
Academic Year of Degree: 2025/26

22172 - Advanced Analysis of Neuronal Signals

Teaching Guide Information

Academic Course: 2025/26

Academic Center: 337 - Engineering School

Study: 3378 - Bachelor's degree in Biomedical Engineering

Subject: 22172 - Advanced Analysis of Neuronal Signals

Credits: 4.0

Course: 3 and 4

Teaching languages:

Theory: Group 1: English

Practice: Group 101: English

Seminar: Group 101: English

Teachers: Ralph Gregor Andrzejak

Teaching Period: Second term

Presentation

Advanced Analysis of Neural Data is a 4 ETCS optional subject from the Biomedical Engineering degree that will be taught during the second trimester. The subject is divided into two parts.

The first part introduces the student to the 'Advanced Analysis of Neural Data' based on a specific example: the theory of linear and nonlinear signal analysis and applications to electroencephalographic (EEG) recordings from epilepsy patients.

The second part is meant to provide the student a broader overview about 'Advanced Analysis of Neural Data' based on real-life examples. For this purpose, former and current students of the UPF (alumni) who are now pursuing a career in neuroscience will be invited to give presentations about their experience and work.

Associated skills | General learning outcomes

CT1. Working in group in international and interdisciplinary contexts.

CT2. Applying leadership and coordination and proving initiative.

CT3. Applying with flexibility and creativity the acquired knowledge and adapting it to new contexts and situations.

CT4. Communicating in academic and professional contexts in English, both orally and in writing

CT5. Generating new ideas and incorporating them in their daily work.

CE4. Mastering the use and programming of computers, operating systems, databases and computer programs with application in engineering.

CE9. Designing and implementing technological solutions related to the acquisition, processing, modelling, visualization and interpretation of biological, physiological and clinical variables and signals that contribute in the processes of prevention, diagnosis, treatment and rehabilitation.

CE10. Designing and implementing computational tools to study biological systems and human physiology with an integrated focus

Learning outcomes | Specific learning outcomes

RA.CE4.1 Master the basic and practical knowledge on the use and programming of computers with application in engineering.

RA.CE9.1. Develop techniques of computational analysis of multimodal signals and images with applications in diagnosis and monitoring.

RA.CE9.2 Design technological solutions related to the acquisition, processing, modelling, visualization and interpretation of biological, physiological and clinical variables and signals that contribute in the processes of prevention, diagnosis, treatment and rehabilitation.

RA.CE9.3 Compare the several techniques and systems of acquisitions of biomedical signals and images capable of providing information and/or functional information of the several biological and physiological processes.

RA.CE10.1 Create computational tools to study biological systems.

RA.CE10.5 Applying computational techniques in the field of neuroscience.

Contents

Both parts of the subject are interleaved in time throughout the entire duration of the trimester. Sessions dedicated to the first and second part alternate. Overall, approximately two-third and one-third of the hours in class are dedicated to the first and second part, respectively.

Motivation first part

The framework of nonlinear signal analysis is a practical spinoff from complex dynamical systems theory and chaos theory. It allows one to characterize dynamical systems in which nonlinearities give rise to a complex temporal evolution. Importantly, this concept can extract information from signals that cannot be resolved using classical linear techniques such as the power spectrum, linear correlation functions, etc. Applications of nonlinear signal analysis to recordings from the brain increasingly contribute to our understanding of brain functions and malfunctions and thereby help to advance cognitive neuroscience and neurology.

We will focus on the particular case of electroencephalographic (EEG) recordings from patients with the neurological disorder epilepsy. The World Health Organization (WHO) regards neurological disorders as “one of the greatest threats to public health”, and the most common serious neurological condition is epilepsy. It affects at least 50 million people worldwide. In a typical European population of 1.000 persons, between 5 and 10 persons have active epilepsy. In Spain the number of patients with active epilepsy is around 400.000, and the total cost of epilepsy accounts for some 5% of total health budget.

There is growing evidence that the application of nonlinear signal analysis to EEG recordings can provide information which is useful for an improved diagnostics and treatment of epilepsy patients. One example, is the localization of the seizure generating brain area from EEG recordings that do not contain any seizure. We will learn about the potential, but also about the limitations of this approach.

