ACE Network Subject Information Guide

Modern Methods of Theoretical Modelling Math4011

Semester 1, 2020

Administration and contact details

Host Department	Mathematics and Statistics.
Host Institution	The University of Western Australia
Name of lecturer	36 hours of lectures = 12 lectures x 3 hours each lecture.
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Subject details

Handbook entry URL	Lecture Notes; E.J. Hinch, Perturbation Methods, Series - Cambridge texts in applied mathematics, Cambridge University Press 1991, ISBN 0-521-37310-7 hardback, ISBN 0-521-37897-4 paperback; C.C. Lin and L.A Siegel, Mathematics Applied to Deterministic Problems in the Natural Sciences, SIAM, Philadelphia, ISBN 0-89871-229-7; L.D. Landau and E.M. Lifschits, Course of Theoretical Physics I-X (Butterworth-Heinemann, 3rd edition 1982).
Subject homepage URL	TBA
Honours student hand-out URL	TBA
Start date:	24 Feb 2020
End date:	22 May 2020
Contact hours per week:	3 hours
Lecture day and time:	Tuesday, 9.00 am – 12.00 pm Perth time
Description of electronic access arrangements for students (for example, WebCT)	dropbox, lms, zoom

Subject content

1. Subject content description

The primary goal of this course is to provide students with the power of principles and methods of theoretical modeling of complex systems 'from drops to stars'. The students will be trained on how to work on real problems at different levels of abstractions. The emphasis throughout is on the synergy between the rigorous mathematical approaches, accurate choice of scientific approximation, engineering estimates, and data analysis.

A broad range of physical phenomena, some engineering applications and biological systems will be considered. The use of methods of applied analysis, theoretical physics, probability and statistics will be described. Starting from linear systems near equilibrium, weakly nonlinear models and perturbative approaches, we proceed to consideration of systems driven by large parameters (asymptotic expansions), to phenomena undergoing strong changes at small scales (singularities), similarity and scale-invariance, as well as group theory considerations. A connection between stochastic and deterministic approaches will be outlined. Several textbooks, books and research articles are used to cover various aspects of the intense course. Mathematica and MatLab will be used for solution of homework.

2. Week-by-week topic overview

Week #	Date starting	Topic	Reading	Assessment	Notes
1	24 Feb	0. Scientific method 0.1 Symmetries and conservation laws 0.2 Regularity, singularity, asymptotic-ness, scale-invariance 1. Systems near equilibrium 1.1 Waves and oscillators - free, forced, damped, under resonance	Text Books, Lecture Notes	HW-1 (1.1-1.2) End of week 2	Lecture Notes
2	02 Mar	1.2 Waves and Oscillators - Parametric resonance	Text Books, Lecture Notes		Lecture Notes
3	09 Mar	1.3 Regular perturbation method - weakly nonlinear oscillator	Text Books, Lecture Notes	HW-2 (1.3-1.4) End of week 4	Lecture Notes
4	16 Mar	1.4 Method of co-strained coordinates, Duffing oscillator	Text Books, Lecture Notes		Lecture Notes

5	23 Mar	2. Nonlinear dynamics 2.1 Nonlinear steady and travelling waves, nonlinear diffusion and dispersion 2.2 Ginzburg-Landau equation, real and complex	Text Books, Lecture Notes	HW-3 (2.1-2.4) End of week 6	Lecture Notes
6	30 Mar	2.3 Nonlinear Schrödinger, Korteweg–de Vries, and Sine-Gordon equations 2.4 Non-equilibrium systems with pattern formation; chaos and stochasticity	Text Books, Lecture Notes		Lecture Notes
7	06 Apr	3. Singularities and singular perturbations 3.1 Matched asymptotic expansions; van Dyke matching rule	Text Books, Lecture Notes	HW-4 (3.1-3.2) End of week 8	Lecture Notes
8	13 Apr	3.2 Ordinary differential and partial differential equations with singularities	Text Books, Lecture Notes		Lecture Notes
	20 Apr	Study Break	Study Break	Study Break	Study Break
9	27 Apr	4. Multi-scale systems and method of multiple scales 4.1 Van der Paul oscillators 4.2 The Mathieu equation	Text Books, Lecture Notes	HW-5 (4.1-4.2) End of week 10	Lecture Notes
10	04 May	4.3 Diffusion-advection equation	Text Books, Lecture Notes		Lecture Notes
11	11 May	4.4 WKBJ approximation	Text Books, Lecture Notes	HW-6 (4.3-4.4) End of week 12	Lecture Notes
12	18 May	5. Symmetry and group theory 5.1 Noether theorem and conservation laws 5.2 Irreducible representations and invariants of groups 5.3 Continuous, discrete and Lie groups 5.4 Scale-invariance and self-similarity	Text Books, Lecture Notes		Lecture Notes

3. Assumed prerequisite knowledge and capabilities

This is the advanced applied mathematics unit intended to complement the specialist studies of students at Level 4 and 5 in relevant master's degree courses. Material includes a selection of topics from perturbation theory, singular perturbation theory, asymptotic expansions, group theory, and nonlinear models.
Prerequisite include the course on differential equations.

