Teaching guide

Subject identification

Subject	11001 - Dynamical Systems and Chaos
Credits	1.52 de presencials (38 hours) 4.48 de no presencials (112 hours) 6 de totals (150 hours).
Group	Group 1, 1S
Teaching period	First semester
Teaching language	English

Professors

Lecturers	**Horari d'atenció als alumnes**					
	Starting time	**Finishing time**	**Day**	**Start date**	**Finish 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.					

Contextualisation

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

This is one of the compulsory courses of the Structural Module of the master of Physics of Complex Systems. It is intended to provide a solid background on dynamical systems which will be needed for the other courses of the master.

Requirements

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Recommendable

It is recommended that the student has a basic knowledge on 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. One dimensional maps. Chaos

Logistic map. Fixed points. Periodic solutions. Chaos. Calculation of Lyapunov exponents. Routes to chaos: period-doubling and intermittency. Universality. Feigenbaum's renormalization theory.

5. Three dimensional flows
   Lorenz model. Chaos. Strange attractors. Poincaré map. Lorenz map. Lyapunov exponents. 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. Kaplan-Yorke conjecture.
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 in the written explanations.

Final grade percentage: 50%

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 answers. Clarity and quality of the explanations.

Final grade percentage: 50%

Resources, bibliography and additional documentation

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 topics 5-8].
K.T. Alligood, T.D. Sauer, and J.A. Yorke, "Chaos. An Introduction to Dynamical Systems", Springer, 1997 [mainly for topics 4-5,7].
A. Pikovsky, M. Rosenblum, J. Kurths, “Synchronization: A universal concept in nonlinear sciences”, Cambridge University Press, 2001 [mainly for topics 7-8].
S.H. Strogatz, "From Kuramoto to Crawford", Physica D **143**, 1-20 (2000) [mainly for topic 8].
J.D. Murray, "Mathematical biology", 3rd edition, Springer, 2003 [mainly for topic 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].