Contents – first part

Theory sessions

(1) Overview

We will start with an overview and motivation of the content of the first part. It will be highlighted why this content is relevant for biomedical engineers regardless of whether they aim at a career in academia or in industry.

(2) Epilepsy and intracranial electroencephalographic recordings.

Those epilepsy patients who cannot be treated satisfactorily with medication can potentially benefit from epilepsy surgery. Apart from some basic facts about epilepsy, we will learn about this type of surgery and how intracranial electroencephalographic recordings are used for the diagnostics.

(3) Deterministic dynamics; (4) Stochastic dynamics

Suppose that you have measured a signal from a real-world dynamical system and you want to know if the system is deterministic or stochastic. Before we analyze real-world data to address this question, we at first have to understand how our analysis techniques work when applied to data with well-known properties. We therefore introduce deterministic and stochastic model dynamics to generate some exemplary toy signals under controlled conditions. This will allow us to understand the power but also the limitations of the different analysis techniques.

(5) Linear signal analysis

The summary above states that nonlinear signal analysis techniques allow extracting information that cannot be resolved using classical linear techniques. To truly appreciate these advantages, we at first briefly revisit some fundamental linear techniques: The power spectrum and the autocorrelation function. We will show that for nonlinear dynamics these linear techniques cannot reliably distinguish between deterministic and stochastic dynamics.

(6) Nonlinear signal analysis

We at first show how delay coordinates can be used to reconstruct an estimate of the system's state space representation from single signals. The nonlinear prediction error is then used to quantify the degree to which similar momentary states evolve in similar ways. Based on several examples we show that this predictability is a sensitive but not specific criterion for a deterministic system.

(7) The concept of surrogates

Surrogates are a very powerful and versatile concept within the framework of nonlinear signal analysis techniques. They allow

us to test a variety of null hypothesis about the system underlying some measured signal. In our context, we will see how surrogates can be combined with the nonlinear prediction error to arrive at a more specific test for determinism.

Laboratory sessions

Already in the first lab session the students will be provided with intracranial EEG recordings from epilepsy patients. They will work in small groups of students, and each group will have a recording from a different patient. The data will be in Matlab files, and the information about these recordings will deliberately be kept to a minimum. In the first few labs, the students' task will write some code to visualize the data, explore the data and to find potential artefacts resulting from external disturbances of the recordings. Of course, the students will receive supervision, advice and assistance by the professor of the labs. However, this situation, where some unknown data needs to be explored with only little background information available, is a typical task for biomedical engineers, and this module is meant to train them in such a situation. Subsequently, the students will have to implement the code to calculate the nonlinear prediction error from signals and the code for the generation of surrogates. Finally, the students will analyze their EEG recordings with a combination of the nonlinear prediction error and surrogates.

Motivation second part

There are countless different career paths which can lead to a work in neuroscience. Here are some examples: (A) Do an undergraduate degree in biomedical engineering, continue with some neuroscience master program, do a PhD in a university research group analyzing neuroscientific data, continue as a postdoc in a university in some foreign country, and become a university professor. (B) Start like in (A) but do the PhD already in some company and later continue to work in this company. (C) Do an undergraduate degree and master in physics, join a neuroscience research group for a PhD, and then work in as a research manager in a company. (D) Start like in (A) but never do a PhD and directly work in a company. Evidently, this list could be continued endlessly.

Contents – second part

The second part of the course is meant to provide the students with some examples for the career paths sketched above. For this purpose, a number of UPF alumni will be invited to report about their career. These presentations will aim to cover as much as possible the different scenarios mentioned above. Importantly, the alumni will give presentations not only about the content and subjects of their work but also about their logistics. Questions such as “How is it like to move to a foreign country to do a PhD?” or “How is it like to work as a research manager in company embedded in an international network?” will be addressed, among many others.

Evaluation and grading system

Delivered by small groups of students:

A) In each laboratory sessions, all groups have to summarize what they have done to prepare the laboratory session. Furthermore, written reports on work done during the laboratory sessions have to be submitted after some laboratory sessions.

Delivered by individual students:

B) Written summaries of the presentations of the UPF alumni.

C) Oral exams about the content of the deliveries of part A.

Each of the blocks A-C contributes 1/3 to the final grade.

In case the minimal grade of 5 is not reached in the regular evaluation (directly during and after the second trimester), part B and C can be repeated in the resit evaluation (at the end of the academic year).