4. Learning outcomes and objectives

Students acquire greatly enhanced knowledge and understanding of sophisticated mathematical ideas and tools enabling them to go to greater depths in their research investigations in mathematics, science and engineering.

AQF specific Program Learning Outcomes and Learning Outcome Descriptors (if available):

AQF Program Learning Outcomes addressed in this subject	Associated AQF Learning Outcome Descriptors for this subject
Understand and gain knowledge on the power of principles and methods of theoretical the method and principles of theoretical modelling of complex systems 'from drops to stars'	K1, K2
Develop skills on modern methods of theoretical modelling and on their applications for particular systems, including analytical, numerical and data analysis aspects	S1, S2, S3
Apply the developed skills in the course project and the research project	S4, S5
Develop the ability to apply the knowledge of modern methods of theoretical modelling for understanding of realistic systems	A1, A2
Develop critical thinking on the use of the methods for modelling realistic systems	A3, A4

Learning Outcome Descriptors at AQF Level 8
Knowledge
K1: coherent and advanced knowledge of the underlying principles and concepts in one or more disciplines
K2: knowledge of research principles and methods
Skills
S1: cognitive skills to review, analyse, consolidate and synthesise knowledge to identify and provide solutions to complex problem with intellectual independence
S2: cognitive and technical skills to demonstrate a broad understanding of a body of knowledge and theoretical concepts with advanced understanding in some areas
S3: cognitive skills to exercise critical thinking and judgement in developing new understanding
S4: technical skills to design and use in a research project
S5: communication skills to present clear and coherent exposition of knowledge and ideas to a variety of audiences
Application of Knowledge and Skills
A1: with initiative and judgement in professional practice and/or scholarship
A2: to adapt knowledge and skills in diverse contexts
A3: with responsibility and accountability for own learning and practice and in collaboration with others within broad parameters
A4: to plan and execute project work and/or a piece of research and scholarship with some independence

5. Learning resources

Basic textbooks:
Lecture notes;
E.J. Hinch, Perturbation Methods, Series - Cambridge texts in applied mathematics, Cambridge University Press 1991, ISBN 0-521-37310-7 hardback, ISBN 0-521-37897-4;
C.C. Lin and L.A Siegel, Mathematics Applied to Deterministic Problems in the Natural Sciences, SIAM, Philadelphia, ISBN 0-89871-229-7;
Additional materials for the course:
L.D. Landau and E.M. Lifschits, Course of Theoretical Physics I-X (Butterworth-Heinemann, 3rd edition 1982)
V.I. Arnold, Geometrical methods in the theory of ordinary differential equations (Springer-Verlag, NY 1983)
S. Selcuk Bayin, Mathematical methods in science and engineering (John Wiley and sons 2006), ISBN 13 978-0-470-04142-0.
A.V. Shubnikov & V.A. Koptsik, Symmetry in science and art (Plenum Press, NY 1974)
M.C. Cross, P.C. Hohenberg, Pattern formation outside of equilibrium, Rev. Mod. Phys. 65, 851-1112 (1993).
Metzler, R., Klafter, J., The random walk's guide to anomalous diffusion: a fractional dynamics approach, Physics Reports 339, 1-77, 2000.

Mathematica and MatLab can be used for solution of homework problems.

6. Assessment

Exam/assignment/classwork breakdown							
Exam	0 %	**Assignment**	90%	**Class work**	10 %		
Assignment due dates		HW1 - End of Week 2	HW2 - End of Week 4	HW3 – End of Week 6	HW4 – End of Week 8	HW5 – End of Week 10	HW6 - – End of Week 12
Approximate exam date				N/A			

Institution Honours program details

Weight of subject in total honours assessment at host department	30 %.
Thesis/subject split at host department	40 %.
Honours grade ranges at host department:	
H1	90 %
H2a	80 %
H2b	70 %
H3	65 %