Syllabus

Subject

Subject / Group 11300 - Mathematical Models in Neuroscience / 1
Degree Master's in Advanced Physics and Applied Mathematics
Credits 3
Period 2nd semester
Language of instruction English

Professors

Lecturers	Office hours for students: Starting time	Finishing time	Day	Start date	End date	Office / Building
Antonio Esteban Teruel Aguilar antonioe.teruel@uib.es	15:30	17:00	Thursday	09/09/2019	14/02/2020	D120/Anselm Turmenda
	12:00	13:30	Wednesday	09/09/2019	14/02/2020	D120/Anselm Turmenda
Catalina Vich Llompart catalina.vich@uib.es	You need to book a date with the professor in order to attend a tutoring session.					

Context

Much of present neuroscience research concerns voltage- and second-messenger-gated currents in individual cells, with the goal of understanding the cell's intrinsic neurocomputational properties. It is widely accepted that knowing the currents suffices to determine what the cell is doing and why it is doing it. This, however, contradicts a half-century–old observation that cells having similar currents can nevertheless exhibit quite different dynamics. This observation was largely ignored by the neuroscience community until the seminal paper by Rinzel and Ermentrout (1989), who showed that the difference in behavior is due to different bifurcation mechanisms of excitability.

In this course we present an introductory study of the relationship between electrophysiology, bifurcations, and computational properties of neurons, where we will learn why cells having nearly identical currents may undergo distinct bifurcations, and hence they will have fundamentally different neurocomputational properties. Conversely, cells having quite different currents may undergo identical bifurcations, and hence they will have similar neurocomputational properties.

Since Ordinary Differential Equations is the language of a big amount of computational neuroscience research, some issues on qualitative theory will be introduced and complemented with simulations on XPPAUT and MAXIMA of various neural models.

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I am part of an international research group in the field of neuroscience which is aimed to model the different behaviors exhibited by neurons by using differential equations. Consequently, my professional profile fits perfectly to the contents of this course.

Requirements

Recommended

It is advisable to have knowledge about qualitative theory of ODEs or to study also the master subjects:

* Introduction to dynamic systems
* Techniques in the study of periodic solutions of ODEs

Skills

Specific

* EMA2 In the field of neuroscience and images, to develop the ability to identify and describe a problem mathematically, to structure the information available and to select an appropriate mathematical model for resolution.
* EMA3 Ability to relate the theory of dynamical systems with applications in different fields covered: mechanics, circuit theory, neuroscience.
* CE1 - Students must possess the learning skills that enable them to combine specialized knowledge in Astrophysics and Relativity, Geophysical Fluids, Materials Physics, Quantum Systems or Applied Mathematics, with the versatility that provides an open training curriculum.
* CE2 - Students must possess the ability to use and adapt mathematical models to describe physical phenomena of different nature.
* CE3 - To acquire edge-line knowledge in the international scientific research context and demonstrate a full comprehension of theoretical and practical aspects, together with the scientific methodology

Generic

* CG1 Systematic understanding of a field of study and mastery of the skills and methods of research associated with that field.
* CB6 - Possess the knowledge and its understanding to provide the basis or opportunity to be original in developing and/or applying ideas, often within a research context..
* CB7 - Students can apply the broader (or multidisciplinary) acquired knowledge and ability to solve problems in new or unfamiliar environments within contexts related to their field of study..
* CB9 - Students can communicate their knowledge to specializaed and non-specialized audiences in a clear way and without ambiguities.
* CB10 - Students gain the learning skills that enable them to continue studying in a way that will be largely self-directed or autonomous.

Basic

* You may consult the basic competencies students will have to achieve by the end of the Master's degree at the following address: http://estudis.uib.cat/master/comp_basiques/

Content

Range of topics

Theme 1. Introduction

In this introductory theme we present neurons as dynamical systems: the membrane potential of the neurons as a variable of the system; resting state of neurons corresponds to a stable equilibrium; the tonic spiking state corresponds to a limit cycle attractor and excitability of neurons corresponds to equilibrium state near a bifurcation.

Theme 2. Electrophysiology of Neurons

Electrical signals in neurons are carried by $Na+$, $Ca2+$, $K+$, and $Cl-$ ions, which move through membrane channels according to their electrochemical gradients. The membrane potential is then determined by the membrane conductances and corresponding reversal potentials. In this theme we present the most accepted description of kinetics of voltage-sensitive conductances, namely the Hodgkin-Huxley gate mode. Besides, we also present a characteristic behaviour, the action potential or spike as a brief regenerative depolarization of the membrane potential followed by its repolarization and possibly hyperpolarization.

