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Course Regulations for Year 3

(https://warwick.ac.uk/fac/sci/maths/undergrad/ughandbook/year3)

MATHEMATICS BSC. G100

Normal Load = 120 CATS. Maximum Load = 150 CATS.

Candidates for Honours are required to take:Modules totalling at least 57 CATS credits from List A (including at least 45 CATS of modules with codes beginning MA3 or ST318), and an appropriate number of modules selected from List B, such that the total number of credits from List B and Unusual Options combined shall not exceed 66 CATS (not including Level 7 MA and ST coded modules where Level 7 are 4th year and MSc. level modules).

Certain students who scored a low maths average at the end of the second year will not be permitted to take more than 132 CATS, but will also offered the opportunity to take MA397 Consolidation to improve their chances of securing an honours degree at the end of the 3rd year. This is a decision of the Second Year Exam Board.

MASTER OF MATHEMATICS MMATH G103

Normal Load = 120 CATS. Maximum Load = 150 CATS.

Students are required to take at least 90 CATS from Lists A and C. Although it is not a requirement to take any List C modules in the 3rd year, note that G103 students must take, in their third and fourth years combined, at least 105 CATS from the Core (MA4K8/MA4K9 Project) plus Lists C and D.

Third year students obtaining an end of year average (with adjustment where there is overcatting) less than 55% and/or less than 55% in their best 90 CATS of List A and List C modules, will normally be considered for the award of a BSc. and not permitted to continue into the 4th year.

Comments

The second year modules below are available as third year List A options worth 6 or 12 CATS if not taken in Year 2. However, not all these modules are guaranteed to take place every year.

Most List A Year 3 Mathematics modules should have a Support Class timetabled in weeks 2 to 10 of the same Term. This is your opportunity to bring the examples you have been working on, to compare progress with fellow students and, where several people are stuck or confused by the same thing, to get guidance from the graduate student in charge. When more than 30 people want to come a second weekly session can be arranged.

It is advisable to check the timetable as soon as possible for two reasons. Firstly, the timing of a module may be unavoidably changed and this page not updated to reflect that yet. Secondly, to guard against clashes. Some will be inevitable, but others may be avoided if they are noticed sufficiently well in advance. This is particularly important if you are doing a slightly unusual combination of options, and if you intend to take options outside the Science Faculty. Pay particular attention to the possibility that modules advertised here as in Term 2 may have been switched to Term 1. Check the Timetable at the start of term.

Maths Modules

Note: Term 1 modules are generally examined in the April exam period directly after the Easter vacation and Term 2 modules in the Summer exam period during weeks 4 to 6.

hide

Term	Code	Module	CATS	List
Term 1	MA241	Combinatorics	12	List A
	MA243	Geometry	12	List A
	MA359	Measure Theory	15	List A
	MA377	Rings and Modules	15	List A
	MA390	Topics in Mathematical Biology	15	List A
	MA397	Consolidation	7.5	Unusual (by invite only)
	MA398	Matrix Analysis and Algorithms	15	List A
	MA3D5	Galois Theory	15	List A
	MA3D9	Geometry of Curves and Surfaces	15	List A
	MA3F1	Introduction to Topology	15	List A
	MA3G7	Functional Analysis I	15	List A
	MA3H3	Set Theory	15	List A
	MA3H5	Manifolds	15	List A
	MA3J3	Bifurcations, Catastrophes and Symmetry	15	List A
Terms 1 & 2	MA250	Introduction to Partial Differential Equations (weeks 6 to 10, 15 to 19)	12	List A
	MA372	Reading Module	15	List A
	MA395	Essay	15	List A
Term 2	MA222	Metric Spaces	12	List A
	MA228	Numerical Analysis (wks 15-19)	6	List A
	MA252	Combinatorial Optimization	12	List A
	MA254	Theory of ODEs	12	List A
	MA257	Introduction to Number Theory	12	List A
	MA3A6	Algebraic Number Theory	15	List A
	MA3B8	Complex Analysis	15	List A
	MA3D1	Fluid Dynamics	15	List A
	MA3D4	Fractal Geometry	15	List A
	MA3E1	Groups and Representations	15	List A
	MA3E7	Problem Solving	15	List B
	MA3F2	Knot Theory	15	List A
	MA3G1	Theory of PDEs	15	List A
	MA3G6	Commutative Algebra	15	List A
	MA3G8	Functional Analysis II	15	List A
	MA3H0	Numerical Analysis and PDEs	15	List A

	MA3H2	Markov Processes and Percolation Theory	15	List A
	MA3H6	Algebraic Topology	15	List A
	MA3H7	Control Theory	15	List A
	MA3J2	Combinatorics II	15	List A
	MA3J8	Approximation Theory and Applications	15	List A
Term 3	MA209	Variational Principles	6	List A

Interdisciplinary Modules (IATL and GSD)

Second, third and fourth-year undergraduates from across the University faculties are now able to work together on one of IATL's 12-15 CAT interdisciplinary modules. These modules are designed to help students grasp abstract and complex ideas from a range of subjects, to synthesise these into a rounded intellectual and creative response, to understand the symbiotic potential of traditionally distinct disciplines, and to stimulate collaboration through group work and embodied learning.

Maths students can enrol on these modules as an Unusual Option, you can register for a maximum of TWO IATL modules but also be aware that on many numbers are limited and you need to register an interest before the end of the previous academic year. Contrary to this is IL006 Challenges of Climate Change which replaces a module that used to be PX272 Global Warming and is recommended by the department, form filling is not required for this option, register in the regular way on MRM (this module is run by Global Sustainable Development from 2018 on).

Please see the IATL page for the full list of modules that you can choose from, for more information and how to be accepted onto them, but some suggestions are in the table below:

hide

Term	Code	Module	CATS	List
Term 1	IL005	Applied Imagination	12/15	Unusual
	IL006	Challenges of Climate Change	7.5/15	Unusual
Term 2	IL016	The Science of Music	7.5/12/15	Unusual
	IL023	Genetics: Science and Society	12/15	Unusual

Statistics Modules

hide

Term	Code	Module	CATS	G100	G103
Term 1	ST220	Introduction to Mathematical Statistics	12	List B	List B
	ST222	Games, Decisions and Behaviour	12	List B	List B
	ST301	Bayesian Statistics and Decision Theory	15	List B	List B
	ST333	Applied Stochastic Processes	15	List B	List B
	ST339	Mathematical Finance	15	List A	List B
	ST407	Monte Carlo Methods	15	List B	List B
	ST411	Dynamic Stochastic Control	15	List A	List C
Term 2	ST305	Designed Experiments	15	List B	List B
	ST318	Probability Theory	15	List A	List A
	ST323	Multivariate Statistics	15	List B	List B
	ST329	Topics in Statistics	15	List B	List B
	ST332	Medical Statistics	15	List B	List B
	ST343	Topics in Data Science	15	List B	List B
	ST337	Bayesian Forecasting and Intervention	15	List B	List B
	ST417	Topics in Applied Probability	15	List A	List C

Economics Modules

The Economics 2nd and 3rd Year Handbook, which includes information on which modules will actually run during the academic year, is available from the Economics web pages.

hide

Term	Code	Module	CATS	List
Term 1	EC220	Mathematical Economics 1A	15	List B
Term 2	EC221	Mathematical Economics 1B	15	List B

Computer Science

hide

Term	Code	Module	CATS	G100	G103
Term 1	CS301	Complexity of Algorithms	15	List A	List B
	CS324	Computer Graphics	15	List B	List B
	CS325	Compiler Design	15	List B	List B
Term 2	CS349	Principles of Programming Languages	15	List B	List B
	CS356	Approximation and Randomised Algorithms	15	List B	List B
	CS409	Algorithmic Game Theory	15	List A	List B

Physics

hide

Term	Code	Module	CATS	G100	G103
Term 1	PX350	Weather and the Environment	7.5	List B	List B
	PX308	Physics in Medicine	7.5	List B	List B
	PX366	Statistical Physics	7.5	List A	List B
	PX382	Quantum Physics of Atoms	7.5	List B	List B
	PX384	Electrodynamics	7.5	List A	List B
	PX390	Scientific programming	15	List A	List B
	PX392	Plasma Electrodynamics	7.5	List A	List B
	PX397	Galaxies	7.5	List B	List B
	PX420	Solar Magnetohydrodynamics	7.5	List A	List B
	PX425	High Performance Computing in Physics	7.5	List A	List C
	PX436	General Relativity	15	List A	List C
Term 2	PX370	Optoelectronics and Laser Physics	7.5	List B	List B
	PX387	Astro Physics	15	List B	List B
	PX389	Cosmology	7.5	List B	List B
	PX396	Nuclear Physics	7.5	List B	List B
	PX408	Relativistic Quantum Mechanics	7.5	List A	List C
	PX423	Kinetic Theory	7.5	List A	List B
	PX430	Gauge Theories for Particle Physics	7.5	List A	List C

Engineering

hide

Term	Code	Module	CATS	G100	G103
Term 2	ES3C8	Systems Modelling and Control	15	List A	List B

Warwick Business School

Students wishing to take Business Studies options should preregister using the online module registration (OMR) in year two. If students wish to take an option for which they have not preregistered in year two they should register as early as possible *directly with the Business School* since occasionally the numbers of places on these modules s restricted. More information is available from Room E0.23, WBS. If you start a Business Studies module and then give it up, you *must* formally deregister with the module secretary. Information for all WBS modules can be found here.

hide

Term	Code	Module	CATS	List

Term 1	IB253	Principles of Finance I	12 or 15	List B
	IB313	Business Studies I	15	List B
	IB349	Operational Research for Strategic Planning	12	List B
Term 2	IB211	Simulation	12 or 15	List B
	IB217	Starting a Business	6	List B
	IB254	Principles of Finance II	12 or 15	List B
	IB314	Business Studies II	15	List B
	IB320	Simulation	12	List B
	IB352	Mathematical Programming III	15	List B
	IB3A7	The Practice of Operational Research	12	List B

Philosophy

hide

Term	Code	Module	CATS	G100	G103
Term 1	PH210	Logic II: Metatheory	15	List B	List B

Centre for Education Studies

Note: we advise students to take this module in their second year rather than third since it involves teaching practice over the Easter vacation which may interfere with revision for final year modules examined immediately after that vacation.

hide

Term	Code	Module	CATS	List
Term 2	IE3E1	Introduction to Secondary School Teaching	24	List B

Languages

The Language Centre offers academic modules in Arabic, Chinese, French, German, Japanese, Russian and Spanish at a wide range of levels. These modules are available for exam credit as unusual options to mathematicians in all years. Pick up a leaflet listing the modules from the Language Centre, on the ground floor of the Humanities Building by the Central Library. Full descriptions are available on request. Note that you may only take one language module (as an Unusual Option) for credit in each year. Language modules are available as whole year modules, or smaller term long modules. Both options are available to maths students. These modules may carry 24 (12) or 30 (15) CATS and that is the credit you get. We used to restrict maths students to 24 (12) if there was a choice, but we no longer do this.

Note 3rd and 4th year students cannot take beginners level (level 1) Language modules.

There is also an extensive and very popular programme of lifelong learning language classes provided by the centre to the local community, with discounted fees for Warwick students. Enrolment is from 9am on Wednesday of week 1. These classes do not count as credit towards your degree.

The Language Centre also offers audiovisual and computer self-access facilities, with appropriate material for individual study at various levels in Arabic, Chinese, Dutch, English, French, German, Greek, Italian, Portuguese, Russian and Spanish. (This kind of study may improve your mind, but it does not count for exam credit.)

A full module listing with descriptions is available on the Language Centre web pages.

Important note for students who pre-register for Language Centre modules

It is essential that you confirm your module pre-registration by coming to the Language Centre as soon as you can during week one of the new academic year. If you do not confirm your registration, your place on the module cannot be guaranteed. If you decide, during the summer, NOT to study a language module and to change your registration details, please have the courtesy to inform the Language Centre of the amendment.

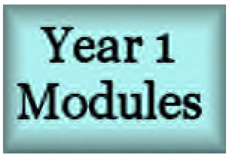
Information on modules can be found at

http://www2.warwick.ac.uk/fac/arts/languagecentre/academic/

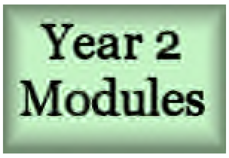
Objectives

After completing the third year of the BSc degree or MMath degree the students will have

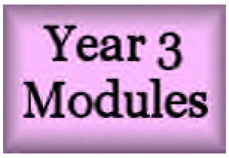
- covered advanced material in mathematics, and studied some of it in depth
- achieved a level of mathematical maturity which has progressed from the skills expected in school mathematics to the understanding of abstract ideas and their applications
- developed
    1. investigative and analytical skills,
    2. the ability to formulate and solve concrete and abstract problems in a precise way, and
    3. the ability to present precise logical arguments
- been given the opportunity to develop other interests by taking options outside the Mathematics Department in all the years of their degree course.



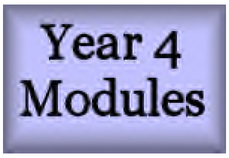
Year 1 regs and modules
G100 G103 GL11 G1NC



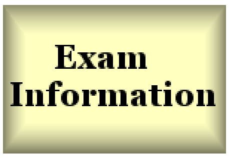
Year 2 regs and modules
G100 G103 GL11 G1NC



Year 3 regs and modules
G100 G103



Year 4 regs and modules
G103



Past Exams
Core module averages

IE420 Problem Solving

(https://warwick.ac.uk/fac/sci/maths/undergrad/ughandbook/year3/ie420)
Lecturer: David Wood

Term: term 2

Status for Mathematics students: List B for second and third years

Commitment: 10 two hour sessions, 10 one hour problem solving seminars (assessed)

Assessment: 10% from weekley seminars, 40% from assignment, 50% two hour exam in June.

Prerequisites: None

Introduction
This module gives you the opportunity to engage in mathematical problem solving and to develop problem solving skills through reflecting on a set of heuristics. You will work both individually and in groups on mathematical problems, drawing out the strategies you use and comparing them with other

approaches.

General aims
This module will enable you to develop your problem solving skills; use explicit strategies for beginning, working on and reflecting on mathematical problems; draw together mathematical and reasoning techniques to explore open ended problems; use and develop schema of heuristics for problem solving.

This module provides an underpinning for subsequent mathematical modules. It should provide you with the confidence to tackle unfamiliar problems, think through solutions and present rigorous and convincing arguments for your conjectures. While only small amounts of mathematical content will be used in this course which will extend directly into other courses, the skills developed should have wide ranging applicability.

Intended Outcomes

Learning objectives
The intended outcomes are that by the end of the module you should be able to:

- Use an explicit problem solving scheme to control your approach to mathematical problems
- Explain the role played by different phases of problem solving
- Critically evaluate your own problem solving practice

Organisation
The module runs in term 2, weeks 1-10

Main Lecture: Friday 3-5pm R0.3/4

Problem Solving Seminar (assessed): Thursday 14:00-15:00 F1.10 (beginning week TWO)

Assessment Details

1. A flat 10% given for 'serious attempts' at problems during the course. Each week, you will be assigned a problem for the seminar. At then end of the seminar, you should present a 'rubric' of your work on that problem so far. If you submit at least 7 rubrics, deemed to be 'serious attempts', you will get 10%.
2. One problem-solving assignment (40%) (deemed to be the equivalent of 2000 words) due by noon on Friday 14th March 2014. Sumbmission will either be paper copies to the Mathematics department Undergraduate Office or electronic upload, to be confirmed nearer the deadline.
3. A 2 hour examination in Summer Term 2014 (50%).

Additional Resources (Moodle page)

MA3E7 Problem Solving

(https://warwick.ac.uk/fac/sci/maths/undergrad/ughandbook/year3/ma3e7)
Lecturer: Dave Wood

Term(s): Term 2

Status for Mathematics students: List B for third years. If numbers permit second and fourth years may take this module as an unusual option, but confirmation will only be given at the start of Term 2.

Commitment: 10 two hour and10 one hour seminars (including some assessed problem solving)

Assessment: 10% from weekley seminars, 40% from assignment, 50% two hour exam in June

Prerequisites: None

Introduction
This module gives you the opportunity to engage in mathematical problem solving and to develop problem solving skills through reflecting on a set of heuristics. You will work both individually and in groups on mathematical problems, drawing out the strategies you use and comparing them with other approaches.

General aims
This module will enable you to develop your problem solving skills; use explicit strategies for beginning, working on and reflecting on mathematical problems; draw together mathematical and reasoning techniques to explore open ended problems; use and develop schema of heuristics for problem solving.

This module provides an underpinning for subsequent mathematical modules. It should provide you with the confidence to tackle unfamiliar problems, think through solutions and present rigorous and convincing arguments for your conjectures. While only small amounts of mathematical content will be used in this course which will extend directly into other courses, the skills developed should have wide ranging applicability.

Intended Outcomes

Learning objectives

The intended outcomes are that by the end of the module you should be able to:

- Use an explicit problem solving scheme to control your approach to mathematical problems
- Explain the role played by different phases of problem solving
- Critically evaluate your own problem solving practice

Organisation

The module runs in term 2, weeks 1-10

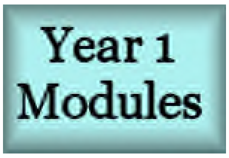
Thursday 14:00-15:00 OC0.04 (Oculus)
Friday 15:00-17:00 OC0.04

Most weeks the Thursday slot will be used for the weekly (assessed) problem session, but this will not be the case every week. You are expected to attend all three timetabled hours.

