Syllabus

Subject

Name	11001 - Dynamical Systems and Chaos
Credits	1.52 in-class (38 hours) 4.48 distance (112 hours) 6 total (150 hours).
Group	Group 1, 1S
Period	First semester
Language	English

Lecturers

Lecturers	Office hours for students					
	Starting time	Finishing time	Day	Start date	End date	Office
Konstantin Klemm -	You need to book a date with the professor in order to attend a tutorial.					
Manuel Alberto Matias Muriel	You need to book a date with the professor in order to attend a tutorial.					

Context

INSTRUCTORS

Manuel Matias holds a PhD in Physics (1997) and has five 6-year terms ("sexenios") recognized by the ANEP. He has research experience in several aspects of Nonlinear Dynamics, like Chaos Theory, coupled oscillators, synchronization, dynamics of localized structures in extended media, etc. More recently, he is working on the dynamics of biological systems.
Konstantin Klemm holds a PhD in Physics (Niels Bohr Institute, 2004). He has research experience in Nonlinear Dynamics of Network Systems, Applications of Dynamical Systems in Biology and further related topics.

COURSE

The aim of this course is to train potential researchers in the study of nonlinear dynamical systems, both continue (systems of differential equations) and discrete (maps).
This includes the basic concepts and the study of dynamical systems with chaotic behavior, tools to study this kind of systems (likes fractals, dimensions and Lyapunov exponents), the study of synchronization and applications, and other special topics including delay systems. The concepts and methods studied in this course are useful in other courses of the Master.

Requirements

Recommended

It is recommended that the student has a basic knowledge of linear algebra, the study of systems of linear ordinary differential equations and numerical integration of differential equations (Euler and Runge-Kutta methods).

Skills

This course develops both specific and generic competences.

Specific

* E8: To know to characterize generic behavior of dynamical systems and their instabilities..
* E9: To know stability analysis techniques and know how to build bifurcation diagrams..
* E10: To know to characterize chaos and know how to calculate Lyapunov exponents.
* E11: To know how to apply dynamical systems techniques to physical, chemical, biological and social systems..

Generic

* TG1: To be able to describe, both mathematically and physically, complex systems in different situations.
* TG2: To acquire the capacity to develop a complete research plan covering from the bibliographic research and strategy to the conclusions..
* TG6: To acquire high power computation skills and advanced numerical methods capabilities in applications to problems in the context of complex systems..

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

Theme content

1. Introduction

   Phase Space, Existence and unicity of trajectories, Liouville theorem, Hamiltonian vs dissipative systems.

2. One dimensional flows

   Geometric representation. Fixed points. Potential representation. Stability analysis. Saddle-node bifurcation. Transcritical bifurcation. Pitchfork bifurcation. Normal forms. Bifurcation diagrams. Structural stability. Imperfect bifurcations and catastrophes.

3. Two dimensional flows

   Phase portraits. Fixed points. Stability. Forced damped oscillators. Limit Cycles. Index theory. Hopf bifurcation. Gradient systems. Lyapunov functions. Poincaré Bendixson theorem. Liénard Systems. Van Der Pol oscillator. Relaxation oscillations. Weakly nonlinear oscillators. Multiple time scale analysis.

4. Three dimensional flows
   Lorenz model. Simple properties of the Lorenz equations. Chaos on a strange attractor. Lorenz map. Exploring Parameter Space.
5. One dimensional maps.
   Fixed points and cobwebs. Logistic map. Numerics. Analysis. Chaos. Calculation of the Lyapunov exponent. Routes to chaos: period-doubling and intermittency. Universality. Feigenbaum's renormalization theory. Poincaré map. Floquet analysis.
6. Fractals
   Cantor set. Self-similarity. Dimension of a self-similar fractal. Dimension of real fractal sets: box counting, information and correlation dimensions. Generalized dimensions D_q. Lyapunov exponents. Kaplan-Yorke conjecture. Strange attractors.
7. Entrainment
   Quasiperiodicity. Circle map. 1:1 frequency locking. Rational lockings. Arnold tongues. Devil's staircase.
8. Syncronization of oscillators
   Weakly coupled oscillators. Reduction to phase dynamics. Synchronization. Landau-Stuart oscillators. Oscillator death. Kuramoto model. Diversity. Order Parameter. Self-consistent solution.
9. Excitability
   Biological motivation. Active rotator. Fizhugh-Nagumo.
10. Non-linear time series analysis
    Poincaré section. Fourier characterization. Embedding methods.
11. Delayed systems
    Delay in physical and biological systems. Fixed points. Stability analysis and oscillatory instabilities. Mackey-Glass model.

Teaching methodology

In-class work activities

Modality	Name	Typ. Grp.	Description	Hours
Theory classes	Theory classes	Large group (G)	Lectures explaining the theoretical concepts given by the professor.	29
Practical classes	Practical sessions	Large group (G)	Resolution of practical examples and questions.	6
Laboratory classes	Lab sessions	Medium group (M)	This activity aims at the visualization of the nonlinear phenomena in real experimental systems. Experiments will be performed in mechanical, electronic or chemical systems.	1
Assessment	Exam	Large group (G)	The student has to answer the questions of a written exam.	2

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 Campus Extens platform.

Distance education work activities

Modality	Name	Description	Hours
Individual self-study	Exercises	The student has to solve exercises assigned and present the solutions in written form.	52
Individual self-study	Study and understanding theoretical concepts	This activity aims at the understanding of the theoretical concepts and techniques explained in the lectures	60

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

Exam

Modality	Assessment
Technique	Objective tests **(retrievable)**
Description	The student has to answer the questions of a written exam.
Assessment criteria	Accuracy of the answers. Clarity and quality of the explanations.

Final grade percentage: 50% with minimum grade 4

Exercises

Modality	Individual self-study
Technique	Papers and projects **(retrievable)**
Description	The student has to solve exercises assigned and present the solutions in written form.
Assessment criteria	Accuracy of the results. Clarity and quality of the explanations and interpretation of the results. Quality of the written presentation

Final grade percentage: 50%

Resources, bibliography and additional documentation

The course follows the most clear textbook at the level of this course (Strogatz book). In addition, there is a complementary bibliography for some of the topics.

Basic bibliography

S.H. Strogatz, "Nonlinear Dynamics and chaos", Addison Wesley 1994 / Westview Press, 2000.

Complementary bibliography

E. Ott, "Chaos in Dynamical Systems", Cambridge University Press, 2nd edition, 2002 [mainly for chapters 5-8].
K.T. Alligood, T.D. Sauer, and J.A. Yorke, "Chaos. An Introduction to Dynamical Systems", Springer, 1997 [mainly for chapters 5,7].
A. Pikovsky, A. Politi, "Lyapunov exponents: A tool to explore complex dynamics, Cambridge University Press, 2016 [mainly for chapter 6].
A. Pikovsky, M. Rosenblum, J. Kurths, “Synchronization: A universal concept in nonlinear sciences”, Cambridge University Press, 2001 [for chapters 7-8].
S.H. Strogatz, "From Kuramoto to Crawford", Physica D **143**, 1-20 (2000) [for chapter 8].
J.D. Murray, "Mathematical biology", 3rd edition, Springer, 2003 [for chapter 9].
H.D.I. Abarbanel, "Analysis of Observed Chaotic Data", Springer, 1996 [mainly for topic 10].
T. Erneux, "Applied Delay Differential Equations", Springer, 2009. [mainly for topic 11].