MA4J5-15 Structures of Complex Systems

23/24

Department
    Warwick Mathematics Institute
Level
    Undergraduate Level 4
Module leader
    Markus Kirkilionis
Credit value
    15
Module duration
    10 weeks
Assessment
    Multiple
Study location
    University of Warwick main campus, Coventry

Description

Introductory description

We keep also this year the partition of the lecture into three parts, structural modelling, dynamic modelling and learning/data analysis. All of these parts have proven to be necessary for any complex systems modelling, sich as models in the Life Sciences, in the Social Sciences, in Economy & Finance or Ecology and Infectious Diseases.

In this lecture will learn how to start the modelling process by thinking about the model's static structure, which then in a dynamic model gives rise to the choice of variables. Finally, with the dive into mathematical learning theories, the students will understand that a mathematical model is never finished, but needs recursive learning steps to improve its parametrisation and even structure.

A very important aspect of the lecture is the smooth transition from static to dynamic stochastic models with the help of rule-based system descriptions which have evolved from the modelling of chemical reactions.

Module web page

Module aims

1. To introduce mathematical structures and methods used to describe, investigate and understand complex systems.
2. To give the main examples of complex systems encountered in the real world.
3. To characterize complex systems as many component interacting systems able to adapt, and possibly able to evolve.
4. To explore and discuss what kind of mathematical techniques should be developed further to understand complex systems better.

Outline syllabus

This is an indicative module outline only to give an indication of the sort of topics that may be covered. Actual sessions held may differ.

Weekly Overview

Introduction:

Week 1: Mathematical Modelling, Past, Present and Future

- What is Mathematical Modelling?
- Why Complex Systems?..
- Philosophy of Science, Empirical Data and Prediction.
- About this course.

Part I Structural Modelling

Week 2: Relational Structures

- Relational family: hypergraphs, simplicial complexes and hierachical hypergraphs.
- Graph characteristics, examples from real world complex systems (social science, infrastructure, economy, biology, internet).
- Introduction to algebraic and computational graph theory.

Week 3: Transformations of Relational Models

- Connections between graphs, hypergraphs, simplicial complexes and hierachical hypergraphs.
- Applications of hierachical hypergraphs.
- Stochastic processes of changing relational model topologies.

Part II Dynamic Modelling

Week 4: Stochastic Processes

- Basic concepts, Poisson Process.
- Opinion formation: relations and correlations.
- Master eqation type-rule based stochastic collision processes.

Week 5: Applications of type-rule based stochastic collision processes

- Chemical reactions and Biochemistry.
- Covid-19 Epidemiology.
- Economics and Sociology, Agent-based modelling.

Week 6: Dynamical Systems (single compartment)

- Basic concepts, examples.
- Relation between type-rule-based stochastic collision processes in single compartments and ODE
- Applications, connections between dynamical systems and structural modelling (from Part I), the interaction graph, feedback loops.
- Time scales: evolutionary outlook.

Week 7: Spatial processes and Partial Differential Equations:

- Type-rule-based multi-compartment models.
- Reaction-Diffusion Equations.
- Applications.

Part III Data Analysis and Machine Learning

Week 8: Statistics and Mathematical Modelling

- Statistical Models and Data.
- Classification.
- Parametrisation.

Week 9: Machine Learning and Mathematical Modelling:

- Mathematical Learning Theory.
- Bayesian Networks.
- Bayesian Model Selection.

Week 10: Neural Networks and Deep Learning:

- Basic concepts.
- Neural Networks and Machine Learning.
- Discussion and outlook.

Learning outcomes

By the end of the module, students should be able to:

- Know basic mathematical modelling techniques to describe different complex systems.
- Choose a set of mathematical methods appropriate to tackle and investigate models of complex systems.
- Develop research interest or practical skills to solve real-world problems related to complex systems, especially with the help of computational methods.
- Know some ideas how mathematical techniques to investigate complex systems should or

could be developed further.

Interdisciplinary

This module is highly interdisciplinary, as is the nature of mathematical modelling lectures. Mathematical Modelling is applied to complex systems, which can be in nearly any scientific area, and combinations of scientific areas. Examples are Biology, Chemistry, Biochemistry, Medicine, Social Sciences, Economy and Finance.

International

As we like to move more towards online lectures, we like to offer this module to Warwick teaching partners online.

Subject specific skills

See learning outcomes.

Transferable skills

Students will acquire key reasoning and problem solving skills which will empower them to address new problems with confidence.

Study

Study time

Type	Required
Lectures	30 sessions of 1 hour (15%)
Tutorials	(0%)
Project supervision	9 sessions of 1 hour (4%)
Private study	111 hours (56%)
Assessment	50 hours (25%)
Total	200 hours

Private study description

Review lectured material and work on set exercises, computational resources.

Costs

Category	Description	Funded by	Cost to student
IT and software	Costs occur for using SARA Education Github repositories and JupyterLab installations, both needed for the associated Course Project preparation.	Department	£0.00

Assessment

You do not need to pass all assessment components to pass the module.

Students can register for this module without taking any assessment.

Assessment group A

	Weighting	Study time
Written Project	80%	40 hours
Written project together with computational components.		
Homework assignments	20%	10 hours
Four sets of homework assignments during the teaching term		

Assessment group R1

	Weighting	Study time
Written project together with computational components.	100%	

Feedback on assessment

Marked coursework and exam feedback.

Availability

Courses

This module is Optional for:

- Year 1 of TMAA-G1PE Master of Advanced Study in Mathematical Sciences
- Year 1 of TMAA-G1PD Postgraduate Taught Interdisciplinary Mathematics (Diploma plus MSc)
- Year 1 of TMAA-G1P0 Postgraduate Taught Mathematics
- Year 1 of TMAA-G1PC Postgraduate Taught Mathematics (Diploma plus MSc)

This module is Option list A for:

- Year 4 of USTA-G1G3 Undergraduate Mathematics and Statistics (BSc MMathStat)
- Year 5 of USTA-G1G4 Undergraduate Mathematics and Statistics (BSc MMathStat) (with Intercalated Year)

This module is Option list B for:

- Year 4 of UCSA-G4G3 Undergraduate Discrete Mathematics
- Year 5 of UCSA-G4G4 Undergraduate Discrete Mathematics (with Intercalated Year)
- Year 3 of USTA-G1G3 Undergraduate Mathematics and Statistics (BSc MMathStat)
- Year 4 of USTA-G1G4 Undergraduate Mathematics and Statistics (BSc MMathStat) (with Intercalated Year)

This module is Option list C for:

- UMAA-G105 Undergraduate Master of Mathematics (with Intercalated Year)
  - Year 3 of G105 Mathematics (MMath) with Intercalated Year
  - Year 4 of G105 Mathematics (MMath) with Intercalated Year
  - Year 5 of G105 Mathematics (MMath) with Intercalated Year
- UMAA-G103 Undergraduate Mathematics (MMath)
  - Year 3 of G103 Mathematics (MMath)
  - Year 3 of G103 Mathematics (MMath)
  - Year 4 of G103 Mathematics (MMath)
  - Year 4 of G103 Mathematics (MMath)
- UMAA-G106 Undergraduate Mathematics (MMath) with Study in Europe
  - Year 3 of G106 Mathematics (MMath) with Study in Europe
  - Year 4 of G106 Mathematics (MMath) with Study in Europe