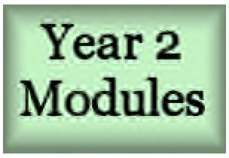
Assessment Details

1. A flat 10% given for 'serious attempts' at problems during the course. Each week, you will be assigned a problem for the seminar. At then end of the seminar, you should present a 'rubric' of your work on that problem so far. If you submit at least 7 rubrics, deemed to be 'serious attempts', you will get 10%.
2. One problem-solving assignment (40%) (deemed to be the equivalent of 2000 words) due by noon on Monday 18th March 2019 by electronic upload (pdf).
3. A 2 hour examination in Summer Term 2019 (50%).

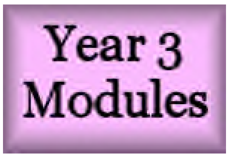
Additional Resources (Moodle page)



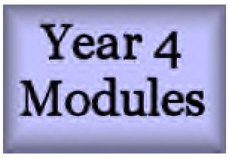
Year 1 regs and modules
G100 G103 GL11 G1NC



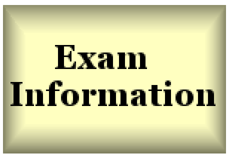
Year 2 regs and modules
G100 G103 GL11 G1NC



Year 3 regs and modules
G100 G103



Year 4 regs and modules
G103



Past Exams
Core module averages

MA3J2 Combinatorics II

(https://warwick.ac.uk/fac/sci/maths/undergrad/ughandbook/year3/ma3j2)
Lecturer: Keith Ball

Term(s): Term 2

Status for Mathematics students: List A

Commitment: 30 Lectures

Assessment: Summer exam (100%)

Prerequisites: MA241 Combinatorics

Leads To: MA4J3 Graph Theory

Content: Some or all of the following topics:

- Partially ordered sets and set systems: Dilworth's theorem, Sperner's theorem, the LYM inequality, the Sauer-Shelah Lemma.
- Symmetric functions, Young Tableaux.
- Designs and codes: Latin squares, finite projective planes, error-correcting codes.
- Colouring: the chromatic polynomial,
- Geometric combinatorics: Caratheodory's Theorem, Helly's Theorem, Radon's Theorem.
- Probabilistic method: the existence of graphs with large girth and high chromatic number, use of concentration bounds.
- Matroid theory: basic concepts, Rado's Theorem.
- Regularity method: regularity lemma without a proof, the existence of 3-APs in dense subsets of integers.

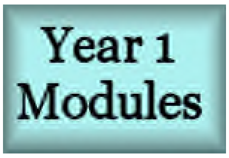
Aims:
To give the students an opportunity to learn some of the more advanced combinatorial methods, and to see combinatorics in a broader context of mathematics.

Objectives:
By the end of the module the student should be able to:
- state and prove particular results presented in the module
- adapt the presented methods to other combinatorial settings
- apply simple probabilistic and algebraic arguments to combinatorial problems
- use presented discrete abstractions of geometric and linear algebra concepts
- derive approximate results using the regularity method

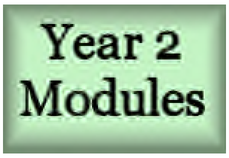
Books:
R. Diestel: Graph Theory, Springer, 4th edition, 2012.
R. Stanley: Algebraic Combinatorics: Walks, Trees, Tableaux and More, Springer, 2013.

Additional Resources

Archived Pages: 2015 2016 2017



Year 1 regs and modules
G100 G103 GL11 G1NC



Year 2 regs and modules
G100 G103 GL11 G1NC

MA3J3 Bifurcations, Catastrophes and Symmetry

(https://warwick.ac.uk/fac/sci/maths/undergrad/ughandbook/year3/ma3j3)
Lecturer: Dr. David Wood

Term(s): Term 1

Status for Mathematics students: List A

Commitment: 30 Lectures

Assessment: 100% exam

Prerequisites: MA133 Differential Equations, MA249 Algebra II, MA225 Differentiation

Leads to:

Content: This module investigates how solutions to systems of ODEs (in particular) change as parameters are smoothly varied resulting in smooth changes to steady states (bifurcations), sudden changes (catastrophes) and how inherent symmetry in the system can also be exploited. The module will be application driven with suitable reference to the historical significance of the material in relation to the Mathematics Institute (chiefly through the work of Christopher Zeeman and later Ian Stewart). It will be most suitable for third year BSc. students with an interest in modelling and applications of mathematics to the real world relying only on core modules from previous years as prerequisites and concentrating more on the application of theories rather than rigorous proof.

Indicative content (precise details and order still being finalised):

1. Typical one-parameter bifurcations: transcritical, saddle-node, pitchfork bifurcations, Bogdanov-Takens, Hopf bifurcations leading to periodic solutions. Structural stability.
2. Motivating examples from catastrophe and equivariant bifurcation theories, for example Zeeman Catastrophe Machine, ship dynamics, deformations of an elastic cube, D_4-invariant functional.
3. Germs, equivalence of germs, unfoldings. The cusp catastrophe, examples including Spruce-Budworm, speciation, stock market, caustics. Thom's 7 Elementary Catastrophes (largely through exposition rather than proof). Some discussion on the historical controversies.
4. Steady-State Bifurcations in symmetric systems, equivariance, Equivariant Branching Lemma, linear stability and applications including coupled cell networks and speciation.
5. Time Periocicity and Spatio-Temporal Symmetry: Animal gaits, characterization of possible spatio-temporal symmetries, rings of cells, coupled cell networks, H/K Theorem, Equivariant Hopf Theorem.

Further topics from (if time and interest):

Euclidean Equivariant systems (example of liquid crystals), bifurcation from group orbits (Taylor Couette), heteroclinic cycles, symmetric chaos, Reaction-Diffusion equations, networks of cells (groupoid formalism).

Aims: Understand how steady states can be dramatically affected by smoothly changing one or more parameters, how these ideas can be applied to real world applications and appreciate this work in the historical context of the department.

Objectives:

Books:

There is no one text book for this module, but the following may be useful references:

- Nonlinear Oscillations, Dynamical Systems and Bifurcations of Vector Fields, Guckenheimer/Holmes 1983
- Catastrophe Theory and its Applications, Poston and Stewart, 1978
- The Symmetry Perspective, Golubitsky and Stewart, 2002
- Singularities and Groups in Bifurcation Theory Vol 2, Golubitsky/Stewart/Schaeffer 1988
- Pattern Formation, an introduction to methods, Hoyle 2006.

Additional Resources

Year 1 Modules

Year 1 regs and modules
G100 G103 GL11 G1NC

Year 2 Modules

Year 2 regs and modules
G100 G103 GL11 G1NC

Year 3 Modules

Year 3 regs and modules
G100 G103

Year 4 Modules

Year 4 regs and modules
G103

Exam Information

Past Exams
Core module averages

MA3J4 Mathematical modelling with PDE

(https://warwick.ac.uk/fac/sci/maths/undergrad/ughandbook/year3/ma3j4)
Lecturer: Marie-Therese Wolfram

Term(s): Term 1

Status for Mathematics students:

Commitment: 30 Lectures

Assessment: Assessed example sheets (15%), Summer exam (85%).

Prerequisites: MA250 PDE

Leads To: The students will be given a general overview on the derivation and use of partial differential equations modeling real world applications. By the end of the course they should have aquired knowledge about the physical interpretation of PDE models and how the learned techniques can be applied to similar problems.

Content:

1. Mathematical modelling
    - Math. modelling in physics, chemistry, biology, medicine, economy, finance, art, transport, architecture, sports
    - Qualitative/quantitative models, discrete/continuum models

    - Scaling, dimensionless variables, sensitivity analysis
    - Examples: projectile motion, chemical reactions
2. Diffusion and drift
    - Microscopic derivation
    - Continuity equation and Fick's law
    - Heat equation: scaling, properties of solutions
    - Reaction diffusion systems: Turing instabilities
    - Fokker-Planck equation
3. Transport and flows
    - Conservation of mass, momentum and energy
    - Euler and Navier-Stokes equations
4. From Newton to Boltzmann
    - Newton's laws of motion
    - Vlasov and Boltzmann equation
    - Traffic flow models

Aims: The module focuses on mathematical modelling with the help of PDEs and the general concepts and techniques behind it. It gives an introduction to PDE modelling in general and provides the neccesary basics.

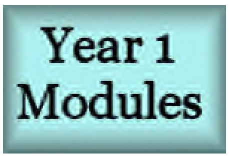
Objectives: By the end of the module students should be able to:

- Understand the nature of micro- and macroscopic models.
- Formulate models in dimensionless quantities
- Have an overview of well known PDE models in physics and continuum mechanics
- Calculate solutions for simple PDE models
- Use and adapt Matlab programs provided during the module

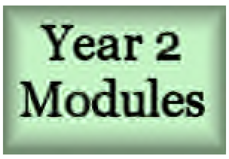
Books:

- J. David Logan, Applied Mathematics: A Contemporary Approach
- C.C.Lin, A. Segel, Mathematics Applied to Deterministic Problems in the Natural Sciences, 1988
- A. Aw, A. Klar, Rascle and T Materne, Derivation of continuum traffic flow models from microscopic follow the leader models, SIAM Appl Math., 2002
- B. Perthame, Transport equations in biology, Birkhäuser, 2007
- R. Illner, Mathematical Modelling: A Case Study Approach, SIAM, 2005
- C. Eck, H. Garcke, P. Knaber, Mathematische Modellierung, Springer, 2008
- L. Pareschi and G. Toscani, Interacting Multiagent Systems, Oxford University Press, 2013

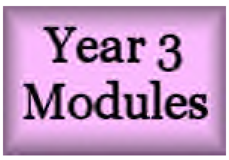
Additional Resources



Year 1 regs and modules
G100 G103 GL11 G1NC



Year 2 regs and modules
G100 G103 GL11 G1NC



Year 3 regs and modules
G100 G103

MA3J8 Approximation Theory and Applications

(https://warwick.ac.uk/fac/sci/maths/undergrad/ughandbook/year3/ma3j8)

Lecturer: Professor Christoph Ortner

Term(s): 2

Status for Mathematics students: List A

Commitment: 30 lectures

Assessment: 100% Exam

Prerequisites: There are no formal prerequisites beyond the core module MA222 Metric Spaces, but any programming module and any of the following modules would be useful complements: MA228 Numerical Analysis, MA250 Introduction to Partial Differential Equations, MA3G7 Functional Analysis I, MA3G1 Theory of Partial Differential Equations, MA3H0 Numerical Analysis and PDE.

Content:

The Module will provide students with a foundation in approximation theory, driven by its applications in scientific computing and data science.

In approximation theory a function that is difficult or impossible to evaluate directly, e.g., an unknown constitutive law or the solution of a PDE, is to be approximated as efficiently as possible from a more elementary class of functions, the approximation space. The module will explore different choices of approximation spaces and how they can be effective in different applications chosen from typical scientific computing and data science, including e.g. global polynomials, trigonometric polynomials, splines, radial basis functions, ridge functions (neural networks) as well as methods to construct the approximations, e.g., interpolation, least-squares, Gaussian process.

Outline Syllabus:

Part 1: univariate approximation

- spline approximation of smooth functions in 1D
- polynomial and trigonometric approximation of analytic functions in 1D
- linear best approximation
- best n-term approximation (to be decided)
- multi-variate approximation by tensor products in $\mathbb{R}^d$, curse of dimensionality

Part 2: Multi-variate approximation: details will depend on the progress through Part 1 and available time, but the idea of Part 2 is to cover a few selected examples of high-dimensional approximation theory, for example a sub-set of the following:

- mixed regularity, splines and sparse grids, Smolyak algorithm
- radial basis functions and Gaussian processes
- ridge functions and neural networks
- compressed sensing and best n-term approximation

Throughout the lecture each topic will cover (1) approximation rates, (2) algorithms, and (3) examples, typically implemented in Julia or Python. Any programming aspects of the module will not be examinable.

Learning Outcomes:

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

- Demonstrate understanding of key concepts, theorems and calculations of univariate approximation theory.
- Demonstrate understanding of a selection of the basic concepts, theorems and calculations of multivariate approximation theory.
- Demonstrate understanding of basic algorithms and examples used in approximation theory.

Books:

I plan to develop lecture notes, possibly a mix of traditional and online notebooks, but they will only become available as we progress through the module.

Approximation Theory and Methods, M. J. D. Powell
Approximation Theory and Approximation Practice, N. Trefethen
A course in approximation theory, E.W.Cheney and W.A.Light
Nonlinear approximation, R. DeVore (Acta Numerica)

Additional Resources

Year 1 Modules

Year 1 regs and modules
G100 G103 GL11 G1NC

Year 2 Modules

Year 2 regs and modules
G100 G103 GL11 G1NC

Year 3 Modules

Year 3 regs and modules
G100 G103

Year 4 Modules

Year 4 regs and modules
G103

Exam Information

Past Exams
Core module averages

CS341 Advanced Topics in Alogrithms

(https://warwick.ac.uk/fac/sci/maths/undergrad/ughandbook/year3/cs341)

Academic Aims

To introduce students to new techniques, methods and results from the rapidly-developing field of algorithms. Typical topics include randomised algorithms, graph algorithms, matrix algorithms and counting algorithms. The module will be research-led, so exact topics will vary from year to year.

Learning Outcomes

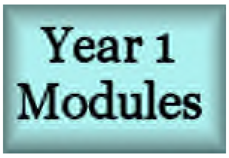
Students will be able to understand a variety of advanced algorithmic techniques, use recently-developed algorithmic techniques to solve problems, and understand the state of the art in some areas of algorithmic research, including new developments and open problems.

Content

- Basic parallel computation models: circuits, comparison networks. Parallel merging and sorting by comparison networks.
- Advanced parallel computation models: PRAM, BSP.
- Fundamental parallel algorithms: total exchange, broadcast/combine, prefix sums, butterfly, grid.
- Further parallel algorithms: list and tree contraction, sorting, convex hull
- Parallel matrix algorithms: matrix-vector multiplication, matrix multiplication, triangular system solution, Gaussian elimination.
- Parallel graph algorithms: algebraic paths, all-pairs shortest paths, minimum spanning tree.

Content in previous years.

- Sorting, selection, etc.
- Search trees, skip lists.
- Cuts, flows, approximation algorithms for graph problems.
- Online algorithms.



Year 1 regs and modules
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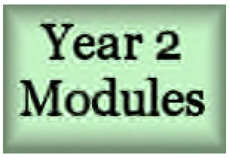

Year 2 regs and modules
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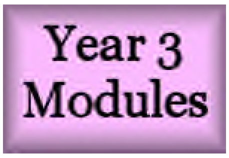
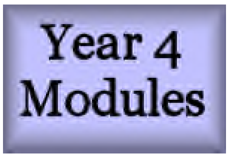
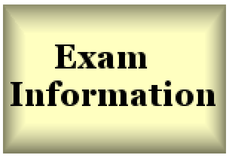


Year 3 regs and modules
G100 G103



Year 4 regs and modules
G103



Past Exams
Core module averages

CS349 Principles of Programming Languages

(https://warwick.ac.uk/fac/sci/maths/undergrad/ughandbook/year3/cs349)

Academic Aims

The module introduces students to fundamental concepts underpinning programming languages and to reasoning about program behaviour.

Learning Outcomes

By the end of the module the student should be able to:

- Understand a variety of concepts underpinning modern programming languages.
- Distinguish type disciplines in various programming languages.
- Use formal semantics to reason aboutprogram behaviour.
- Implement program interpreters and type inference algorithms.

Content

Scope and binding, untyped programming, type systems, type inference, evaluation relations, higher-order types, references, control operators, subtyping, recursive types, polymorphism.

CS356 Approximation and Randomised Algorithms

(https://warwick.ac.uk/fac/sci/maths/undergrad/ughandbook/year3/cs356)

Academic Aims

The module aims to introduce students to the area of approximation and randomised algorithms, which often provide a simple and viable alternative to standard algorithms.
Students will learn the mathematical foundations underpinning the design and analysis of such algorithms.

Learning Outcomes

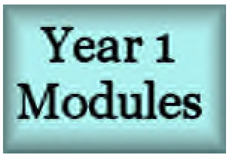
By the end of the module, students should:

- Understand and use suitable mathematical tools to design approximation algorithms and analyse their performance.
- Understand and use suitable mathematical tools to design randomised algorithms and analyse their performance.
- Learn how to design faster algorithms with weaker (but provable) performance guarantees for problems where the best known exact deterministic algorithms have large running times.

