tests and Selective Inference, Prof. Livio Finos; 8 hours (2nd year)

- Introduction to Permutation methods, the univariate and the multivariate tests
- Introduction to Selective Inference and Multiple Testing: a review of the Errors (Familywise Error Rate, False Discovery Rate and True Discovery Proportions) and of the most common methods in Neurosciences.

Final evaluation: Brief homework assigned after each class.

TOPIC 2: NEUROIMAGING TECHNIQUES (34 hours)

Basic course on programming in Python, Prof. Emanuele Di Buccio; 8 hours

- What is Python?
- Environment Setup

- Python Basics
- Functions
- Control statements and Loops
- Lists, Tuples, Sets and Dictionaries
- Libraries for Data Science
- How to get data from APIs

Final evaluation: TBA

Analysis of EEG signal (theory and hands-on), Prof. Camillo Porcaro; 12 hours

The course will provide the basic skills to collect and analyze electroencephalographic (EEG) signals. Practical sessions will allow students to gain experience with EEG recording. If access to the laboratory is limited, the EEG recording will be addressed by showing ad hoc video tutorials. The course will also underline step-by-step EEG pre-processing for data at rest and during event-related potential (ERP) analysis. The analysis will be conducted using EEGLAB software or other open-access software based on the student's specific needs. All lessons will include theoretical and practical sessions to allow the students to familiarize themselves with the software. Direct interactions will be encouraged during the lessons.

Final evaluation: Use the Toolbox EEGLAB on real data of the topics covered.

Analysis of fMRI and PET signals (theory and hands-on), Prof. Alessandra Bertoldo and Dr. Lorenzo Pini; 14 hours

- Introduction (structural/functional sequences)
- Atlases
- Pre-processing of resting state fMRI data: coregistration, segmentation, regression, filtering
- Despiking and censoring
- Functional connectivity (FC)
- Graph measures (principals)
- Dynamic FC: sliding windows, coactivation patterns
- Introduction to effective connectivity
- Static PET: PET tracer, partial volume, reference region, early phase, late phase
- Dynamic PET: experimental setup
- Multimodal integration: PET versus resting state fMRI

Final evaluation: Yes.

TOPIC 3: NEUROANATOMY, NEUROPHYSIOLOGY & NEUROPSYCHOLOGY (42 hours)

Neuroanatomy, Prof. Renzo Manara; 12 hours

The present Neuroimaging Course deals with the recognition of the main anatomical brain landmarks (sulci, gyri, nuclei and neural structures including cranial nerves). In addition, main intracranial vessels (arteries and venous sinuses), the anatomy of the temporal bone (inner ear, ossicle chain, VII and VIII cranial nerves) and the spine anatomy (spinal cord, nerve roots and bone structures) will be shown in routine MRI and CT exams.

Final evaluation: TBA

Neurophysiology (theory and laboratory), Prof. Aram Megighian; 10 hours (6 + 4)

Visuomotor responses; navigation; basal ganglia.

Final evaluation: TBA

Psychophysiology, Prof. Chiara Spironelli and Prof. Simone Messerotti Benvenuti; 6 hours

The Psychophysiology course provides a brief review of the main psychophysiological models along with the basic techniques and methods used in this field during a psychophysiological assessment. The association between body and mind is scientifically analyzed not only by introducing the characteristics of every approach, but also with a practical/supervised training session.

1. First module (3 hours) – Prof. Spironelli: (1) The key concepts of the psychophysiological approach; dependent and independent variables. (2) Electroencephalography (EEG), electromyography (EMG) and eye movement/blinks: basic information and practical/supervised training on EEG.
2. Second module (3 hours) – Prof. Messerotti Benvenuti: Emotion, attention and the startle reflex. Autonomic psychophysiology: models and basic techniques, including examples of clinical applications and practical activity.

Final evaluation: None.

Cognitive Science and Neuropsychology, Dr. Andrea Zangrossi; 12 hours

The Cognitive Science and Neuropsychology course will give a theoretical and practical introduction to the brain-behavior link. We will focus on a selection of cognitive functions (e.g., memory, attention and visuospatial functions, executive functions) and related deficits, quantitative assessment (i.e., tests) and neural correlates.

Final evaluation: None.

Lab in Neuroanatomy, Prof. Raffaele De Caro and Dr. Aron Emmi; 2 hours

The Neuroanatomy Lab will consist in a practical session focusing on brain cutting and dissection. The aim of the laboratory is to allow PhD students to evaluate neuroanatomical structures first-hand by employing human specimens deriving from the body donation program of the University of Padua. A personal lab coat is recommended.