* Constant ionic conductances and linear model.
* Non-constant ionic conductances and gating variables.
* Hodgkin-Huxley model.
* Action potential (spikes) in the HH model.

Theme 3. Conductance-Based Models and Their Reductions

We introduce minimal conductance-based models exhibiting action potentials or spikes. We start with a one dimensional reduction formed by one equation for voltage and instantaneous amplifying current. We us this easy context to introduce some analytical tools. A caricature of such a systems are the family of integrate and fire systems.

We continue with models which can be reduced to two-dimensional systems having one equation for voltage and instantaneous amplifying currents, and one equation for a resonant gating variable. In particular, we introduce the FitzHugh–Nagumo model. The behavior of a two-dimensional model depends on the position of its nullclines. Many models have an cubic-shaped nullcline and a sigmoid-shaped nullcline for the gating variable. Quite different electrophysiological models can have similar nullclines, and hence essentially the same dynamics.

The spike generation mechanism of detailed electrophysiological models depends on the dynamics near the left knee of the fast nullcline, and it can be captured by a simple model.

* One dimensional systems: Slow-fast reduction. Saddle-node bifurcation. Quadratic integrate and fire model.
* Two dimensional systems: Nullclines. Andronov-Hopf bifurcation. SNIC bifurcation. Homoclinic bifurcation. FitzHugh-Nagumo model.

Theme 4. Bursting

A burst is two o more spikes followed by a period of quiescence. Together with spikes, burst is on of the most characteristic behaviour of neurons. In this theme we describe the geometry of slow-fast bursters and classify their differences.

* Electrophysiology
* Geometry: Fast-Slow Bursters. Phase portrait. Averaging.
* Classification.

Teaching methodology

In-class work activities (0.96 credits, 24 hours)

Modality	Name	Typ. Grp.	Description	Hours
Theory classes	Theory class	Large group (G)	Exhibition in master classes of the contents presented on the table of content.	15
Laboratory classes	Computer room.	Medium group (M)	Introduction of the usual simulation tools in neuroscience, XPPAUTO, and in the symbolic manipulation WXMAXIMA. With these tools we illustrate some of the exemples presented in the theory classes.	6
Assessment	Exposition of the works.	Large group (G)	The student will present the contents of a previously assigned work.	3

At the beginning of the semester a schedule of the subject will be made available to students through the UIBdigital platform. The schedule shall at least include the dates when the continuing assessment tests will be conducted and the hand-in dates for the assignments. In addition, the lecturer shall inform students as to whether the subject work plan will be carried out through the schedule or through another way included in the Aula Digital platform.

Distance education tasks (2.04 credits, 51 hours)

Modality	Name	Description	Hours
Individual self-study	Assigned problems	The student must make a list of the problems that subsequently delivered for evaluation.	51

Specific risks and protective measures

The learning activities of this course do not entail specific health or safety risks for the students and therefore no special protective measures are needed.

Student learning assessment

Frau en elements d'avaluació

In accordance with article 33 of Regulation of academic studies, "regardless of the disciplinary procedure that may be followed against the offending student, the demonstrably fraudulent performance of any of the evaluation elements included in the teaching guides of the subjects will lead, at the discretion of the teacher, a undervaluation in the qualification that may involve the qualification of "suspense 0" in the annual evaluation of the subject".

Exposition of the works.

Modality	Assessment
Technique	Papers and projects **(retrievable)**
Description	The student will present the contents of a previously assigned work.
Assessment criteria	The student will submit a report of the work that the teacher will evaluate. This note will be complemented by observation techniques and questions during the exhibition. CE1,CE2,CEMA1,CEMA2,CG1.

Final grade percentage: 50%

Assigned problems

Modality	Individual self-study
Technique	Papers and projects **(retrievable)**
Description	The student must make a list of the problems that subsequently delivered for evaluation.
Assessment criteria	Objective evaluation of the solutions of a list of assigned problems. CE1,CE2,CEMA1.

Final grade percentage: 50%

Resources, bibliography and additional documentation

Basic bibliography

* Eugene M. Izhikevich. Dynamical systems in neuroscience : the geometry of excitability and bursting. Computational neuroscience. MIT, Press, 2007.
* G. Bard Ermentrout, David H. Terman: Mathematical Fundations of Neuroscience. Springer. 2010.
* Lawrence Perko. Differential equations and dynamical systems 3rd. ed. Springer. 2001.

Other resources

Materials designed by the teacher and available on the website of the course.