Content

- - Linearity of expectation, moments and deviations, coupon collector's problem
- - Chernoff bounds and its applications
- - Balls into bins, hashing, Bloom filters
- - The probabilistic method, derandomization using conditional expectations
- - Markov chains and random walks
- - LP duality, relaxations, integrality gaps, dual fitting analysis of the greedy algorithm for set cover.
- -The primal dual method: Set cover, steiner forest
- - Deterministic rounding of LPs: Set cover, the generalized assignment problem
- - Randomized rounding of LPs: Set cover, facility location

- - Multiplicative weight update method: Approximately solving packing/covering LPs



Year 1 regs and modules
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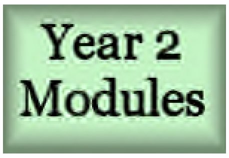

Year 2 regs and modules
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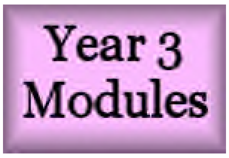
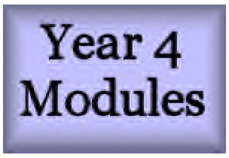
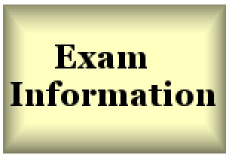


Year 3 regs and modules
G100 G103



Year 4 regs and modules
G103



Past Exams
Core module averages

CS409 Algorithmic Game Theory

(https://warwick.ac.uk/fac/sci/maths/undergrad/ughandbook/year3/cs409)

Academic Aims

To familiarise students with formal methods of strategic interaction, as studied in game theory. The focus of the module is on algorithmic and computational complexity aspects of game-theoretic models. One of the aims will be to give a flavour of current research and most recent advances in the field of algorithmic game theory.

Learning Outcomes

On successful completion of the module students should be able to:

- Understand the fundamental concepts of non-co-operative and co-operative game theory, in particular standard game models and solution concepts.
- Understand a variety of advanced algorithmic techniques and complexity results for computing game-theoretic solution concepts (equilibria).
- Apply solution concepts, algorithms, and complexity results to unseen games that are variants of known examples.
- Understand the state of the art in some areas of algorithmic research, including new developments and open problems.

Content

- Game models: Strategic form, extensive form, games of incomplete information (eg auctions), succinct representations, market equilibria, network games, co-operative games.
- Solution concepts: Nash equilibria, subgame perfection, correlated equilibria, Bayesian equilibria, core and Shapley value.
- Quality of equilibria: Price of anarchy, price of stability, fairness.
- Finding equilibria: Linear programming algorithms, Lemke-Howson algorithm, finding all equilibria.
- Complexity of results: Efficient algorithms, NP-completeness of decision problems relating to set of equilibria, PPAD-completeness.

Some parts of the module will be research-led, so some topics will vary from year to year.

MA3H7 Control Theory

(https://warwick.ac.uk/fac/sci/maths/undergrad/ughandbook/year3/ma3h7)
Lecturer: Professor Robert MacKay

Term(s): Term 2

Status for Mathematics students: List A

Commitment: 30 one hour lectures

Assessment: Three hour examination

Prerequisites: MA106 Linear Algebra, MA133 Differential Equations [Recommended: ST112 Probability B]

Leads to:

Content:
Will include the study of controllability, stabilization, observability, filtering and optimal control. Furthermore connections between these concepts will also be studied. Both linear and nonlinear systems will be considered. The module will comprise six chapters. The necessary background material in linear algebra, differential equations and probability will be developed as part of the course.
1. Introduction to Key Concepts.
2. Background Material.
3. Controllability.
4. Stabilization.
5. Observability and Filtering.
6. Optimal Control.

Aims:
The aim of the module is to show how, as a result of extensive interests of mathematicians, control theory has developed from being a theoretical basis for control engineering into a versatile and active branch of applied mathematics.

Objectives:
By the end of the module the student should be able to:
Explain and exploit role of controllability matrix in linear control systems.
Explain and exploit stabilization for linear control systems.
Derive and analyze the Kalman filter.
Understand linear ODEs and stability theory.
Understand and manipulate Gaussian probability distributions.
Understand basic variational calculus for constrained minimization in Hilbert space.

Books:
E. D. Sontag, *Mathematical Control Theory: deterministic finite dimensional systems*, Texts in Applied Mathematics No 6, Springer Verlag, 1990.
J. Zabczyk, *Mathematical Control Theory: An Introduction*, Birkhauser, 1992.

Additional Resources

PH341 Modal Logic

(https://warwick.ac.uk/fac/sci/maths/undergrad/ughandbook/year3/ph341)
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Year 1 Modules

Year 1 regs and modules
G100 G103 GL11 G1NC

PH342 Philosophy of Mathematics

(https://warwick.ac.uk/fac/sci/maths/undergrad/ughandbook/year3/ph342)
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Year 1 Modules

Year 1 regs and modules
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Year 2 Modules

Year 2 regs and modules
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Year 3 Modules

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Year 4 Modules

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Exam Information

Past Exams

Core module averages

PH345 Philosophy of Computation

(https://warwick.ac.uk/fac/sci/maths/undergrad/ughandbook/year3/ph345)

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Year 1 Modules

Year 1 regs and modules

G100 G103 GL11 G1NC

Year 2 Modules

Year 2 regs and modules

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Year 3 Modules

Year 3 regs and modules

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Year 4 Modules

Year 4 regs and modules

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Exam Information

Past Exams

Core module averages

PX408 Relativistic Quantum Mechanics

(https://warwick.ac.uk/fac/sci/maths/undergrad/ughandbook/year3/px408)

Lecturer: Tim Gershon

Weighting: 7.5 CATS

The module sets up the relativistic analogues of the Schrödinger equation and analyses their consequences. Constructing the equations is not trivial - knowing the form of the ordinary Schrödinger equations turns out not to be much help. The correct equation for the electron, due to Dirac, predicts antiparticles, spin and other surprising phenomena. One is the 'Klein Paradox': When a beam of particles is incident on a high potential barrier, more particles can be 'reflected' than are actually incident on the barrier.

Aims:

This module should start from the premise that quantum mechanics and relativity need to be mutually consistent. The Klein Gordon and Dirac equations should be derived as relativistic generalisations of Schrödinger and Pauli equations respectively. The Dirac equation should be analysed in depth and its successes and limitations stressed.

Objectives:

At the end of this module you should:

- have an appreciation of the general nature of Relativistic Quantum Mechanics.
- have an understanding of the Dirac equation, its significance and its transformation properties
- be able to explain how some physical phenomena including spin, the gyromagnetic ratio of the electron and the fine structure of the hydrogen atom can be accounted for using relativistic quantum mechanics

Syllabus:

Introductory Remarks
Revision of relativity, electromagnetism and quantum mechanics; problems with the non-relativistic Schrödinger equation; unnaturalness of spin in NRQM and the Pauli Hamiltonian; phenomenology of relativistic quantum mechanics, such as pair production
Klein Gordon Equation
Derivation of the Klein-Gordon equation; continuity equation and the Klein-Gordon current; problems with the interpretation of the Klein-Gordon Equation
The Dirac Equation
Deriviation of the Dirac equation; the unavoidable emergence of the quantum phenomena of spin; gamma matrix algebra and equivalence transformations
Solutions of the Dirac Equation
The helicity operator and spin; normalisation of Dirac spinors; Lorentz transformations of Dirac spinors; interpretation of negative energy states
Applications of Relativistic Quantum Mechanics
The gyromagnetic ratio of the electron; non-relativistic limit of the Dirac equation; fine structure of the hydrogen atom

Commitment: 15 Lectures

Assessment: 1.5 hour examination

The module has a website.

Recommended Text: The course closely follows
R.Feynman, Quantum Electrodynamics, Perseus Books 1998

Leads from: PX109 Relativity; PX262 Quantum Mechanics and its Applications

Leads to: PX430 Gauge Theories of Particle Physics;

Year 1 Modules
Year 1 regs and modules
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Year 2 Modules
Year 2 regs and modules
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Year 3 Modules
Year 3 regs and modules
G100 G103

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Exam Information
Past Exams
Core module averages

PX420 Solar Magnetohydrodynamics

(https://warwick.ac.uk/fac/sci/maths/undergrad/ughandbook/year3/px420)

Lecturer: Valery Nakariakov

Weighting: 7.5 CATS

Our knowledge of what is happening in the sun is increasing rapidly, largely as a result of space-based instrumentation. The challenge now is to understand it. The basic process is simple: Heat moves outwards from its source at the centre (nuclear fusion). However, on its way out, this energy drives many processes on many different length scales many of which are not at all well understood. For example, there is still no convincing theory of how the sun's magnetic field is generated and how the atmosphere is heated.

This module starts by stating the basic properties of the sun as deduced from observation and general physical principles, and introduces a hydrodynamic model of the sun. This treats the solar matter as a fluid. There are the usual gravitational and pressure gradient forces governing the fluid motion but, because the constituent particles of the fluid are charged, there are also electromagnetic forces. As a result, we need to worry about Maxwell's equations as well as Newton's laws. The module then discusses applications of this theory, called magnetohydrodynamics, to model and understand phenomena like sunspots, coronal loops, prominences, solar flares, coronal mass ejections and space weather.

Aims:
To review the basic physics underlying the structure and the dynamics of the sun, to provide a background in the description of physical processes in the Sun in terms of magnetohydrodynamics and to show the results of recent observations.

Objectives:
At the end of this module you should:

- Know the structure of the Sun and the main features and phenomena observed on the solar surface and in the solar atmosphere
- Understand the basic physical processes at work in the sun
- Be able to describe the basic dynamic processes operating in the Sun, in terms of MHD

Syllabus:

1. An outline of observational properties ranging from the solar interior ot the Sun's outer atmosphere
2. Theoretical aspects of solar magnetohydrodynamics (MHD)
3. Magnetic equilibria. Stratification. Force-free magnetic fields. Magnetic arcades, prominences, suspots, intense flux tubes.
4. MHD Waves. Helioseismology.
5. Solar flares. Heating of the solar corona. Coronal mass ejections and space weather.

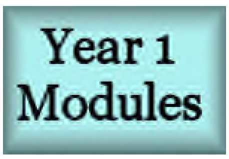
Commitment: 15 Lectures

Assessment: 1.5 hour examination

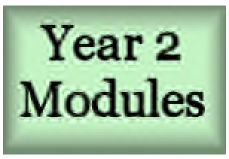
The module has a website.

Recommended Texts:
ER Priest, *Solar Magnetohydrodynamics*, Dordrecht ;
L Golub and JM Pasachoff,*Nearest Star: The Surprising Science of Our Sun*, Harvard Univ. press

Leads from: PX264 Physics of Fluids and PX392 Plasma Electrodynamics



Year 1 regs and modules
G100 G103 GL11 G1NC



Year 2 regs and modules
G100 G103 GL11 G1NC

Year 3 Modules

Year 3 regs and modules
G100 G103

Year 4 Modules

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Exam Information

Past Exams
Core module averages

PX421 Relativity and Electrodynamics

(https://warwick.ac.uk/fac/sci/maths/undergrad/ughandbook/year3/px421)
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Year 1 Modules

Year 1 regs and modules
G100 G103 GL11 G1NC

Year 2 Modules

Year 2 regs and modules
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Year 3 Modules

Year 3 regs and modules
G100 G103

Year 4 Modules

Year 4 regs and modules
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Exam Information

Past Exams
Core module averages

PX423 Kinetic Theory

(https://warwick.ac.uk/fac/sci/maths/undergrad/ughandbook/year3/px423)
This page has no content yet.

PX425 High Performance Computing in Physics

(https://warwick.ac.uk/fac/sci/maths/undergrad/ughandbook/year3/px425)

Lecturer: Nick Hine

Weighting: 7.5 CATS

The aim of this module is to complete your training in the use of computers by exploring the use of super-computers to solve super problems. The module teaches how to write scalable, portable programs for parallel computer systems and explore how large-scale physics problems are tackled. This module is 100% continuously assessed (there is no examination).

Aims:
To explain the methods used in computer simulations and data analysis on high performance computers, for research in all fields of computational physics and other sciences.

Objectives:
At the end of this module you should be able to:

- Identify and correct common inefficiencies in both serial scientific computer codes
- Choose an appropriate programming paradigm for a particular problem or hardware architecture
- Write a parallel program using shared-memory or message passing constructs in a physics context
- Write a simple GPU accelerated program.
- Identify sources of performance bottlenecks in parallel computer programs and understand how these relate to the computer architecture
- Use batch systems to access parallel computing hardware and to validate the correctness of a parallel computer program vs equivalent serial software

Syllabus:

Programming for efficiency. Modern cache architectures and CPU pipelining. Avoiding expensive and repeated operations. Compiler optimisation flags. Profiling with gprof.

Introduction to parallel computing. Modern HPC hardware and parallelisation strategies. Applications in Physics, super problems need super-computers.

Shared memory programming. The OpenMP standard. Parallelisation using compiler directives. Threading and variable types. Loop and sections constructs. Program correctness and reproducibility. Scheduling and false sharing as factors influencing performance.

Distributed memory programming. The MPI standard for message passing. Point-to-point and collective communication. Synchronous vs asynchronous communication. MPI communicators and topologies.

GPU programming. CUDA vs OpenCL. Kernels and host-device communication. Shared and constant memory, synchronicity and performance. GPU coding restrictions.

Limitations to parallel performance. Strong vs weak scaling. Amdahl's law. Network contention in modern many-core architectures. Mixed mode OpenMP+MPI programming.

Commitment: 15 Lectures + 5 Laboratory Sessions

Assessment: Assignments (100%)

Recommended Texts: R Chandra et. al,. *Parallel Programming in OpenMP* , Morgan Kaufmann,
P Pacheco, *Parallel Programming with MPI* Morgan Kaufmann
M Quinn, *Parallel Programming in C with MPI and OpenMP* McGraw-Hill
D Kirk and W Hwu, *Programming Massively Parallel Processors* Elsevier

Module Homepage

This module has its own website where lecture notes and other resources are available.

Leads from: PX390 Scientific Computing A good working knowledge of a scientific programming language preferably C is essential.

Year 1 Modules

Year 1 regs and modules
G100 G103 GL11 G1NC

Year 2 Modules

Year 2 regs and modules
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Year 3 Modules

Year 3 regs and modules
G100 G103

Year 4 Modules

Year 4 regs and modules
G103

Exam Information

Past Exams
Core module averages

PX429 Scattering and Spectroscopy

(https://warwick.ac.uk/fac/sci/maths/undergrad/ughandbook/year3/px429)

Lecturer: Gareth Alexander

Weighting: 15 CATS

Einstein's general theory of relativity is the basis for our understanding of black holes and the Universe on its largest scales. In general relativity the Newtonian concept of a gravitational force is abolished, to be replaced by a new notion, that of the curvature of space-time. This leads in turn to predictions of phenomena such as the bending of light and gravitational time dilation that are well tested, and others, such as gravitational waves, which are only now coming into the regime of direct detection.

The module starts with a recap of Special Relativity, emphasizing its geometrical significance. The formalism of curved coordinate systems is then developed. Einstein's equivalence principle is used to link the two to arrive at the field equations of GR. The remainder of the module looks at the application of general relativity to stellar collapse, neutron stars and black-holes, gravitational waves, including their detection, and finally to cosmology where the origin of the "cosmological constant" -- nowadays called "dark energy" - becomes apparent.

Aims:

To present the theory of General Relativity and its applications in modern astronomy, and to give an understanding of black-holes.

Objectives:
At the end of this module you should:

- understand the metric nature of special and general relativity, how the metric determines the motion of particles
- be able to undertake elementary calculations involving the Schwarzschild metric
- be able to describe the key features of black-holes
- be able to demonstrate knowledge of current attempts to detect gravitational waves

Syllabus:

- The geometry of space-time and the invariant "interval" in special relativity; the 4-vector formulation of special relativity; the metric of special relativity
- The equivalence principle and local inertial frames; the motivation for considering curved space-time; vectors and tensors in curved coordinate systems
- Geodesics: how the metric determines equations of motion; motion in almost-flat space-time: the Newtonian limit
- The curvature and stress-energy tensors; how the metric is determined: Einstein's field equations
- The Schwarzschild metric; observable consequences; black-holes; stability of orbits; extraction of energy
- Gravitational radiation and its detection; cosmology: the Robertson-Walker metric

Commitment: 25 Lectures (and 5 problems classes)

Assessment: 2 hour examination

The module has a website.

Recommended Texts: BF Schutz *A first course in general relativity*, Cambridge University Press,
M.P Hobson, G. Efstathiou, A.N. Lasenby, *General Relativity -- An Introduction for Physicists*, CUP.

Year 1 Modules

Year 1 regs and modules
G100 G103 GL11 G1NC

Year 2 Modules

Year 2 regs and modules
G100 G103 GL11 G1NC

Year 3 Modules

Year 3 regs and modules
G100 G103

Year 4 Modules
Year 4 regs and modules
G103
Exam Information
Past Exams
Core module averages

PX430 Gauge Theories for Particle Physics

(https://warwick.ac.uk/fac/sci/maths/undergrad/ughandbook/year3/px430)

Lecturer: Tim Gershon

Weighting: 7.5 CATS

The electromagnetic field is a gauge field. Gauge changes to the vector potential ($A^\mu \rightarrow A^\mu - \partial^\mu \Phi$ with Φ an arbitrary function of postion and time), combined with multiplication of the wavefunction of particles with (dimensionless) charge q by the phase factor, $e^{iq\Phi}$, leave all physical properties unchanged. This is called a gauge symmetry. In particle physics, this idea is generalized to (space- and time-dependent) unitary matrix-valued fields multiplying spinor wavefunctions and fields. This generalization of the theory of an electron in an electromagnetic field is the basis for current theories of elementary particles. The module starts with the theory of the electron in the electromagnetic field making the gauge symmetry explicit. It then discusses the gauge symmetries appropriate for the various theories and approximate theories used to describe other elementary particles and their interactions with their corresponding gauge fields.