Final evaluation: TBA

SOFT SKILLS (mandatory for all)

Presentation skills and public outreach, Prof. Giorgia Cona; 4 hours

This course illustrates the basic guidelines to make an effective talk and includes practical exercises. In the first part of the course, theoretical lessons will deal with: (a) how to prepare slides; (b) communicative aspects; (c) emotional aspects; (d) content of the talk. In the second part of the course PhD students will be challenged with theatrical and public speaking exercises.

Final evaluation: TBA

Academic writing: How to write a scientific paper, Prof. Judit Gervain; 4 hours (1st semester of the 2nd year)

This course is a hands-on, practical course introducing students to the basic principles of writing academic texts in English. Students will be familiarized with basic guidelines and best practices, will carry out exercises and small assignments and will then be working on an individual writing project for which they will get personalized feedback.

- 1h: How to write an efficient sentence
- 1h: How to write an efficient paragraph
- 1h: How to write an efficient text
- 1h: Project discussion and individual feedback

Final evaluation: written assignment.

Publication matters: a practical workshop, Dr. Elena Becker Barroso; 1 hour

The workshop will be divided into three parts: intro and questions (about 20 minutes) + hands-on workshop (about 45 minutes) + summary of take-home lessons (about 15 minutes).
Given the hands-on session, please bring your laptop with you.

Final evaluation: None.

Grantsmanship: how to write a grant, Prof. Antonio Vallesi; 6 hours (January or February semester of 2nd year and also for PhD students in their 3rd year)

Writing a successful grant application is an ability that needs being trained to fully flourish. While the primary focus of the evaluation process is on the scientific content, feasibility, impact and methodological soundness, the way you present your proposal and your adherence to the specific requirements of the funding agency are also critical factors that can help determining the fate of your application. In this 4-hour interactive course, I will provide some guidelines and practical examples on how to manage grant applications from the generation of the idea to the submission of the final proposal and even further.

Final evaluation: Active participation to the classroom exercises and performance on the assigned work will be considered to pass.

The way we were, the way we will be. Open Science: monitoring a change of scientific paradigm, Prof. Massimo Grassi; 2 hours

This course will give a brief overview of how the scientific paradigm is changing in recent years. We will start from the replication crisis, which has affected empirical sciences in the recent past, to the proposals of the Open Science movement, to limit the main reasons of such a crisis.

Final evaluation: None.

ADVANCED COURSES (in person)

PhD students are required to choose the modules that they find more useful and interesting for their research training to complete the required number of hours (minimum: 16 hours). PhD students are also allowed to choose courses from other Institutions or curricula (the classification in curricula is only meant to better cluster methodological skills and knowledge), as they are strongly encouraged to broaden their horizon to the different aspects of Neurosciences.

1. PROGRAMMING AND COMPUTATIONAL NEUROSCIENCE

Dimensionality reduction and controllability of neural systems, Dr. Michele Allegra and Prof. Samir Suweis; 12 hours

An outstanding problem in contemporary neuroscience is understanding how to intervene on the brain to control its global activity – chiefly, with the aim of restoring a normal activity balance in subject affected by brain pathologies. From the microscopic scale of a few neurons to the macroscopic one of large brain areas, control requires understanding how to collectively modulate the behavior of several neural units at the same time. As these units are not independent, it is convenient to apply suitable dimensionality reduction schemes to achieve a low-dimensional representation of the system in terms of a few collective variables effectively controlling the global behavior of the system.

In this course, we shall introduce the traditional paradigm for "brain controllability", highlighting its limitations when many units are simultaneously considered. We will then provide a few dimensionality reduction techniques that can be applied to neural activity, including both data-driven approaches and physically-informed ones. Finally, we will describe an example of "brain control" exploiting the effective low-dimensionality of the activity.

Contents:

- The Kalman approach to dynamical controllability
- Kalman control for brain activity and its limitations
- Dimensionality reduction (1): data-driven approaches (PCA, ICA, Autoencoders)
- Dimensionality reduction (2): physically-informed approaches (mean-field reduction)
- Dimensionality reduction and brain control in epilepsy.

Final evaluation: Written report.

Programming in Python—Advanced, Dr. Emanuele Di Buccio; 10 hours

PhD students can choose whether to do only the Basic Course or the Advanced Course, too.

