UAB
Universitat Autònoma de Barcelona

From Microscopic to Macroscopic Modelling

Code: 45560
ECTS Credits: 6

2025/2026

Degree	Type	Year
Modelización para la Ciencia y la Ingeniería / Modelling for Science and Engineering	OP	1

Contact

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Teaching groups languages

You can view this information at the end of this document.

Prerequisites

Calculus of several variables. Ordinary and partial differential equations. Introduction to probability theory

Objectives and Contextualisation

The main goal of the first part of this course is to provide powerfull tools to deal with the analysis and numerical simulations of stochastic processes both for systems affected by external noise of by internal noise. Applications to ecological and biological systems will be discussed in detail. The goal of the second part is to understand the foundations and applications of physical pheniomena numerically solving partial differential equations. First, the finite difference method will be introduced and illustrated using micromagnetism simulations. Then, the finite element method will be introduced and illustrated using thermal diffusion, elasticity, and fluid mechanics as examples.

Learning Outcomes

1. CA12 (Competence) Communicate to an expert audience the results obtained from the analysis of problems based on stochastic processes and partial differential equations.
2. CA13 (Competence) Develop models based on partial differential equations to solve specific practical problems.
3. CA14 (Competence) Develop modelling studies and stochastic analysis to analyse real datasets.
4. KA11 (Knowledge) Recognise the main types of platforms and computer tools to implement partial differential equations.
5. KA12 (Knowledge) Identify the levels of description of stochastic processes and the main mathematical techniques associated with each of them.
6. SA12 (Skill) Implement specific partial differential equations in software, including the appropriate meshing techniques and boundary conditions.
7. SA13 (Skill) Establish relationships between the different levels of description of stochastic processes.
8. SA14 (Skill) Associate the solutions and results of partial differential equations with the properties of the corresponding physical and natural systems that they represent.

Content

PART 1

- Deterministic vs stochastic modelling
- An introduction to probability theory. Random variables. Probability distribution functions and generating functions. Laws of large numbers. Central limit theorems.
- Stochastic processes: microscopic vs macroscopic descriptions. Classification of stochastic processes. Langevin equations. Master equation. Fokker-Planck equation.
- Visualization and characterization of stochastic processes. Visualization methods. Recurrence. First-passage statistics. Extreme value statistics.
- Phenomena induced by noise/stochasticity. Demographic extinction. Noise-induced phase transitions. Noise-induced order. Stochastic resonance. Noise suppresion.

PART 2

- Micromagnetism with finite differences. Problem definition. Boundary conditions implementation. Temporal evolution. Iterative alternative methods.
- Examples: Domain formation; magnetic vortices; magnetic skyrmions.
- Finite Differences for singularity point studies.
- Examples: Bloch points; dynamic reversal of magnetic vortices; creation and destruction of skyrmions.
- Fundamentals of the finite element method. Weak formulation of partial differential equations. Boundary conditions. Element types and meshing.
- Examples: Thermal diffusion and elasticity.
- Variational principles. Galerkin method. Lagrange multipliers. Stabilization, convergence and error estimation.
- Advanced examples: Fluid mechanics (laminar and turbulent)

Activities and Methodology

Title	Hours	ECTS	Learning Outcomes
Type: Directed			
Teaching classes	39	1.56	CA13, CA14, KA12, SA13, CA13
Type: Supervised			
Solving questions	9	0.36	CA12, CA12
Type: Autonomous			
Study and homework	50	2	KA11, SA12, SA14, KA11

The methodology of the course will combine traditional lectures in the classroom with autonomous activities by the student to practice the concepts seen in the course.

Annotation: Within the schedule set by the centre or degree programme, 15 minutes of one class will be reserved for students to evaluate their lecturers and their courses or modules through questionnaires.

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Assessment

Continous Assessment Activities

Title	Weighting	Hours	ECTS	Learning Outcomes
Exam	70	2	0.08	CA13, CA14, KA12, SA13, SA14
Homework	30	50	2	CA12, CA13, CA14, KA11, KA12, SA12, SA13, SA14

First part. (50%)

There will be a problems assignment (30%) and a general exam of this part (70%)

Second part. (50%)

There will be a problems assignment (30%) and a general exam of this part (70%)

Bibliography

Basic:

- V. Méndez, D. Campos, F. Bartumeus. Stochastic Foundations in Movement Ecology, Springer-Verlag, 2014
- C.W. Gardiner, ***Handbook of Stochastic Methods for Physics, Chemistry and the Natural Sciences***. Springer. Berlin. 1990
- L.J.S. Allen, ***An Introduction to Stochastic Processes with Applications to Biology***. Chapman & Hall/CRC, Boca Ratón. 2011
- R. Toral, P. Colet. ***Stochastic Numerical Methods***. Wiley-VCH, 2014

Complementary:

- N. van Kampen, ***Stochastic Processes in Physics and Chemistry***, Third Edition (North-Holland Personal Library) 2007
- J. Rudnick and G. Gaspari. ***Elements of the Random Walk***. Cambridge Univ. Press, 2004
- N.C. Petroni. ***Probability and Stochastic Processes for Physicists***. Springer-Verlag, 2020
- N. Lanchier. ***Stochastic Modelling***. Springer-Verlag, 2017

Software

The practical activities of the course will be carried out using Python and R languages

Groups and Languages

Please note that this information is provisional until 30 November 2025. You can check it through this link. To consult the language you will need to enter the CODE of the subject.

Name	Group	Language	Semester	Turn
(TEm) Theory (master)	1	English	first semester	afternoon