Aims:
To follow from *Relativistic Quantum Mechanics* (which is a pre-requisite), to develop ideas of gauge theories and apply these to the field of particle physics. To study, in particular, the theory underpinning the Standard Model of Particle Physics and to highlight the symmetry properties of the theory. Quantum electrodynamics (QED) should be considered in some detail, and its success illustrated by comparison with experiments.

Objectives:
At the end of this module you should:

- have an appreciation of the theoretical framework of the Standard Model
- understand the symmetry properties associated with gauge invariance
- be able to calculate amplitudes for simple QED processes
- be able to discuss qualitatively properties of the strong and weak interactions

Syllabus:

1. Introduction and revision: relativistic quantum mechanics and notation; the Klein Gordon equation; the Dirac equation and interpretation of negative energy solutions; quantum numbers and spin; revision of matrices, Hermitan, unitary, determinants
2. Group theory: definition of a group, examples of discrete groups; continuous groups, Lie groups, examples: U(1), SU(2), SU(3)
3. Gauge invariance: symmetries and conservation laws; current conservation; Noether's theorem; the gauge principle; examples: Maxwell's equations, quantum electrodynamics
4. Quantum field theories: brief outline of the deeper theory; Feynman rules and diagrams
5. Non Abelian gauge theories: SU(2) and the electroweak interaction; SU(3) and QCD; local nonAbelian gauge theory; gauge fields; self-interaction
6. Quantum electrodynamics: perturbation theory; scattering and cross sections

Commitment: 13 Lectures and 2 problem classes

Assessment: 1.5 hour examination

The module has a website.

Recommended Texts:
IJR Aitchison and AJG Hey *Gauge Theories in Particle Physics*, IoPP

Leads from: PX395 The Standard Model and PX408 Relativistic Quantum Mechanics

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ST411 Dynamic Stochastic Control

(https://warwick.ac.uk/fac/sci/maths/undergrad/ughandbook/year3/st411)
Lecturer(s): Dr Gechun Liang

Commitment: 3 x 1-hour lectures per week and one revision class in Term 3. This module runs in Term 1.

Prerequisite(s): ST318 Probability Theory; ST333 Applied Stochastic Processes.

An example of a stochastic control problem is the 'Red and Black' problem. Essentially, this asks what the best betting strategy is if you want to maximise your chance of winning £1000 playing roulette.

Syllabus: This module will cover:

- Recapitulation of the theory of stochastic processes.
- Introduction to finite horizon control problems and optimal stopping.
- The Hamilton-Jacobi-Bellman equation.
- Infinite horizon discounted problems.
- Applications to finance, clinical trials, planning production processes and insurance, *and, time permitting*
- Discussion of long-run average problems.

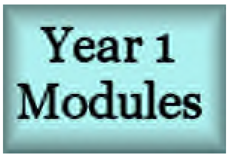
Aims: This module is designed to cover the important area of stochastic control within applied probability. The taught material will prepare students for careers in business, industry or government and will also lead up to the boundaries of research.

Learning Outcomes: Students who have successfully completed this module will be able to:

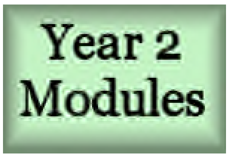
- Identify and deal with stochastic control and optimal stopping problems.
- Solve simple Hamilton-Jacobi-Bellman equations.
- Apply the above techniques to finance, to clinical trials and to the planning of production processes.

Books: Ross, S.M., *Introduction to Stochastic Dynamic Programming*, 1983, Academic Press

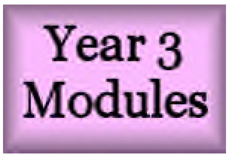
Assessment: 100% by 2 hour examination.



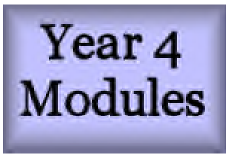
Year 1 regs and modules
G100 G103 GL11 G1NC



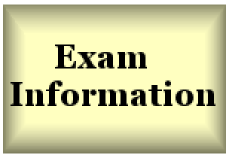
Year 2 regs and modules
G100 G103 GL11 G1NC



Year 3 regs and modules
G100 G103



Year 4 regs and modules
G103



Past Exams
Core module averages

ST416 Advanced Topics in Biostatistics

(https://warwick.ac.uk/fac/sci/maths/undergrad/ughandbook/year3/st416)
Lecturer(s)

*** Please note that this module will not be running in the 2018/19 academic year. ***

Commitment: 3 lectures per week over 10 weeks. This module will run in Term 2.

Assessment: 100% by 2 hour examination

Prerequisite(s): ST111/112 Probability A and B, ST218/219 Mathematical Statistics A&B, basic computing literacy (R, Matlab,...)

Aims: This module presents the application of methods from probability, statistical theory, and stochastic processes to problems of interest to bioinformaticians and systems biologists, mainly in the area of biosequence analysis.

Objectives: It is expected that students who have taken the module will have mastered the basic set of ideas required in order to carry out further research in bioinformatics methods and algorithms, or to apply these ideas in biomedical applications.

Content:

• Single DNA sequence analysis:
- Signal modelling
- Pattern analysis

• Multiple DNA/protein sequence analysis:
- Detailed study of pairwise alignment algorithms and substitution matrices

• BLAST:
- a detailed study of the algorithm and underlying theory

• Hidden Markov models:
- Forward-Backward algorithm and parameter estimation
- Applications to protein family modelling, sequence alignment and gene finding

• Gene Expression, Microarrays and Multiple Testing:
- differential expression – one gene and multiple genes

• Evolutionary Models:
- Discrete-Time Models
- Continuous-Time Models

• Phylogenetic Tree Estimation:
- Modelling, Estimation and Hypothesis Testing

Illustrative Bibliography:

1. Statistical Methods in Bioinformatics - An Introduction, by W. J. Ewens and G. R. Grant (Springer-Verlag New York, Second Edition, 2005)
2. Biological Sequence Analysis by R. Durbin, S. Eddy, A. Krogh, G. Mitchison Cambridge University Press, 1998, ISBN: 0 521 62971 3
3. Computational Genome Analysis: An Introduction by Michael S. Waterman, Simon Tavare, Richard C. Deonier , Springer Verlag , 2005

ST417 Topics in Applied Probability

(https://warwick.ac.uk/fac/sci/maths/undergrad/ughandbook/year3/st417)
∗∗∗ Please note that this module will not be running in the 2018/19 academic year. ∗∗∗

Lecturer(s): Dr Nikos Zygouras

Important: This module is only available to final year (4) integrated Masters students and MSc students. Please note that Topics in Applied Probability will only be taught if 5 students or more register for the module.

Lecturer(s):

Prerequisites: Being comfortable with stochastic processes, law of large numbers, central limit theorem.

Aims: This module will cover several topics chosen from modern applied probability. The topics will be selected to demonstrate how probability theory can be used to study various phenomena in the real world. Examples might include random graphs, spatial point processes, branching processes and interacting particle systems.

Commitment: 3 lectures/week. This module runs in Term 2.

Content: In the academic year 2017-2018 the topic will be " Random growth and random matrices".

The famous Kardar-Parisi-Zhang (KPZ) universality states that a large class of randomly growing models have fluctuations governed by a nonlinear stochastic partial differential equation (the KPZ equation) and fall outside the scope of the classical central limit theory. For example, the outer boundary of a colony of bacteria growing for time will exhibit fluctuations of order $t^{1/3}$, rather than $t^{1/2}$, as manifested by the central limit theorem. More surprisingly, the limiting distributions are different than gaussian and agree with distributions arising in a seemingly very different setting, that of eigenvalues of random matrices.

Both areas have witnessed remarkable progress in recent years. In random matrix theory the works of the groups of Tao-Vu and Erdos-Yau have resolved the longstanding universality conjecture (ie limiting eigenvalues statistics do not depend on the distribution of the matrix elements). In the field of KPZ significant progress has been recently made in analysing the underlying combinatorial and integrable structure, explaining (to some extend but not fully) the links to random matrix theory.

The course will aim to familiarise students with the forefronts of some fast developing research areas and equip them with a wide range of tools that can find applications in various settings beyond the focus topics.

The course will be ideal for students who want to pursue or are pursuing doctoral studies in probability but can also be of interest to students with interests outside probability (in the second case the students are encouraged to consult with the lecturer).

Objectives: By the end of the course, the student will:
- Familiarise with rapidly developing areas of modern probability.
- Understand and be able to use key methods and concepts with wide applicability.

References:

1) "Topics in Random Matrix Theory" by Terence Tao
2) " Log-gases and random matrices" by P. Forrester
3) "Dynamical approach to random matrix theory" by L. Erdos and H.T. Yau
4) "A pedestrian's view on interacting particle systems, KPZ universality, and random matrices" , by T. Kriecherbauer and J. Krug

Assessment: 100% by 2hr exam.

MA359 Measure Theory

(https://warwick.ac.uk/fac/sci/maths/undergrad/ughandbook/year3/ma359)
Lecturer: Professor Oleg Pikhurko

Term(s): Term 1

Status for Mathematics students: List A

Commitment: 30 hours

Assessment: examination (85%), assignments (15%)

Prerequisites: MA132 Foundations, MA222 Metric Spaces, MA244 Analysis III.

Leads To: ST318 Probability Theory, MA3D4 Fractal Geometry, MA482 Stochastic Analysis, MA496 Signal Processing, Fourier Analysis and Wavelets

Content: The modern notion of measure, developed in the late 19th century, is an extension of the notions of length, area or volume. A *measure m* is a law which assigns a number $m(A)$ to certain subsets *A* of a given space and is a natural generalization of the following notions: 1) length of an interval, 2) area of a plane figure, 3) volume of a solid, 4) amount of mass contained in a region, 5) probability that an event from *A* occurs, etc.

It originated in the real analysis and is used now in many areas of mathematics like, for instance, geometry, probability theory, dynamical systems, functional analysis, etc.

Given a measure *m*, one can define the *integral* of suitable real valued functions with respect to *m*. Riemann integral is applied to continuous functions or functions with ``few`` points of discontinuity. For measurable functions that can be discontinuous ``almost everywhere'' Riemann integral does not make sense. However it is possible to define more flexible and powerful *Lebesgue's integral* (integral with respect to *Lebesgue's measure*) which is one of the key notions of modern analysis.

The Module will cover the following topics: Definition of a measurable space and σ-additive measures, Construction of a measure form outer measure, Construction of Lebesgue's measure, Lebesgue-Stieltjes measures, Examples of non-measurable sets, Measurable Functions, Integral with respect to a measure, Lusin's Theorem, Egoroff's Theorem, Fatou's Lemma, Monotone Convergence Theorem, Dominated Convergence Theorem, Product Measures and Fubini's Theorem. Selection of advanced topics such as Radon-Nikodym theorem, covering theorems, differentiability of monotone functions almost everywhere, descriptive definition of the Lebesgue integral, description of Riemann integrable functions, *k*-dimensional measures in *n*-dimensional spaces, divergence theorem, Riesz representation theorem, etc.

Aims: To introduce the concepts of *measure* and *integral with respect to a measure*, to show their basic properties, and to provide a basis for further studies in Analysis, Probability, and Dynamical Systems.

Objectives: To gain understanding of the abstract measure theory and definition and main properties of the integral. To construct Lebesgue's measure on the real line and in *n*-dimensional Euclidean space. To explain the basic advanced directions of the theory.

Books: There is no official textbook for the course. As the main recommended book, I would suggest:

- Cohn, D.L, Measure Theory, Second Edition, Birkhauser (2013). *

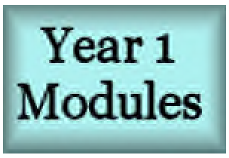
The list below contains some of many further books that may be used to complement the lectures.

- Folland, G.b.: Real Analysis, Second Edition, Wiley (1999). *
- Halmos, P. R.: Measure Theory, D. Van Nostrand Company Inc., Princeton, N.J. (1950) (Reprinted by Springer (1974)).
- Kubrusly, C.S: Essentials of Measure Theory, Springer (2015). *
- Loeb, P.A: Real Analysis, Birkhauser (2016). *
- Royden, H. L. and Fitzpatrick, P.M: Real Analysis, Fourth Edition, Macmillan Publishing Company (2010).
- Rudin, W.: Real and Complex Analysis, Third Edition, McGraw-Hill Book Company (1987).
- Stein, E. M. and Shakarchi, R.: Real Analysis - measure theory, integration and Hilbert spaces. (Princeton Lectures in Analysis III) Princeton University Press (2005).

* = E-book avaliable from Warwick Library.

Additional Resources

Archived Pages: 2012 2013 2014 2015 2016 2017



Year 1 regs and modules
G100 G103 GL11 G1NC

MA371 Qualitative Theory of ODEs

(https://warwick.ac.uk/fac/sci/maths/undergrad/ughandbook/year3/ma371)

Not Running in 2015/16

Lecturer:

Term(s):

Status for Mathematics students: Years 3 and 4: List A

Commitment: 30 lectures

Assessment: 3 hour examination

Prerequisites: MA133 Differential Equations, MA131 Analysis, MA106 Linear Algebra, MA222 Metric Spaces, and MA225 Differentiation. Also parts of MA235 Intro to Math Biology provide helpful background.

Leads To: MA424 Dynamical Systems and lots of fun areas of research!

Content:
The module presents the geometric approach to ordinary differential equations and some of the key ways in which it permits one to go well beyond the traditional approach. The emphasis is on techniques to determine the phase portrait. So the module is a natural sequel to Differential Equations.

1. Geometric approach versus explicit solutions: flow, phase portrait. Existence, uniqueness and continuity of solution to initial value problem.
2. Orbits, invariant sets, omega-limit sets; Lyapunov stability and asymptotic stability, attracting set and basin of attraction. Conservative systems. Lyapunov functions, La Salle's Invariance Principle.
3. Dynamics near equilibria: sinks and sources; Lyapunov Stability Theorems; hyperbolic equilibria, stable and unstable manifolds; linearisation theorems.
4. Periodic orbits: in 2D flows, Poincare-Bendixson theorem and Divergence test; first return map, Floquet multipliers and Lyapunov exponents; Lienard systems; Energy balance method for near-conservative systems.
5. Bifurcations of 2D flows: use of implicit function theorem, centre manifolds, normal forms and return maps.

Aims:
To teach you some tools to understand the asymptotic behaviour of systems of ODEs and the ways this can change with parameters.

Objectives:
By the end of the module, students should be familiar with the geometric approach to ODEs and the tools presented, and be able to use them to determine phase portraits for some simple systems and to recognize simple bifurcations taking place in one-parameter families.

Book:
We will not follow any particular book. The most recommended is:
M Hirsch and S Smale, *Differential equations, dynamical systems and linear algebra*, Academic Press 1974.

Other books which can be useful (from easy but not covering the module to substantial but going beyond the module):
PA Glendinning, *Stability, instability and chaos*, CUP 1994.
A.C. King, J. Billingham & S.R. Otto, *Differential Equations*, CUP, 2003.
DW Jordan and P Smith, *Nonlinear ODEs*, Oxford 1987.
PG Drazin, *Nonlinear systems*, CUP 1992.
R Grimshaw, *Nonlinear ODEs*, CRC Press 1991.
DK Arrowsmith and CM Place, *Introduction to Dynamical Systems*, CUP 1990.
S Wiggins, *Introduction to applied nonlinear dynamical systems and chaos*, Springer 1990.
VI Arnold, *Ordinary Differential equations*, Springer 1973. VI Arnold, *Geometrical methods in the theory of ODEs*, Springer 1988.

Additional Resources

Year 1 Modules

Year 1 regs and modules
G100 G103 GL11 G1NC

Year 2 Modules

Year 2 regs and modules
G100 G103 GL11 G1NC

Year 3 Modules

Year 3 regs and modules
G100 G103

Year 4 Modules

Year 4 regs and modules
G103

Exam Information

Past Exams
Core module averages

MA390 Topics in Mathematical biology

(https://warwick.ac.uk/fac/sci/maths/undergrad/ughandbook/year3/ma390)
Lecturer: Professor Nigel Burroughs

Term(s): Term 1

Status for Mathematics students: List A

Commitment: 30 one hour lectures

Assessment: 3 hour examination (100%)

Prerequisites: There are no prerequisites but the following is advised: Probability A & B (ST111), Introduction to partial differential equations (MA250), Theory of ODEs (MA254), Introduction to Systems Biology (MA256).

Content:
Mathematical modelling of biological systems and processes is a growing field that uses multiple mathematical techniques. This course will cover a range of these techniques, using examples from primarily medical systems. Topics include:

1. Small gene circuits (bifurcations, phase plots, linearization analysis, stochastic analogues through master equations).

2. Virus dynamics (ODEs) and mutation, including HIV/AIDS and basic immunology.

3. Cancer modelling (branching processes). Therapy.

4. Waves in biology (excitable systems, neurobiology).

This course leads on to MA4J6, Mathematics and Biophysics of Cell dynamics.