The course aims to introduce, through the adoption of the Python programming language, elements of software design, some programming paradigms, approaches to monitor and improve

programs' efficiency, and libraries/frameworks to store and process a large amount of data efficiently. As for software design and programming paradigms, the course will focus on Object Oriented Programming and Functional Programming. Libraries to monitor execution time and memory consumption and Python functionalities for parallel processing will then be introduced. The last part of the course will focus on libraries for data science and machine learning, specifically on storing very sparse matrices with NumPy, libraries for data visualization, and an introduction to scikit-learn and PyTorch.
Final evaluation: None.

Theoretical models of classification learning in neural systems and of the primary visual cortex, Dr. Davide Bernardi; 12 hours
This class aims to offer an intuitive understanding of two fundamental topics in Computational Neuroscience. The first part focuses on a core computational task faced by living systems: learning categories and associations. We will show how idealized models of neurons and synaptic plasticity can create and store associations. Notably, this kind of task is one that artificial intelligence algorithms inspired by biological networks excel at. In the second part, we will explore the primary visual system, illustrating how phenomenological models can effectively describe and predict neuronal responses to stimuli. The course includes a hands-on component in which simple tasks related to the course topics will be solved using basic analytical calculations and computer programming in Python. Only a basic math and programming knowledge is assumed as a prerequisite.
Final evaluation: TBA

2. COGNITIVE AND BEHAVIORAL NEUROSCIENCE

Practical course for EEG recording and analysis—Advanced, Prof. Camillo Porcaro; 8 hours
The course will provide advanced skills to analyze electroencephalographic (EEG) signals. Practical sessions will allow the students to gain experience with EEG recording. If access to the laboratory is limited, the EEG recording will be addressed by showing ad hoc video tutorials.
The course will also underline step-by-step advance EEG data analysis such as:

- Independent Components (ICs) dimensionality reduction through Principal Component Analysis (PCA) in the high-density EEG (hdEEG);
- Application of methods of automatic identification of artifacts and management of the effects of down-cleaning and over-cleaning of the data;
- EEGLAB Study Design implementation, pre-calculation and statistics.

Final evaluation: Use the Toolbox EEGLAB on real data of the topics covered.

Practical course for transcranial magnetic stimulation, Prof. Giorgia Cona; 4 hours

The course will address theoretical, methodological and practical issues of transcranial magnetic stimulation including: 1) Basic TMS principles, 2) TMS parameters; 3) safety issues; 4) possible applications. The course includes also a practical part in which students will familiarize with coil position, selection of motor threshold, change of frequency and paradigm (single-pulse vs. repetitive TMS).

Final evaluation: TBA

Systematic review meta-analysis and study quality in neuroimaging, Prof. Claudio Gentili; 8 hours

Basic knowledge for the course:

- Principles of neuroimaging techniques (principal techniques, main differences among techniques)
- Basic knowledge in literature search
- Basic knowledge in neuroanatomy

Knowledge to be acquired:

- How to perform a systematic search
- How to write a systematic review
- How to assess quality of a neuroimaging paper
- How to perform a basic ALE meta-analysis

Possibly the students will be guided toward the different steps of systematic review and meta-analysis in order to perform their own meta-analysis.

Final evaluation: TBA

Practical course for Functional Near-Infrared Spectroscopy (fNIRS) and infant brain imaging, Prof. Judit Gervain; 4 hours

NIRS is an increasingly popular brain-imaging technique, which, apart from its classical use in developmental cognitive neuroscience, has wide range of applications in freely behaving participants and in situations where MRI/EEG are not applicable, such as real-time brain-computer interfaces, cochlear implant users, pilots flying planes or athletes performing physical activities. The course overviews the basic principles, different uses and analysis methods of this technique, with hands-on applications.

The course has two parts. Part 1 provides a theoretical overview of the basic physical (optical) and physiological principles behind NIRS. Part 2 is a hands-on, lab-based demo where students are invited to test the technique themselves and familiarize themselves with analysis methods.

Final evaluation: oral exam.

Graph theory analysis of the functional connectome: theory and applications, Dr. Arianna Menardi, 8 hours

The interaction between separate agents in a system can be described by looking at their network structure. To achieve this aim, a common procedure is to graphically represent the position of each agent in space, to highlight their connections to one another and to overall look at their geometric organization. The use of graphs to model complex systems is the ground of graph theory analysis, a mathematical framework in which the independent, coherent elements of a network are represented as nodes and their connections as edges. The use of graphs to represent complex systems is a simple and effective way to understand their properties. For example, we can look at the spatial proximity or, on the contrary, distance of nodes to estimate the easiness of information transfer from one end of the network to another end. On top of these simplistic geometric analyses, more complex topological measures can be integrated, and these are useful to detail the underlying network backbone. In this short course, we will study some basic graph theory measures applied to neuroimaging data in order to gain understanding of the strengths and limitations of this technique. Practical hands-on sessions will be carried out to familiarize with the data, the extrapolation of measures, as well as getting acquainted with several different tools to plot and visually represent brain graphs.