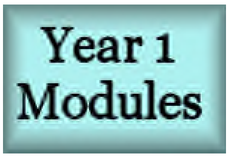
Aims:
To introduce ideas and techniques of mathematical modelling (deterministic and stochastic) in biology.

Objectives:
To gain an insight into modelling techniques and principles in gene regulation, virus growth, cancer and physiology; to consolidate basic mathematical techniques used in these approaches, such as ODEs, PDEs, probability theory, branching processes and Markov Chains.

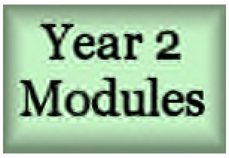
Books.
There is no dedicated text. A classic text (only deterministic modelling, I is predominantly ODEs, II is PDEs) is Mathematical Biology I & II. James Murrey. Springer. Useful texts for specific topics are: Branching process models of cancer. Richard Durrett. 2015. Springer. [https://0-link-springer-com.pugwash.lib.warwick.ac.uk/book/10.1007/978-3-319-16065-8], Mathematical Physiology I: Cellular Physiology and II: Systems physiology. James Keener, James Sneyd. 2009. Springer. Virus dynamics : mathematical principles of immunology and virology. Martin Nowak and Robert May. 2000. OUP.

Additional Resources

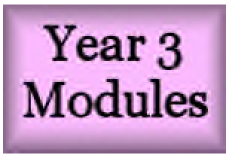
Archived Pages: Pre-2011 2011 2012 2013 2014 2015 2016



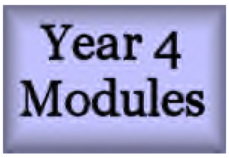
Year 1 regs and modules
G100 G103 GL11 G1NC



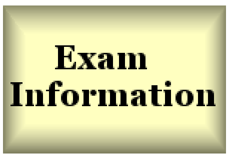
Year 2 regs and modules
G100 G103 GL11 G1NC



Year 3 regs and modules
G100 G103



Year 4 regs and modules
G103



Past Exams
Core module averages

MA397 Consolidation

(https://warwick.ac.uk/fac/sci/maths/undergrad/ughandbook/year3/ma397)
Lecturer: Nicholas Jackson

Term(s): Term 1

Status for Mathematics students: Core for third year Pass Degree students. **Not Available** to others

Commitment: Weekly meetings

Assessment: Wholly based upon the student's portfolio of written assignments, performance in two short tests, and his/her explanations in the tutorials. The tutorials themselves form an essential part of the assessment process.

Prerequisites: None

Leads To: 3rd year modules

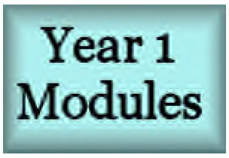
Content: The tutor selects problems related to first year modules and to second year modules where the student's record indicates that further study is desirable. Each week, the student receive an assignment of written work to be handed in. At the following tutorial, the student and the tutor discuss the student's answers and related material.

Aims: To provide individual attention for students recommended by the Second Year Exam Board to improve prospects of a good honours degree.

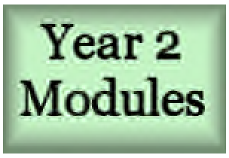
Objectives: To improve upon your understanding of the material from the first two years, focusing primarily on the topics that you struggled with first time around.

Books: Recommendations will depend upon the individual. But, a comprehensive book list will be provided at the start of the course.

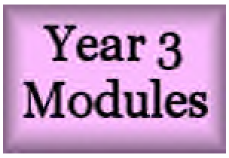
Additional Resources



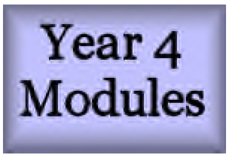
Year 1 regs and modules
G100 G103 GL11 G1NC



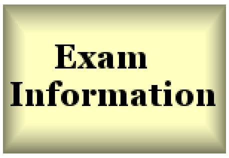
Year 2 regs and modules
G100 G103 GL11 G1NC



Year 3 regs and modules
G100 G103



Year 4 regs and modules
G103



Past Exams
Core module averages

MA398 Matrix Analysis and Algorithms

(https://warwick.ac.uk/fac/sci/maths/undergrad/ughandbook/year3/ma398)

Lecturer: Geneviève Dusson

Term(s): Term 1

Status for Mathematics students: List A

Commitment: 30 lectures

Assessment: Exam (85%) Assignments (15%)

Prerequisites: Core module of the first and second year, in particular MA106 Linear Algebra and MA225 Differentiation, are sufficient. Helpful but not mandatory is some knowledge of numerical concepts as accuracy, iteration, and stability as provided in MA228 Numerical Analysis.

Leads To: A few notions used for the analysis are shared with MA3G7 Functional Analysis I. With respect to implementation and software issues but also towards optimisation problems the module MA4G7 Computational Linear Algebra and Optimization is recommended. A nice application area where various methods provided in this module are needed are numerical methods for partial differential equations, MA3H0 Numerical Analysis and PDEs

Content: Many large scale problems arising in data analysis and scientific computing require to solve systems of linear equations, least-squares problems, and eigenvalue problems, for which highly efficient solvers are required. The module will be based around understanding the mathematical principles underlying the design and the analysis of effective methods and algorithms.

Aims: Understanding how to construct algorithms for solving some problems central in numerical linear algebra and to analyse them with respect to accuracy and computational cost.

Objectives: At the end of the module you will familiar with concepts and ideas related to:

1. various matrix factorisations as the theoretical basis for algorithms,
2. assessing algorithms with respect to computational cost,
3. conditioning of problems and stability of algorithms,
4. direct versus iterative methods.

Books:

AM Stuart and J Voss, *Matrix Analysis and Algorithms*, script.

G Golub and C van Loan, *Matrix Computations*, 3. ed., Johns Hopkins Univ. Press, London 1996.

NJ Higham, *Accuracy and Stability of Numerical Algorithms*, SIAM 1996.

RA Horn and CR Johnson, *Matrix Analysis*, Cambridge University Press 1985.

D Kincaid and W Cheney, *Numerical Analysis*, 3. ed., AMS 2002.

LN Trefethen and D Bau, *Numerical Linear Algebra*, SIAM 1997.

Additional Resources

Archived Pages: Pre-2011 2011 2012 2013 2014 2015

Year 1 Modules

Year 1 regs and modules
G100 G103 GL11 G1NC

Year 2 Modules

Year 2 regs and modules
G100 G103 GL11 G1NC

Year 3 Modules

Year 3 regs and modules
G100 G103

Year 4 Modules
Year 4 regs and modules
G103

Exam Information
Past Exams
Core module averages

MA3D4 Fractal Geometry

(https://warwick.ac.uk/fac/sci/maths/undergrad/ughandbook/year3/ma3d4)
Lecturer: Simon Baker

Term(s): Term 2

Status for Mathematics students: List A

Commitment: 30 one-hour lectures

Assessment: 100% by 3 hour Examination

Prerequisites: MA222 Metric Spaces

Leads To:

Content: Fractals are geometric forms that possess structure on all scales of magnification. Examples are the middle third Cantor set, the von Koch snowflake curve and the graph of a nowhere differentiable continuous function.

The main focus of the module will be the mathematical theory behind fractals, such as the definition and properties of the Hausdorff dimension, which is a number quantifying how ``rough'' the fractal is and which reduces to the usual dimension when applied to Euclidean space. However, more recent developments will be included, such as iterated function systems (used for image compression) where we study how a fractal is approximated by other compact subsets.

Books: K. Falconer, Fractal geometry: mathematical foundations and applications, Wiley, 1990 or 2003. (We shall cover much of the first half of this book.)

Additional Resources

Archived Pages: Pre-2011 2011 2012 2013 2014 2015 2016 2017

Year 1 Modules
Year 1 regs and modules
G100 G103 GL11 G1NC

Year 2 Modules
Year 2 regs and modules
G100 G103 GL11 G1NC

Year 3 Modules
Year 3 regs and modules
G100 G103

MA3D5 Galois Theory

(https://warwick.ac.uk/fac/sci/maths/undergrad/ughandbook/year3/ma3d5)
Lecturer: Dr. Saul Schleimer

Term(s): Term 1

Status for Mathematics students: List A

Commitment: 30 lectures + assessment sheets

Assessment: 3-hour examination (85%), best 3 out of 4 assessed worksheets (15%).

Prerequisites: MA106 Linear Algebra, MA249 Algebra II: Groups and Rings

Leads To:

Content: Galois theory is the study of solutions of polynomial equations. You know how to solve the quadratic equation $ax^2 + bx + c = 0$ by completing the square, or by that formula involving plus or minus the square root of the discriminant $b^2 - 4ac$. The cubic and quartic equations were solved ``by radicals'' in Renaissance Italy. In contrast, Ruffini, Abel and Galois discovered around 1800 that there is no such solution of the general quintic. Although the problem originates in explicit manipulations of polynomials, the modern treatment is in terms of field extensions and groups of ``symmetries'' of fields. For example, a general quintic polynomial over Q has five roots $\alpha_1 \dots . \alpha_5$, and the corresponding symmetry group is the permutation group S_5 on these.

Aims: The course will discuss the problem of solutions of polynomial equations both in explicit terms and in terms of abstract algebraic structures. The course demonstrates the tools of abstract algebra (linear algebra, group theory, rings and ideals) as applied to a meaningful problem.

Objectives: By the end of the module the student should understand

1. Solution by radicals of cubic equations and (briefly) of quartic equations.
2. The characteristic of a field and its prime subfield. Field extensions as vector spaces.
3. Factorisation and ideal theory in the polynomial ring k[x]; the structure of a simple field extension.
4. The impossibility of trisecting an angle with straight-edge and compass.
5. The existence and uniqueness of splitting fields.
6. Groups of field automorphisms; the Galois group and the Galois correspondence.
7. Radical field extensions; soluble groups and solubility by radicals of equations.
8. The structure and construction of finite fields.

Books: DJH Garling, *A course in Galois theory*, CUP.

IN Stewart, *Galois Theory*, Chapman and Hall.

Additional Resources

MA3D9 Geometry of curves and Surfaces

(https://warwick.ac.uk/fac/sci/maths/undergrad/ughandbook/year3/ma3d9)
Lecturer: Dr. Weiyi Zhang

Term(s): Term 1

Status for Mathematics students: List A

Commitment: 30 lectures

Assessment: 3-hour examination (100%)

Prerequisites: MA225 Differentiation, MA231 Vector Analysis Some familiarity with MA222 Metric Spaces may be useful but not essential.

Leads To:

Content: This will be an introduction to some of the ``classical'' theory of differential geometry, as illustrated by the geometry of curves and surfaces lying (mostly) in 3-dimensional space. The manner in which a curve can twist in 3-space is measured by two quantities: its curvature and torsion. The case a surface is rather more subtle. For example, we have two notions of curvature: the gaussian curvature and the mean curvature. The former describes the intrinsic geometry of the surface, whereas the latter describes how it bends in space. The gaussian curvature of a cone is zero, which is why we can make a cone out of a flat piece of paper. The gaussian curvature of a sphere is strictly positive, which is why planar maps of the earth's surface invariably distort distances. One can relate these geometric notions to topology, for example, via the so-called Gauss-Bonnet formula. This is mostly mathematics from the first half of the nineteenth century, seen from a more modern perspective. It eventually leads on to the very general theory of manifolds.

Aims: To gain an understanding of Frenet formulae for curves, the first and second fundamental forms of surfaces in 3-space, parallel transport of vectors and gaussian curvature. To apply this understanding in specific examples.

Books: John McCleary, *Geometry from a differential viewpoint* Cambridge University Press 1994.

Dirk J. Struik, *Lectures on classical differential geometry* Addison-Wesley 1950.

M Do Carmo, *Differential geometry of curves and surfaces*, Prentice Hall.

Additional Resources

Archived Pages: 2011 2015 2017

MA3E1 Groups & Representations

(https://warwick.ac.uk/fac/sci/maths/undergrad/ughandbook/year3/ma3e1)
Lecturer: Professor John Greenlees

Term(s): Term 2

Status for Mathematics students: List A

Commitment: 30 one-hour lectures

Assessment: Assigned work/tests 15%. Three-hour written exam 85%

Prerequisites: The Group theory and linear algebra taught in core modules

Leads To:

Content: The concept of a group is defined abstractly (as set with an associative binary operation, a neutral element, and a unary operation of inversion) but is better understood through concrete examples, for instance

- permutation groups
- matrix groups
- groups defined by generators and relations. All these concrete forms can be investigated with computers. In this module we will study groups by
- finding matrix groups to represent them
- using matrix arithmetic to uncover new properties. In particular, we will study the irreducible characters of a group and the square table of complex numbers they define. Character tables have a tightly-constrained structure and contain a great deal of information about a group in condensed form. *The emphasis of this module will be on the interplay of theory with calculation and examples.*

Aims: To introduce representation theory of finite groups in a hands-on fashion.

Objectives: To enable students to:

- understand matrix and linear representations of groups and their associated modules,

- compute representations and character tables of groups, and
- know the statements and understand the proofs of theorems about groups and representations covered in this module.

Books:

We will work through printed notes written by the lecturer.
A nice book that we shall not use is:
G James & M Liebeck, *Representations and Characters of Groups*, Cambridge University Press, 1993. Second edition, 2001. (IBSN: 052100392X).

Additional Resources

Archived Pages: Pre-2011 2013 2014 2015 2016 2017

Year 1 Modules

Year 1 regs and modules
G100 G103 GL11 G1NC

Year 2 Modules

Year 2 regs and modules
G100 G103 GL11 G1NC

Year 3 Modules

Year 3 regs and modules
G100 G103

Year 4 Modules

Year 4 regs and modules
G103

Exam Information

Past Exams
Core module averages

MA3E5 History of Mathematics

(https://warwick.ac.uk/fac/sci/maths/undergrad/ughandbook/year3/ma3e5)
Lecturer: Jeremy Gray

Term(s): Term 1

Status for Mathematics students: List A

Commitment: 30 one-hour lectures. Students are to submit three essays

Assessment: One essay (500 words, 14%) by week 5. One essay (1,500 words, 26%) by week 8. One essay (2,000 words, 60%) at the start of Term 2. The deadline is enforced as described in the Exams and Assessment section of the Course Handbook.

Prerequisites: Prerequisites: MA133 Differential Equations, MA131 Analysis and MA106 Linear Algebra.

Leads To: Leads To: In terms of the mathematics, the course introduces some of the topics in MA250 Introduction to Partial Differential Equations and MA371 Qualitative Theory of ODEs in their historical settings, but will be studied independently.

Content: Mathematicians seek answers to questions, problems, and challenges of various kinds. They have at their disposal methods that may or may not work, and they get answers that may or may not be any use. This is clearest in mathematical physics (e.g. when a power series converges too slowly to be any help) but it can also be true in pure mathematics. This is a historical course about getting good answers to good problems in mathematics.

Aims: The module aims to:

- consider topics in the history of ordinary and partial differential equations from their introduction in the 17th century to the early 20th century;
- discuss what was taken to be so important about them.

Objectives:

- To develop a critical sense of what was, and even what is, important and exciting about mathematics and its evolution.
- To raise questions about the rigour in mathematics and its relation to problem solving.

Books: A full set of Lecture Notes will be provided. There is no book on the topic, and in that sense the course will present the result of ongoing historical research. There are some specialist treatments of individual topics, and these will be pointed out as and when they are relevant.

Additional Resources

Year 1 Modules

Year 1 regs and modules
G100 G103 GL11 G1NC

Year 2 Modules

Year 2 regs and modules
G100 G103 GL11 G1NC

Year 3 Modules

Year 3 regs and modules
G100 G103

Year 4 Modules

Year 4 regs and modules
G103

Exam Information

Past Exams
Core module averages

History of Maths 2016 Results

(https://warwick.ac.uk/fac/sci/maths/undergrad/ughandbook/year3/ma3e5/2016results)
Please find below your final marks for the 2015/16 History of Maths module which have changed for some of the students registered on it since the Exam Board first met due to an unfortunate administrative error. Any finalist for whom this has changed a Board decision will have been contacted already by email, all students whose marks have changed will have been looked at again by the Board.

The Maths Department is extremely sorry for any inconvenience or worry caused by this, we are putting in place procedures so that this will not happen again in future years, and are very aware that, in this instance, something went wrong that shouldn't have. Apologies.

Dave

Dr. David Wood
Director of Undergraduate Studies (Maths)

MA3F1 Introduction to Topology

(https://warwick.ac.uk/fac/sci/maths/undergrad/ughandbook/year3/ma3f1)
Lecturer: Martin Lotz

Term(s): Term 1

Status for Mathematics students: List A

Commitment: 30 one-hour lectures

Assessment: One 3-hour examination (85%), assignments (15%)

Prerequisites: MA132 Foundations, MA251 Algebra I, MA222 Metric Spaces

Leads To: MA3H6 Algebraic Topology,MA3H5 Manifolds, MA3F2 Knot Theory.

Content:
Topology is the study of properties of spaces invariant under continuous deformation. For this reason it is often called ``rubber-sheet geometry''. The module covers: topological spaces and basic examples; compactness; connectedness and path-connectedness; identification topology; Cartesian products; homotopy and the fundamental group; winding numbers and applications; an outline of the classification of surfaces.

Aims:
To introduce and illustrate the main ideas and problems of topology.