Final evaluation: TBA.

Deep Learning for Biomedical Images, Dr. Marco Castellaro; 20 hours

Credits: 5 [Mutuato da Ingegneria]

The rapid evolution of deep learning in the field of computer vision provided state-of-the-art solutions for classical tasks such as object detection, classification, segmentation, and activity recognition. Besides, medical imaging is the ideal candidate model for the application of complex deep neural network (DNN) or Convolutional neural network (CNN) and more recent introduced Transformers architectures. In this course the teacher will provide students the knowledge and the practical skills to understand the most recent networks and to use them in the field of biomedical imaging.

Topics:

- Introduction to biomedical images (DICOM/Nifti standards)
- Introduction to Pytorch and Monai (Medical Open Network for Artificial Intelligence)
- Pre-processing, transform and data augmentation
- Case studies: DNN and CNN architectures for image classification, segmentation, and image reconstruction
- Training procedures, algorithms, and strategies
- Transfer learning and fine tuning
- Transformers, attention principle and its application to biomedical images analysis tasks.

Course requirements: Python programming and basic machine learning theoretical background.
Final evaluation: The examination will be based on a team-work to implement a deep learning based task to be applied to a real dataset of biomedical images.

3. CELLULAR AND MOLECULAR NEUROSCIENCE

<u>Light-based methods for reconstructing brain activity at cellular resolution, Prof. Marco Dal Maschio and Prof. Mario Bortolozzi; 8 hours</u>
Teachers: Prof. Mario Bortolozzi (Dept. of Physics & Astronomy) and Prof. Marco Dal Maschio (Dept. of Biomedical Sciences)
Tutors: Dr. Matteo Bruzzone, Dr. Marco Salamanca, Dr. Marica Albanesi
Workload: about 8 hours in classes and 5 hours for the exam preparation (group activity with teachers and tutors)
The course combines a set of lessons on basic concepts of light microscopy and fluorescence imaging with practical sessions dealing with optics and microscopy along with the acquisition and the analysis of a functional dataset from a living model organism.

- **Part 1**
  - Lesson on optics theory: light propagation, reflection, refraction, lenses, image formation, transverse and longitudinal magnification, magnifier, angular magnification.
  - Hands-on session: playing with a lens.
- **Part 2**
  - Lesson on fluorescence: irradiance, absorption and transmission, fluorescence emission, Jablonsky diagram, saturation irradiance, quenching, bleaching, fluorescence spectra.
- **Part 3**
  - Lesson on microscopy: upright and inverted microscopes, filters and beam splitters, point spread function, diffraction limit, numerical aperture.
  - Hands-on session: working with a microscope.
- **Part 4**
  - Lesson on Multiphoton microscopy: the basic principles, pulsed lasers, 2P-microscope configuration, 2P resolution, typical 2P dye spectra, examples of typical experiments.
- **Part 5**
  - Lesson on Calcium Imaging: fluorescent dyes, deriving Ca2+ concentration from fluorescence, practical limitations and formula, examples, ratiometric dyes, non-equilibrium conditions, genetically encoded fluorescent activity reporters.

- **Part 6**
  - Lesson on light-based methods to modulate circuit activity.
- **Part 7 (2h)**
  - Hands-on session on the acquisition of a functionally activity dataset using a multi-photon microscope: sample preparation, visual stimulus presentation, multiphoton microscope configuration and acquisition of the dataset.
- **Part 8 (2h)**
  - Hands-on session on the data analysis using Suite2P and Python: segmenting the dataset and retrieving the neuronal time series, plotting of the time series, regression analysis to highlight visual stimulus tuning.

Final evaluation: 30 minutes, preparation of short report on the activity (max 3 pages).

<u>Invertebrate nervous system: a way to study higher brain function and their evolution in a simpler (not so simple) nervous system, Prof. Aram Megighian, Dr. Nicola Cellini and Prof. Mauro Zordan; 4 hours</u>

- Visuomotor mechanisms in invertebrates and vertebrates
  - Optic flow and optomotor responses
  - Selective visual responses
  - Pursuit?
- Navigation in invertebrates and vertebrates
  - Navigation as a goal directed response
  - Internal and external sensory information
  - Cognitive maps in navigation

Final evaluation: TBA

<u>Inhibitory interneurons in the neocortex: from cellular properties to circuits, Prof. Daniela Pietrobon; 4 hours</u>

- Cortical microcircuits core motifs involving inhibitory interneurons which mediate feedback inhibition, feedforward inhibition and disinhibition
- Interneurons diversity: anatomy, input-output connectivity, electrophysiology, synaptic short-term dynamics, neuromodulation
- Role of different interneurons and different microcircuits core motifs in network function and animal behavior.

Final evaluation: TBA

<u>Electrophysiological recordings in animals, Prof. Stefano Vassanelli; 4 hours</u>

The course deals with the fundamentals of electrophysiology in rodents as a model of human

physiology and pathology. The following topics are addressed: biophysics and origin of neural signals recorded by EEG, ECoG, implanted electrodes; microstimulation of the brain; single units, multiunit, local field potentials; advanced electrophysiology technologies for high resolution recording and stimulation.
Final evaluation: TBA

4. TRANSLATIONAL AND CLINICAL NEUROSCIENCE

Translating neuroscience into clinical practice, Prof. Angelo Antonini; 4 hours
Syllabus: TBA
Final evaluation: TBA

Motor recovery and neuroplasticity after central nervous system injury, Prof. Alessandra Del Felice; 4 hours
Neurobiological and neurophysiological signatures of recovery after CNS injury; basic principles of neurorehabilitation.
Final evaluation: TBA

Neurodegenerative disorders, Prof. Annachiara Cagnin; 4 hours
Syllabus: TBA
Final evaluation: TBA

Multiple sclerosis, Dr. Marco Puthenparanmpil; 2 hours
Multiple Sclerosis (MS) is an autoimmune and neurodegenerative disorder that affects young adults' brain. The pathogenic mechanisms driving this disorder can be summarized into an initial inflammation, which is then followed by a progressive neurodegeneration.
A great effort has been spent to investigate the mechanism behind these two processes. In the last decades, a substantial help came from the neuroimaging, especially from MRI. Indeed, data derived from this methodology play now a pivotal role in MS diagnosis and give to physician crucial clues on patient's prognosis. Moreover, a new methodology has been recently applied in MS, namely Optical Coherence Tomography (OCT), that allowed to explore in vivo the microglia activation in the human retina, as well as to characterize the relevance of anterograde or retrograde, transsynaptic or direct degeneration in the optic pathways in different disease stages. The application of these methodology on different CNS autoimmune disorders might give the chance to understand comprehensively the link between inflammation and neurodegeneration.
All these aspects will be discussed in the Symposium.
Final evaluation: TBA

Brain-body interactions in psychopathology and the bio-neurofeedback, Dr. Elisabetta Patron; 6 hours

This course intends to provide an introduction to the psychophysiological basis of brain-body interaction, with a particular focus on brain-heart interplay in emotion and psychopathology. Bio- and neurofeedback are interventions based on brain body interaction. The course will provide theoretical framework and clinical protocols.

- First module (3 hours): The psychophysiological basis of brain body interaction with a particular focus on the role of brain heart interplay.
- Second module (3 hours): The scientific basis of biofeedback and neurofeedback and their main clinical applications.

The second part of the scheme includes advanced short classes of 2-8 hours, among which the student will choose some: they focus on the individual research subject of the proposing faculty and have been clustered on the different platforms of the PNC. The courses are conceived to provide, in addition to the theoretical background, the skills to use the concepts/tools in the students' research project and should also be considered as an opportunity to explore areas not directly related to the student background or research project.

Final evaluation: TBA

JOURNAL CLUB

Journal Clubs will take place weekly and they will last 1 hour in total.
PhD students in their 1st, 2nd and 3rd year will be presenting in pairs and each presentation should last 20 minutes. Presentations should either be presenting conflicting or converging points of views, so to create more interactive presentations and to stimulate a real debate (20 minutes) with the audience, i.e. the other PhD students.

For example, PhD students could present:

- Two conflicting theories, accounts or models of a phenomenon or construct (e.g. a single G-factor or multiple intelligence; innate or learn linguistic knowledge; distributed or modular representations etc.);
- Two (or more) papers/studies/models that provide conflicting results or positions;
- Two (or more) papers/studies/models that provide converging evidence for a phenomenon from different points of view or using different methods (e.g. animal and human models of the same ability, data from neuroimaging and behavioral studies, computational models and clinical approaches of the same pathology etc.).

The format can be switched also to more interactive and original formats (e.g. speaker 1 presents point 1 in 5 minutes, then speaker 2 responds/presents their point of view, then there is an open discussion etc.).

PhD students should aim at proposing a high quality presentation and being able to engage the public and generate a lively discussion, but they should use their creativity, too.