Objectives:
To explain how to distinguish spaces by means of simple topological invariants (compactness, connectedness and the fundamental group); to explain how to construct spaces by gluing and to prove that in certain cases that the result is homeomorphic to a standard space; to construct simple examples of spaces with given properties (eg compact but not connected or connected but not path connected).

Books:
Chapter 1 of Allen Hatcher's book Algebraic Topology

MA Armstrong *Basic Topology* Springer (recommended but not essential).

Additional Resources

Archived Pages: 2011 2012 2013 2014 2015 2016 2017

Year 1 regs and modules
G100 G103 GL11 G1NC

Year 2 regs and modules
G100 G103 GL11 G1NC

Year 3 regs and modules
G100 G103

Year 4 regs and modules
G103

MA3G7 Functional Analysis I

(https://warwick.ac.uk/fac/sci/maths/undergrad/ughandbook/year3/ma3g7)
Lecturer: Professor Vassili Gelfreich

Term(s): Term 1

Status for Mathematics students: List A

Commitment: 30 lectures

Assessment: 3 hour examination

Prerequisites: MA244 Analysis III (or MA258 Mathematical Analysis III); MA225 Differentiation and MA222 Metric Spaces would be useful but not essential; MA359 Measure Theory would be a natural course to take in parallel.

Leads To: MA3G8 Functional Analysis II, MA4A2 Advanced PDEs, MA4L3 Large Deviation theory.

Content: This is essentially a module about infinite-dimensional Hilbert spaces, which arise naturally in many areas of applied mathematics. The ideas presented here allow for a rigorous understanding of Fourier series and more generally the theory of Sturm-Liouville boundary value problems. They also form the cornerstone of the modern theory of partial differential equations.

Hilbert spaces retain many of the familiar properties of finite-dimensional Euclidean spaces ($\mathbb{R}^n$) - in particular the inner product and the derived notions of length and distance - while requiring an infinite number of basis elements. The fact that the spaces are infinite-dimensional introduces new possibilities, and much of the theory is devoted to reasserting control over these under suitable conditions.

The module falls, roughly, into three parts. In the first we will introduce Hilbert spaces via a number of canonical examples, and investigate the geometric parallels with Euclidean spaces (inner product, expansion in terms of basis elements, etc.). We will then consider various different notions of convergence in a Hilbert space, which although equivalent in finite-dimensional spaces differ in this context. Finally we consider properties of linear operators between Hilbert spaces (corresponding to the theory of matrices between finite-dimensional spaces), in particular recovering for a special class of such operators (compact self-adjoint operators) very similar results to those available in the finite-dimensional setting.

Throughout the abstract theory will be motivated and illustrated by more concrete examples.

Books: A useful book to use as an accompanying reference is:
BP Rynne & MA Youngson, *Linear Functional Analysis*, Springer-Verlag, London, 2000.

Additional Resources

Archived Pages: 2011 2013 2014 2015 2016 2017

Year 1 Modules
Year 1 regs and modules
G100 G103 GL11 G1NC

Year 2 Modules
Year 2 regs and modules
G100 G103 GL11 G1NC

Year 3 Modules
Year 3 regs and modules
G100 G103

MA3H1 Topics in Number Theory

(https://warwick.ac.uk/fac/sci/maths/undergrad/ughandbook/year3/ma3h1)

Not Running in 2015/16

Lecturer:

Term(s):

Status for Mathematics students: List A

Commitment: 30 lectures, plus a willingness to work hard at the homework

Assessment: 15% by a number of assessed worksheets, 85% by 3-hour examination

Prerequisites: First-year mathematics and common sense. This module is **independent** of MA246 Number Theory and can be taken regardless of whether or not you have done MA246.

Leads To: MA3A6 Algebraic Number Theory, MA426 Elliptic Curves.

Content: We will cover the following topics:

1. Review of factorisation, divisibility, Euclidean Algorithm, Chinese Remainder Theorem.
2. Congruences. Structure on $/m$ and U_m. Theorems of Fermat and Euler. Primitive roots.
3. Quadratic reciprocity, Diophantine equations
4. Tonelli-Shanks, Fermat's factorization, Quadratic Sieve.
5. Introduction to Cryptography (RSA, Diffie-Hellman)
6. p-adic numbers, Hasse Principle
7. Geometry of numbers, sum of two and four squares
8. Irrationality and trancendence
9. Binary quadratic forms, genus theory (ONLY if time allows!)

Books:

R. P. Burn, A Pathway into Number Theory, Cambridge University Press, 1997.

H. Davenport, The Higher Arithmetic, Cambridge University Press.

G. H. Hardy and E. M. Wright, An Introduction to the Theory of Numbers, Oxford University Press, 1979.

K. Ireland and M. Rosen, A Classical Introduction to Modern Number Theory, Springer-Verlag, 1990.

I. Niven, H. S. Zukerman and H. L. Montgomery, An Introduction to the Theory of Numbers, John Wiley, 1991.

H. E. Rose, A Course in Number Theory, Oxford University Press, 1988.

W. Stein, Elementary Number Theory: Primes, Congruences, and Secrets, Springer-Verlag, 2008. Online version available from `http://modular.math.washington.edu/ent/ent.pdf`

Additional Resources

Year 1 Modules
Year 1 regs and modules
G100 G103 GL11 G1NC

MA3H3 Set Theory

(https://warwick.ac.uk/fac/sci/maths/undergrad/ughandbook/year3/ma3h3)
Lecturer: András Máthé

Term(s): Term 1

Status for Mathematics students: List A

Commitment: 30 lectures

Assessment: 3 hour exam 100%

Prerequisites: MA132 Foundations or PH126 Starting Formal Logic. Some exposure to at least one of MA222 Metric Spaces, MA359 Measure Theory or PH210 Symbolic Logic is also recommended

Leads To:

Content: Set theoretical concepts and formulations are pervasive in modern mathematics. For this reason it is often said that set theory provides a foundation for mathematics. Here `foundation' can have multiple meanings. On a practical level, set theoretical language is a highly useful tool for the definition and construction of mathematical objects. On a more theoretical level, the very notion of a foundation has definite philosophical overtones, in connection with the reducibility of knowledge to agreed first principles.

The module will commence with a brief review of naive set theory. Unrestricted set formation leads to various paradoxes (Russell, Cantor, Burali-Forti), thereby motivating axiomatic set theory. The Zermelo-Fraenkel system will be introduced, with attention to the precise formulation of axioms and axiom schemata, the role played by proper classes, and the cumulative hierarchy picture of the set theoretical universe. Transfinite induction and recursion, cardinal and ordinal numbers, and the real number system will all be developed within this framework. The Axiom of Choice, and various equivalents and consequences, will be discussed; various other principles also known to be independent of Zermelo-Fraenkel set theory, such as the Continuum Hypothesis and the existence of Inaccessible Cardinals, will be touched on.

Books:

- *Set Theory*, T. Jech (a comprehensive advanced text which goes well beyond the above syllabus)
- *Notes on set theory*, Y. Moschovakis
- *Elements of set theory*, H. Enderton
- *Introduction to set theory*, K. Hrbacek and T. Jech

Additional Resources

Archived Pages: Pre-2011 2011 2012 2013 2014 2015 2016 2017

MA3H4 Random Discrete Structures

(https://warwick.ac.uk/fac/sci/maths/undergrad/ughandbook/year3/ma3h4)

Not Running in 2015/16

Lecturer:

Term(s):

Status for Mathematics students: List A

Commitment: 30 lectures

Assessment: 3 hour exam 85%, assigned exercises 15%

Prerequisites: MA132 Foundations or PH126 Starting Formal Logic. Some exposure to at least one of MA222 Metric Spaces, MA359 Measure Theory or PH210 Symbolic Logic is also recommended

Leads To:

Content: Random discrete structures such as random graphs or matrices play a crucial role in discrete mathematics, because they enjoy properties that are difficult (or impossible) to obtain via deterministic constructions. For example, random structures are essential in the design of algorithms or error correcting codes. Furthermore, random discrete structures can be used to model a large variety of objects in physics, biology, or computer science (e.g., social networks). The goal of this course is to convey the most important models and the main analysis techniques, as well as a few instructive applications. Topics include

- fundamentals of discrete probability distributions,
- techniques for the analysis of rare events,
- random trees and graphs,
- applications in statistical mechanics,
- sampling and rapid mixing,

- applications in efficient decoding. The module is suitable for students of mathematics or discrete mathematics.

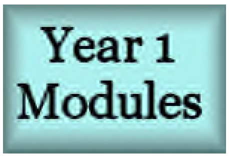
Aims:

- To acquire knowledge of the basic phenomena that occur in random discrete structures.
- To gain competence in using basic techniques such as the first and second moment method.
- To understand large deviations phenomena.
- To be in a position to apply random structures in physics or computer science.

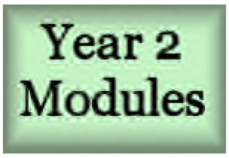
Books:

Alon, Spencer: The probabilistic method. Wiley 2000. Dembo, Montanari: Gibbs measures and phase transitions on sparse random graphs. Stanford 2009. Durrett: Random graph dynamics. Combridge 2007. Janson, Luczak, Rucinski: Random graphs. Wiley 2000.

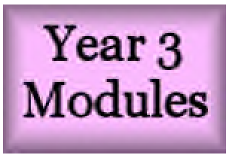
Additional Resources



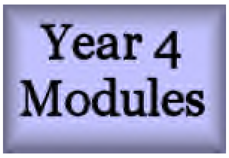
Year 1 regs and modules
G100 G103 GL11 G1NC



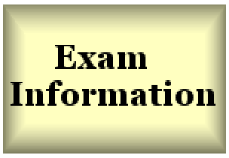
Year 2 regs and modules
G100 G103 GL11 G1NC



Year 3 regs and modules
G100 G103



Year 4 regs and modules
G103



Past Exams
Core module averages

MA3H5 Manifolds

(https://warwick.ac.uk/fac/sci/maths/undergrad/ughandbook/year3/ma3h5)
Lecturer: Brian Bowditch

Term(s): Term 1

Status for Mathematics students: List A

Commitment: 30 hours

Assessment: Three hour examination (100%)

Prerequisites: Basic theory of differentiation, including statements (though not proofs) of Inverse and Implicit Function Theorems. Integration in several variables. MA225 Differentiation, Basic topology, including compactness and connectedness, MA222 Metric Spaces, Basic theory of differentiation, including statements (though not proofs) of Inverse and Implicit Function Theorems.

Leads To: MA4C0 Differential Geometry.
Also useful for:
MA4E0 Lie groups
It might also be a useful complement to the Year 3 module:
MA3D9 Geometry of Curves and Surfaces.

Content:
Smooth manifolds are generalisations of the notion of curves and surfaces R^3 and provide a rigorous mathematical concept of space as well as a natural setting for analysis. They form a fundamental part of modern mathematics and are used widely in pure and applied subjects such as differential geometry, general relativity and partial differential equations. Almost all the manifolds discussed in the course will be assumed to have a smooth structure. This allows us to perform the standard operations of differentiation in a very general context. We will begin by discussing manifolds embedded in euclidean space, R^n. We develop some of the basic notions such as smooth maps and tangent spaces in this context. We go on to describe the notion of an abstract manifold, and explain how these concepts generalise. We discuss basic concepts of orientability, differential forms and integration. Time permitting, we will aim to give a proof of the general form of Stokes's Theorem. We may briefly touch on subjects such as riemannian manifolds and Lie groups. These are the subject of dedicated courses in the 4th year.

Syllabus:
Manifolds in euclidean space, smooth maps, tangent spaces, immersions and submersions, tangent and normal bundles, orientations, abstract manifolds, vector bundles, partitions of unity, differential forms, integration, Stokes's theorem.

Books:
Tu, L. W. An Introduction to Manifolds, Springer-Verlag
Lee, J .M. Introduction to Smooth Manifolds, Springer-Verlag
Warner, F. Foundations of differentiable manifolds and Lie groups, Springer-Verlag
Boothby, W. An introduction to differentiable manifolds and Riemannian geometry, Academic Press

Additional Resources

Archived Pages: 2011 2012 2013 2014

Year 1 Modules

Year 1 regs and modules
G100 G103 GL11 G1NC

Year 2 Modules

Year 2 regs and modules
G100 G103 GL11 G1NC

Year 3 Modules

Year 3 regs and modules
G100 G103

Year 4 Modules

Year 4 regs and modules
G103

Exam Information

Past Exams

Core module averages

MA3J1 Tensors, Spinors and Rotations

(https://warwick.ac.uk/fac/sci/maths/undergrad/ughandbook/year3/ma3j1)

Not Running 2016/17

Lecturer: Dmitriy Rumynin

Term(s): 2

Status for Mathematics students: List A

Commitment: 30 hours

Assessment: Three hour examination (85%), coursework (15%)

Prerequisites: MA251 Algebra I: Advanced Linear Algebra and MA249 Algebra II

Leads To and/or related to:
MA3E1 Groups & Representations, MA3H6 Algebraic Topology, MA377 Rings and Modules, MA4C0 Differential Geometry, MA4E0 Lie Groups and MA4J1 Continuum Mechanics

Content:

This module will be in the spirit of Algebra-I rather than Algebra-II. In fact, it could have even been called Very Advanced Linear Algebra. It will focus on explicit calculations with various linear algebraic objects, such as multilinear forms, which are a generalised version of linear functionals and bilinear forms. It could be useful in a range of modules.

Quaternions were discovered by Hamilton in 1843. We will introduce quaternions and develop computational techniques for 3D and 4D orthogonal transformations.

The word tensor was introduced by Hamilton at the time of discovery of quaternions. It used to mean the quaternionic absolute value. It acquired its modern meaning only in 1898, by which time Ricci had developed his Theory of Curvature (a prime example of tensor in Geometry). Later tensors spread not only to Algebra and Topology but also to some faraway disciplines such as Continuum Mechanics (elasticity tensor) and General Relativity (stress-energy tensor). Our study of tensors will concentrate on understanding the concepts and computation: we will not have time to develop any substantial applications.

When Elie Cartan discovered spinors in 1913, he could hardly imagine the role they would play in Quantum Physics. In 1928 Dirac wrote his celebrated electron equation, and since then there was no way back for spinors. According to Atiyah, “No one fully understands spinors. Their algebra is formally understood but their general significance is mysterious. In some sense they describe the “square root” of geometry and, just as understanding the square root of −1 took centuries, the same might be true of spinors.”

As with tensors, our study of spinors will concentrate on understanding the concepts and computation: we will not have time to do any Physics. We plan to finish the module with Bott Periodicity for Clifford algebras.

Objectives:
This course will give the student a solid grounding in tensor algebra which is used in a wide range of disciplines.

Books:
There will be lecture notes. Some great books that the module will follow locally are:
Rotations, Quaternions, and Double Groups, by Simon L Altmann
The Algebraic Theory of Spinors, by Claude Chevalley
The Construction and Study of Certain Important Algebras, by Claude Chevalley
Rethinking Quaternions, by Ron Goldman
Quick Introduction to Tensor Analysis, by Ruslan Shapirov
Tensor Spaces and Exterior Algebras, by Takeo Yokonuma

Additional Resources

Year 1 Modules

Year 1 regs and modules

G100 G103 GL11 G1NC

MA372 Reading Course

(https://warwick.ac.uk/fac/sci/maths/undergrad/ughandbook/year3/ma372)
Term(s): Terms 1-2

Status for Mathematics students: List A

Commitment: Mostly independent study with guidance from staff member offering the module

Assessment: 100% by 3 hour exam

Content:
This scheme is designed to allow any student to offer for exam any reasonable piece of mathematics not covered by the lecture modules, for example a 3rd/4th year or M.Sc. module given at Warwick in a previous year. Any topic approved for one student will automatically be brought to the attention of the other students in the year. Note that a student offering this option will be expected to work largely on his or her own.

The aims of this option are (a) to extend the range of mathematical subjects available for examination beyond those covered by the conventional lecture modules, and (b) to encourage the habit of independent study. In the following outline regulations, the term ``book'' includes such items as published lecture notes, one or more articles from mathematical journals, etc.

1. A student wishing to offer a book for a reading module must first find a member of staff willing to act as moderator. The moderator will be responsible for obtaining approval of the module from the Director of Undergraduate Studies of the Mathematics Department, and for circulating a detailed syllabus to all 3rd and 4th year Mathematics students before the end of Term 1 registrations (week 3).

2. The moderator will be responsible for setting a three-hour exam paper, to be taken during one of the examination sessions in Term 3.

3. The mathematical level and content of a reading module must be at least that of a standard 15 CATS 3rd Year Mathematics module. A reading module must not overlap significantly with any other module in the university available to 3rd Year Mathematics students.

4. Students may not take more than one reading module in any one year (MA372, MA472 or a reading module with its own code).

Additional Resources

Archived Pages: 2011 2013 2016 2017

MA395 Essay

(https://warwick.ac.uk/fac/sci/maths/undergrad/ughandbook/year3/ma395)
Organiser: Roman Kotecký

Term(s): Terms 1-2

Status for Mathematics students: List A - a student may offer at most one MA395 essay. Not available to 4th Year MMath students

Commitment:

Assessment: Essay 80%, Oral Presentation 20%

Aims: The 3rd year essay offers the opportunity of producing an original and personal account of a mathematical topic of your own choice going beyond the scope of existing lecture modules. It will test your ability to understand new mathematical ideas without detailed guidance, to use the library in a resourceful and scholarly way, and to produce a personal account of a piece of maths. The essay should be 6,000-8,000 words in length, and comparable in content to ten lectures from a 3rd year maths module. As a rough guide, you should expect to spend at least 100 hours on this option. You are supposed to find a member of staff willing to give you, and advise on, a choice of the topic (to learn about scientific interests of members of staff in the domain of mathematics you are interested in is already a part of your task) who will be also responsible for the marking and suggesting the second marker.

Deadlines: You are supposed to find your supervisor within the first weeks of Term 1 and register for your essay (name of the supervisor and title of the essay) at the undergraduate office before the end of week 5.

The essay must normally be submitted to the Undergraduate Office by 12:00 noon on Thursday of the first week of Term 3. This deadline is enforced by the mechanism described in the Course Handbook section on Assessment. The oral presentation should be completed in week 3 or 4 of Term 3.

Essay: The essay makes up 80% of the mark for this module. It will be marked on various aspects such as presentation, referencing, content, understanding and originality. The markers will be given more guidance, but they do have the flexibility to give more weight to some aspects than others depending on whether the essay is, for example, an exposition of a known result or an investigation of an original problem. Cases of plagiarism will be dealt with severely, so please make sure that you reference material that has been taken from elsewhere correctly (see, for example, the documents listed in the resources for the second year essay).

Oral Presentation: 20% of the module mark comes from an oral presentation. This presentation should consist of a talk of approximately 20-30 minutes length followed by questions. The whole process should take less than one hour. You should arrange the time and venue for the talk with the supervisor of the essay, and it is usual for both the supervisor and second marker to attend.

The purpose of the presentation is to demonstrate your understanding of the material contained within the essay and to clarify anything that the examiners feel requires further explanation; the marking will reflect this. With this in mind, in preparation you should concentrate on organising the content in a coherent manner (and choosing which aspects of the essay to concentrate on and which to leave out). You should not spend a lot of time producing a glossy presentation - all that is required is a simple but clear presentation and a willingness to answer questions on the content of your essay. If you wish you may use the blackboard, or a short handout, or uncomplicated slides.

The oral is not supposed to be a performance, and students who are nervous or find public speaking difficult will not be at a disadvantage. Marks will be given for clarity and organisation of the presentation, and for answering questions about and demonstrating understanding of the material in the essay.

Tip: You should also bear in mind that 20 to 30 minutes is not actually a very long time (as you may appreciate from your second year essay presentation), and should certainly try to make sure that you have a dry run through beforehand, perhaps in front of housemates.

MA377 Rings and Modules

(https://warwick.ac.uk/fac/sci/maths/undergrad/ughandbook/year3/ma377)
Lecturer: Dr. Diane Maclagan

Term(s): Term 1

Status for Mathematics students: List A

Commitment: 30 lectures

Assessment: 85% by 3-hour examination 15% coursework

Prerequisites: MA106 Linear Algebra, familiarity with elementary group theory and the ring theory part of MA249 Algebra II: Groups and Rings is desirable

Leads To:

Content: A ring is an important fundamental concept in algebra and includes integers, polynomials and matrices as some of the basic examples. Ring theory has applications in number theory and geometry. A module over a ring is a generalization of vector space over a field. The study of modules over a ring *R* provides us with an insight into the structure of *R*. In this module we shall develop ring and module theory leading to the fundamental theorems of Wedderburn and some of its applications.

Aims: To realise the importance of rings and modules as central objects in algebra and to study some applications.

Objectives: By the end of the course the student should understand:

- The importance of a ring as a fundamental object in algebra.
- The concept of a module as a generalisation of a vector space and an Abelian group.

- Constructions such as direct sum, product and tensor product.
- Simple modules, Schur's lemma.
- Semisimple modules, artinian modules, their endomorphisms. Examples.
- Radical, simple and semisimple artinian rings. Examples.
- The Artin-Wedderburn theorem.
- The concept of central simple algebras, the theorems of Wedderburn and Frobenius.

Books: Recommended Reading:
Abstract Algebra by David S. Dummit, Richard M. Foote, ISBN: 0471433349
Noncommutative Algebra (Graduate Texts in Mathematics) by Benson Farb, R. Keith Dennis, ISBN: 038794057X

Additional Resources

Archived Pages: 2011 2015 2016 2017

Year 1 Modules

Year 1 regs and modules
G100 G103 GL11 G1NC

Year 2 Modules

Year 2 regs and modules
G100 G103 GL11 G1NC

Year 3 Modules

Year 3 regs and modules
G100 G103

Year 4 Modules

Year 4 regs and modules
G103

Exam Information

Past Exams
Core module averages

MA3A6 Algebraic Number Theory

(https://warwick.ac.uk/fac/sci/maths/undergrad/ughandbook/year3/ma3a6)
Lecturer: Dr. Martin Orr

Term(s): Term 2

Status for Mathematics students: List A

Commitment: 30 one-hour lectures.

Assessment: Three-hour examination (85%), assignments (15%)

Prerequisites: MA251 Algebra I, MA249 Algebra II

Leads To:

Content: Algebraic number theory is the study of algebraic numbers, which are the roots of monic polynomials

$$x^n + a_{n-1}x^{n-1} \ \cdots + a_1x + a_0$$

with rational coefficients, and algebraic integers, which are the roots of monic polynomials with integer coefficients. So, for example, the nth roots of natural numbers are algebraic integers, and so is

$$\frac{\sqrt{5}\ +\ 1}{2}$$

The study of these types of numbers leads to results about the ordinary integers, such as determining which of them can be expressed as the sum of two integral squares, proving that any natural number is a sum of four squares and, as a much more advanced application, which combines algebraic number theory with techniques from analysis, the proof of Fermat's Last Theorem.

One of the differences between rings of algebraic integers and the ordinary integers, is that we do not always get unique factorization into irreducible elements. For example, in the ring

$$\{a + b\sqrt{-5}\ \mid\ a, b\ \in\ Z\ \},$$

it turns out that 6 has two distinct factorizations into irreducibles:

$$6 = 2 \times\ 3$$

and

$$6 = (1 - \sqrt{-5}) \times (1 + \sqrt{-5}).$$

However, we do get a unique factorization theorem for ideals, and this is the central result of the module.

This main result will be followed by some more straightforward geometric material on lattices in n, with applications to sums of squares theorems, and then finally various groups associated with the ideals in a number field.

- Algebraic numbers, algebraic integers, algebraic number fields, integral bases, discriminants, norms and traces.
- Quadratic and cyclotomic fields.
- Factorization of algebraic integers into irreducibles, Euclidean and principal ideal domains.
- Ideals, and the prime factorization of ideals.
- Lattices.
- Minkowski's Theorem. Application: every integer is the sum of four squares.
- The geometric representation of algebraic numbers.
- The ideal class group.

Aims: To demonstrate that uniqueness of factorization into irreducibles can fail in rings of algebraic integers, but that it can be replaced by the uniqueness of factorization into prime ideals.

To introduce some geometric lattice-theoretic techniques and their applications to algebraic number theory.

Objectives: By the end of the course students will:

- be able to compute norms and discriminants and to use them to determine the integer rings in algabraic number fields;
- be able to factorize ideals into prime ideals in algebraic number fields in straightforward examples;
- understand the proof of Minkowski's Theorem on lattices, and be able to apply it, for example, to prove that all positive integers are the sum of four squares.

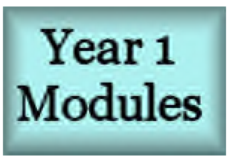
Books:

This module is based on the book *Algebraic Number Theory and Fermat's Last Theorem*, by I.N. Stewart and D.O. Tall, published by A.K. Peters (2001). The contents of the module forms a proper subset of the material in that book. (The earlier edition, published under the title *Algebraic Number Theory*, is also suitable.)

For alternative viewpoints, students may also like to consult the books *A Brief Guide to Algebraic Number Theory*, by H.P.F. Swinnerton-Dyer (LMS Student Texts # 50, CUP), or *Algebraic Number Theory*, by A. Fröhlich and M.J. Taylor (CUP).

Additional Resources

Archived Pages: 2011 2012 2013 2014 2015 2016 2017



Year 1 regs and modules
G100 G103 GL11 G1NC

MA3B8 Complex Analysis

(https://warwick.ac.uk/fac/sci/maths/undergrad/ughandbook/year3/ma3b8)
Lecturer: Dr. Stefan Adams

Term(s): Term 2

Status for Mathematics students: List A

Commitment: 30 one-hour lectures

Assessment: 3 hour examination (85%) and in term assignments (15%)

Prerequisites: MA225 Differentiation MA244 Analysis III, and MA231 Vector Analysis. MA3F1 Introduction to Topology would be helpful but not essential.

Leads To: MA475 Riemann Surfaces.

Content: The course focuses on the properties of differentiable functions on the complex plane. Unlike real analysis, complex differentiable functions have a large number of amazing properties, and are very ``rigid'' objects. Some of these properties have been explored already in Vector Analysis. Our goal will be to push the theory further, hopefully revealing a very beautiful classical subject.

We will start with a review of elementary complex analysis topics from vector analysis. This includes complex differentiability, the Cauchy-Riemann equations, Cauchy's theorem, Taylor's and Liouville's theorem, Laurent expansions. Most of the course will be new topics: Winding numbers, the generalized version of Cauchy's theorem, Morera's theorem, the fundamental theorem of algebra, the identity theorem, classification of singularities, the Riemann sphere and Weierstrass-Casorati theorem, meromorphic functions, Rouche's theorem, integration by residues.

Books:

Stewart and Tall, *Complex Analysis: (the hitchhiker's guide to the plane)*, (Cambridge University Press).

Conway, *Functions of one complex variable*, (Springer-Verlag).

Ahlfors, *Complex Analysis: an introduction to the theory of analytic functions of one complex variable*, (McGraw-Hill Book Co).

Additional Resources

Archived Pages: 2011 2012 2013 2014 2015 2017

MA3D1 Fluid Dynamics

(https://warwick.ac.uk/fac/sci/maths/undergrad/ughandbook/year3/ma3d1)
Lecturer: James Sprittles

Term(s): Term 2

Status for Mathematics students: List A

Commitment: 30 lectures

Assessment: 3 hour exam

Prerequisites: MA231 Vector Analysis and MA250 PDEs.
MA3B8 Complex Analysis is desirable.

Leads To:

Content: The lectures will provide a solid background in the mathematical description of fluid dynamics. They will cover the derivation of the conservation laws (mass, momentum,energy) that describe the dynamics of fluids and their application to a remarkable range of phenomena including water waves, sound propagation, atmospheric dynamics and aerodynamics. The focus will be on deriving approximate expressions using (usually) known mathematical techniques that yield analytic (as opposed to computational) solutions.

The module will cover the following topics:

- ***Mathematical modelling of fluid flow.*** Specification of the flow by field variables; vorticity; stream function; strain tensor; stress tensor. Euler's equation. Navier-Stokes equation. Introduction of non-dimensional parameters
- ***Additional conservation laws***. Bernoulli's equations. Global conservation laws.
- ***Vortex dynamics***. Kelvin's circulation theorem. Helmholtz theorems. Cauchy-Lagrange theorem. 3D vorticity equation, vortex lines, vortex tubes and vortex stretching.
- ***2D flows***. Flow in a pipe. Shear flows. Jet flow by similarity solution. Round vortices.

- ***Irrotational 2D flows & classical aerofoil theory***. Complex analysis methods in Fluid Dynamics. Blasius theorem. Zhukovskii lift theorem. Force on a cylinder and force on an aerofoil.
- ***Rotating flows.*** Navier-Stokes in a rotating frame. Rossby number. Taylor-Proudman theorem. Geophysical flow.
- ***Boundary layers.*** Prandtl's boundary layer theory. Ekman boundary layer in rotating fluids.
- ***Waves***. General theory of waves. Sound waves. Free-surface flows & surface tension. Gravity-capillary water waves.
- ***Instabilities.*** Rayleigh criterion. Orr-Sommerfeld equation. Kelvin-Helmholtz instability. Stability of parallel flows.

Aims:
An important aim of the module is to provide an appreciation of the complexities and beauty of fluid motion. This will be highlighted in class using videos of the phenomena under consideration (usually available on YouTube).

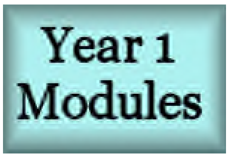
Objectives: It is expected that by the end of this module students will be able to:
- be able to understand the derivation of the equations of fluid dynamics
- master a range of mathematical techniques that enable the approximate solution to the aforementioned equations
- be able to interpret the meanings of these solutions in 'real life' problems

Strongly recommended texts:
D.J. Acheson, Elementary Fluid Dynamics, OUP. (Excellent text with derivations, examples and solutions)
S. Nazarenko, *Fluid Dynamics via Examples and Solutions*, Taylor and Francis. (Great source of questions and detailed solutions.)

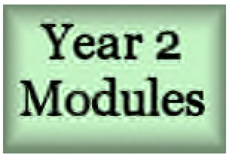
Further Reading:
A.R. Paterson, *A First Course in Fluid Dynamics*, CUP. (Easier than Acheson.)
L.D. Landau and E.M. Livshitz, *Fluid Mechanics*, OUP. (A classic for those with a deep interest in fluid dynamics in modern physics.)
D.J. Tritton, Physical Fluid Dynamics , Oxford Science Publs. (The emphasis is on the physical phenomena and less on the mathematics.)

Additional Resources

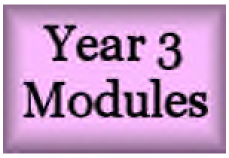
Archived Pages: Pre-2011 2012 2013 2014 2015 2017



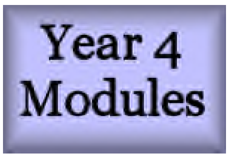
Year 1 regs and modules
G100 G103 GL11 G1NC



Year 2 regs and modules
G100 G103 GL11 G1NC



Year 3 regs and modules
G100 G103



Year 4 regs and modules
G103

Past Exams
Core module averages

MA3F2 Knot Theory

(https://warwick.ac.uk/fac/sci/maths/undergrad/ughandbook/year3/ma3f2)
Lecturer: Daan Krammer

Term(s): Term 2

Status for Mathematics students: List A

Commitment: 30 lectures

Assessment: 3 hour exam

Prerequisites: MA3F1 Introduction to Topology

Leads To: MA408 Algebraic Topology and MA447 Homotopy Theory.

Content: A knot is a smooth embedded circle in R^3. After a geometric introduction of knots our approach is rather algebraic, heavily leaning on Reidemeister moves.

Prerequisites: Little more than linear algebra plus an ability to visualise objects in 3-dimensions. Some knowledge of groups given by generators and relations, and some basic topology would be helpful.

Books:

Listed in order of accessibility:

Colin C Adams, *The Knot Book*, W H Freeman, 1994.

Livingston, Charles. *Knot Theory* Washington, DC: Math. Assoc. Amer., 1993. 240 p.

N.D. Gilbert and T. Porter, *Knots and surfaces*, Oxford, Oxford University Press, 1994.

Peter Cromwell, *Knots and Links*, CUP, 2004.

Louis H. Kauffman, *Knots and physics*, Singapore, Teaneck, N.J., World Scientific, 1991 Series on knots and everything, v.1.

Louis H. Kauffman, *On knots*, Princeton, N.J., Princeton University Press, 1987 Annals of mathematics studies, 115.

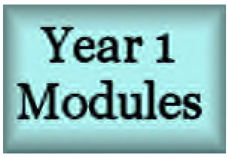
Dale Rolfsen, *Knots and links*, Berkeley, CA, Publish or Perish, c1976 Mathematics lecture series, 7.

Gerhard Burde, Heiner Zieschang, *Knots*, Berlin, New York, W. De Gruyter, 1985 De Gruyter studies in mathematics, 5.

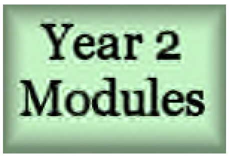
Lectures from previous years are available on the web.

Additional Resources

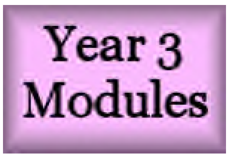
Archived Pages: 2014 2015 2016 2017



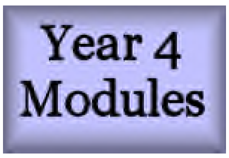
Year 1 regs and modules
G100 G103 GL11 G1NC



Year 2 regs and modules
G100 G103 GL11 G1NC



Year 3 regs and modules
G100 G103



Year 4 regs and modules
G103

MA3G0 Modern Control Theory (now MA3H7)

(https://warwick.ac.uk/fac/sci/maths/undergrad/ughandbook/year3/ma3g0)

Please note that this module is now being taught as MA3H7

Status for Mathematics students: List A

Commitment: 30 one-hour lectures plus 8 example classes

Assessment: 3 hour examination

Prerequisites: MA106 Linear Algebra. , MA133 Differential Equations

Leads To:

Content: Will include the study of controllability, stabilization, observability, filtering and optimal control. Furthermore connections between these concepts will also be studied. Both linear and nonlinear systems will be considered. The module will comprise six chapters. The necessary background material in linear algebra, differential equations and probability will be developed as part of the course.

1. Introduction to Key Concepts.
2. Background Material.
3. Controllability.
4. Stabilization.
5. Observability and Filtering.
6. Optimal Control.

Aims: The aim of the module is to show how, as a result of extensive interests of mathematicians, control theory has developed from being a theoretical basis for control engineering into a versatile and active branch of applied mathematics.

Objectives: The objective is to ensure the aims are carried out by teaching the state space theory approach as outlined in the syllabus.

Books:

E. D. Sontag, *Mathematical Control Theory*, Texts in Applied Mathematics No 6, Springer Verlag, 1990.

J. Zabczyk, *Mathematical Control Theory: An Introduction*, Systems and Control, Birkhauser, 1992.

MA3G1 Theory of Partial Differential Equations

(https://warwick.ac.uk/fac/sci/maths/undergrad/ughandbook/year3/ma3g1)

Lecturer: Julian Braun

Term(s): Term 2

Status for Mathematics students: List A

Commitment: 30 lectures

Assessment: Exam 100%

Prerequisites: This module uses material from many of the Core 1st and 2nd year modules, particularly MA231 Vector Analysis, MA244 Analysis III and MA250 Introduction to Partial Differential Equations. A student taking this module will benefit from having taken MA222 Metric Spaces but this not a formal prerequisite.

Leads To: MA4L3 Large Deviation theory

Content:
The important and pervasive role played by pdes in both pure and applied mathematics is described in MA250 Introduction to Partial Differential Equations. In this module I will introduce methods for solving (or at least establishing the existence of a solution!) various types of pdes. Unlike odes, the domain on which a pde is to be solved plays an important role. In the second year course MA250, most pdes were solved on domains with symmetry (eg round disk or square) by using special methods (like separation of variables) which are not applicable on general domains. You will see in this module the essential role that much of the analysis you have been taught in the first two years plays in the general theory of pdes. You will also see how advanced topics in analysis, such as MA3G7 Functional Analysis I, grew out of an abstract formulation of pdes. Topics in this module include:

- Method of characteristics for first order PDEs.
- Fundamental solution of Laplace equation, Green's function.
- Harmonic functions and their properties, including compactness and regularity.
- Comparison and maximum principles.
- The Gaussian heat kernel, diffusion equations.
- Basics of wave equation (time permitting).

Aims:
The aim of this course is to introduce students to general questions of existence, uniqueness and properties of solutions to partial differential equations.

Objectives:
Students who have successfully taken this module should be aware of several different types of pdes, have a knowledge of some of the methods that are used for discussing existence and uniqueness of solutions to the Dirichlet problem for the Laplacian, have a knowledge of properties of harmonic functions, have a rudimentary knowledge of solutions of parabolic and wave equations.

Books:
Fritz John, *Partial Differential Equations*, Springer, 1982.
L.C. Evans, *Partial Differential Equations*, American Mathematical Society, 1998.
E. Dibenedetto, *Partial Differential Equations*, Birkhauser, 2010.
D.Gilbarg - N.Trudinger, *Elliptic Partial Differential Equations of Second Order*, Springer, 2001 (more advanced, optional).

More detailed advice on books will be given during lectures.

Additional Resources

Archived Pages: 2011 2012 2013 2014 2015 2017

MA3G6 Commutative Algebra

(https://warwick.ac.uk/fac/sci/maths/undergrad/ughandbook/year3/ma3g6)
Lecturer: Chunyi Li

Term(s): Term 2

Status for Mathematics students: List A

Commitment: 30 one-hour lectures.

Assessment: 3 hour examination (85%), 15% coursework (15%)

Prerequisites: MA251 Algebra I: Advanced Linear Algebra and MA249 Algebra II

Leads To and/or related to: MA3A6 Algebraic Number Theory, MA4A5 Algebraic Geometry, MA377 Rings and Modules (which concentrates more on non-commutative theory), MA3D5 Galois Theory.

Content:
Commutative Algebra is the study of commutative rings, and their modules and ideals. This theory has developed over the last 150 years not just as an area of algebra considered for its own sake, but as a tool in the study of two enormously important branches of mathematics: algebraic geometry and algebraic number theory. The unification which results, where the same underlying algebraic structures arise both in geometry and in number theory, has been one of the crowning glories of twentieth century mathematics and still plays an absolutely fundamental role in current work in both these fields.

One simple example of this unification will be familiar already to anyone who has noticed the strong parallels between the ring Z (a Euclidean Domain and hence also a Unique Factorization Domain) and the ring F[X] of polynomials over a field (which has both the same properties). More generally, the rings of algebraic integers which have been studied since the 19th century to solve problems in number theory have parallels in rings of functions on curves in geometry.

While self-contained, this course will also serve as a useful introduction to either algebraic geometry or algebraic number theory.

Topics: Gröbner bases, modules, localization, integral closure, primary decomposition, valuations and dimension.

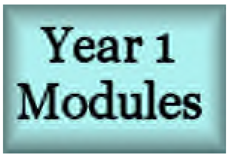
Objectives:
This course will give the student a solid grounding in commutative algebra which is used in both algebraic geometry and number theory.

Books:
Recommended texts:

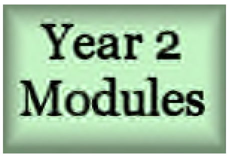
M.F. Atiyah, I.G. MacDonald, *Introduction to Commutative Algebra*. Addison-Wesley 1969; reprinted by Perseus 2000. [QA251.3.A8]
D. Eisenbud, Commutative algebra with a view toward algebraic geometry. Springer 1995. [QA251.3.E4]
M. Reid, *Undergraduate Commutative Algebra*. CUP 1995. [QA251.3.R3]
R.Y. Sharp, *Steps in Commutative Algebra* (2nd ed.) CUP 2000. [QA251.3.S4]
O. Zariski and P. Samuel, *Commutative Algebra*, (vols I and II). Springer 1975-6. [QA251.3.Z2]

Additional Resources

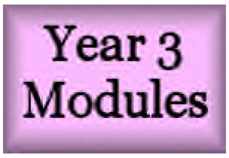
Archived Pages: 2011 2012 2013 2014 2015 2016 2017



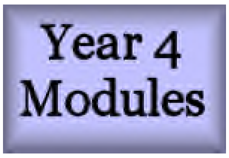
Year 1 regs and modules
G100 G103 GL11 G1NC



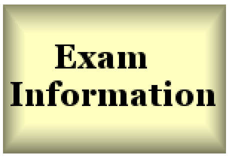
Year 2 regs and modules
G100 G103 GL11 G1NC



Year 3 regs and modules
G100 G103



Year 4 regs and modules
G103



Past Exams
Core module averages

MA3G6 Forum 2016

(https://warwick.ac.uk/fac/sci/maths/undergrad/ughandbook/year3/ma3g6/forum2016)

Search this forum

MA3G6 Forum 2016

5 followers

1. Revision lecture rescheduled

   6 posts, started by Diane Maclagan, 10:29, Wed 11 May 2016, latest post by A guest user, 13:09, Tue 17 May 2016

2. Primary decomposition

   3 posts, started by A guest user, 09:25, Sun 15 May 2016, latest post by Diane Maclagan, 17:09, Sun 15 May 2016

3. Solutions to any questions

   9 posts, started by A guest user, 08:41, Wed 11 May 2016, latest post by Diane Maclagan, 17:05, Sun 15 May 2016

4. Cayley Hamilton Proof I

   2 posts, started by A guest user, 13:26, Fri 13 May 2016, latest post by Diane Maclagan, 13:39, Fri 13 May 2016

5. Results in assignments not covered in lectures

   2 posts, started by A guest user, 21:08, Wed 11 May 2016, latest post by Diane Maclagan, 22:36, Wed 11 May 2016

6. Assignment 3 q 6 b

   2 posts, started by A guest user, 14:45, Mon 9 May 2016, latest post by Diane Maclagan, 15:24, Mon 9 May 2016

7. Lemma on R[U^-1]

   2 posts, started by A guest user, 12:09, Mon 9 May 2016, latest post by Diane Maclagan, 15:20, Mon 9 May 2016

8. Emailed question about the exam

   1 post, started by Diane Maclagan, 10:19, Sun 8 May 2016

9. Commutative Assumption

   3 posts, started by A guest user, 12:56, Fri 6 May 2016, latest post by Diane Maclagan, 10:10, Sun 8 May 2016

10. Proof of Cayley Hamilton

    2 posts, started by A guest user, 10:02, Thu 5 May 2016, latest post by Diane Maclagan, 10:09, Sun 8 May 2016

11. Products of ideals

    1 post, started by Diane Maclagan, 01:13, Mon 2 May 2016

12. Typo in Primary Decomposition hand-out?

    2 posts, started by Tom Hanna, 18:18, Tue 29 Mar 2016, latest post by Diane Maclagan, 22:24, Tue 29 Mar 2016

13. Conventions about notation

    1 post, started by Diane Maclagan, 18:52, Fri 25 Mar 2016

14. HW5

    2 posts, started by Osian Shelley, 21:39, Tue 15 Mar 2016, latest post by Diane Maclagan, 22:36, Wed 16 Mar 2016

15. HW sheet 5

    2 posts, started by A guest user, 20:27, Tue 15 Mar 2016, latest post by Diane Maclagan, 22:30, Wed 16 Mar 2016

16. Confusion on Q6 and Q7

    6 posts, started by A guest user, 15:18, Mon 14 Mar 2016, latest post by Diane Maclagan, 10:52, Tue 15 Mar 2016

17. QB2 of HW5

    4 posts, started by A guest user, 10:21, Sun 13 Mar 2016, latest post by Diane Maclagan, 20:21, Sun 13 Mar 2016

18. HW4 Q5

    4 posts, started by A guest user, 11:27, Mon 7 Mar 2016, latest post by Diane Maclagan, 04:04, Tue 8 Mar 2016

19. HW4 Q1

    7 posts, started by A guest user, 16:58, Tue 1 Mar 2016, latest post by Diane Maclagan, 04:03, Tue 8 Mar 2016

20. HW4 QB5

7 posts, started by A guest user, 12:41, Sun 28 Feb 2016, latest post by Diane Maclagan, 22:56, Thu 3 Mar 2016

MA3G6 Forum 2017

(https://warwick.ac.uk/fac/sci/maths/undergrad/ughandbook/year3/ma3g6/forum2017)

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MA3G6 Forum 2017

14 followers

1. Revision questions

   41 posts, started by Diane Maclagan, 16:20, Sat 6 May 2017, latest post by A guest user, 23:12, Tue 16 May 2017
2. Support class week 6 question

   10 posts, started by A guest user, 14:32, Sun 14 May 2017, latest post by A guest user, 18:26, Mon 15 May 2017
3. Revision Lecture Mon 8 May 12-2pm in L5 Sciences.

   4 posts, started by Vladimir Eremichev, 13:38, Fri 5 May 2017, latest post by Bruno Sterner, 17:29, Wed 10 May 2017
4. Notes Sharing Thread

   6 posts, started by Ben Swannack, 17:43, Fri 17 Mar 2017, latest post by A guest user, 10:12, Tue 9 May 2017
5. Support Class Exercises

   8 posts, started by Vladimir Eremichev, 13:07, Wed 8 Mar 2017, latest post by Vladimir Eremichev, 10:06, Tue 4 Apr 2017
6. Monday's Lecture Week 10

   2 posts, started by Bruno Sterner, 12:12, Mon 13 Mar 2017, latest post by Diane Maclagan, 12:19, Mon 13 Mar 2017
7. Extra Supervision in Week 10

   1 post, started by Vladimir Eremichev, 14:56, Thu 9 Mar 2017
8. Sheet 5 'generated by some of the variables' terminology

   3 posts, started by Ben Windsor, 16:14, Wed 8 Mar 2017, latest post by Ben Windsor, 08:46, Thu 9 Mar 2017
9. Sheet 5 Topic Coverage

   2 posts, started by David Brown, 22:48, Tue 7 Mar 2017, latest post by Diane Maclagan, 09:43, Wed 8 Mar 2017
10. Sheet 5 Section B Question 3

    2 posts, started by A guest user, 19:01, Tue 7 Mar 2017, latest post by Diane Maclagan, 20:56, Tue 7 Mar 2017
11. Sheet 4, Q4

    2 posts, started by A guest user, 19:30, Sat 4 Mar 2017, latest post by Diane Maclagan, 11:27, Sun 5 Mar 2017
12. Sheet 4, Q2

    6 posts, started by A guest user, 20:26, Mon 27 Feb 2017, latest post by Diane Maclagan, 11:22, Fri 3 Mar 2017

13. Assignment Solutions

    2 posts, started by Jelena Starovic, 10:26, Wed 22 Feb 2017, latest post by Diane Maclagan, 12:06, Wed 22 Feb 2017

14. HW3 Queries

    13 posts, started by Diane Maclagan, 09:14, Mon 13 Feb 2017, latest post by Diane Maclagan, 07:33, Sun 19 Feb 2017

15. Handout Query

    3 posts, started by A guest user, 19:14, Fri 10 Feb 2017, latest post by Diane Maclagan, 08:59, Mon 13 Feb 2017

16. Problems with online version of Macaulay 2

    1 post, started by Diane Maclagan, 06:35, Tue 7 Feb 2017

17. Sheet 2 Question B5 ⃠

    2 posts, started by A guest user, 18:21, Sat 4 Feb 2017, latest post by A guest user, 18:26, Sat 4 Feb 2017

18. HW2 Q2

    1 post, started by Diane Maclagan, 15:31, Sat 4 Feb 2017

19. Sheet 2, Question 3

    2 posts, started by A guest user, 16:19, Fri 3 Feb 2017, latest post by Diane Maclagan, 18:28, Fri 3 Feb 2017

20. Sheet 2, Section B, Q3

    3 posts, started by A guest user, 15:03, Wed 25 Jan 2017, latest post by A guest user, 18:18, Wed 25 Jan 2017

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MA3G8 Functional Analysis 2

(https://warwick.ac.uk/fac/sci/maths/undergrad/ughandbook/year3/ma3g8)
Lecturer: James Robinson

Term(s): Term 2

Status for Mathematics students: List A

Commitment: 30 lectures

Assessment: 3 hour examination (100%)

Prerequisites: MA3G7 Functional Analysis I, MA359 Measure Theory would be useful but is not required

Leads To: MA4A2 Advanced PDEs, MA433 Fourier Analysis, MA4G6 Calculus of Variations, MA4A2 Advanced PDEs and MA4J0 Advanced Real Analysis.

Content: Problems posed in infinite-dimensional space arise very naturally throughout mathematics, both pure and applied. In this module we will concentrate on the fundamental results in the theory of infinite-dimensional Banach spaces (complete normed linear spaces) and linear transformations between such spaces.

We will prove some of the main theorems about such linear spaces and their dual spaces (the space of all bounded linear functionals) - e.g. the Hahn-Banach Theorem and the Principle of Uniform Boundedness - and show that even though the unit ball is not compact in an infinite-dimensional space, the notion of weak convergence provides a way to overcome this.

Books: Useful books to use as an accompanying reference to your lecture notes are:

E. Kreyszig, *Introductory Functional Analysis with Applications*, Wiley, 1989.

W. Rudin, *Functional Analysis*, McGraw-Hill, 1973.

G. B. Folland, *Real Analysis*, Wiley, 1999.

E.H. Lieb and M. Loss, *Analysis*, 2nd ed. American Mathematical Society, 2001.

Additional Resources

Archived Pages: Pre-2011 2011 2012 2013 2014 2015 2016 2017

Year 1 Modules

Year 1 regs and modules
G100 G103 GL11 G1NC

Year 2 Modules

Year 2 regs and modules
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Year 3 Modules

Year 3 regs and modules
G100 G103

Year 4 Modules

Year 4 regs and modules
G103

Exam Information

Past Exams
Core module averages

MA3H0 Numerical Analysis and PDE's

(https://warwick.ac.uk/fac/sci/maths/undergrad/ughandbook/year3/ma3h0)
Lecturer: Björn Stinner

Term(s): Term 2

Status for Mathematics students: List A

Commitment: 30 lectures

Assessment: 3 hour exam 100%

Prerequisites: This module uses material from many of the Core 1st and 2nd year modules, particularly MA231 Vector Analysis, MA244 Analysis III and MA250 Introduction to PDE. Although not prerequisites MA3G7 *Functional analysis Functional Analysis I* and MA3G1 *Theory of PDEs* are excellent companion courses.

Leads To:

Content:
This module addresses the mathematical theory of discretization of partial differential equations (PDEs) which is one of the most important aspects of modern applied mathematics. Because of the ubiquitous nature of PDE based mathematical models in biology, finance, physics, advanced materials and engineering much of mathematical analysis is devoted to their study. The complexity of the models means that finding formulae for solutions is impossible in most practical situations. This leads to the subject of computational PDEs. On the other hand, the understanding of numerical solution requires advanced mathematical analysis. A paradigm for modern applied mathematics is the synergy between analysis, modelling and computation. This course is an introduction to the numerical analysis of PDEs which is designed to emphasise the interaction between mathematical theory and numerical methods.

Topics in this module include:
Analysis and numerical analysis of two point boundary value problems.
Model finite difference methods and and their analysis.
Variational formulation of elliptic PDEs; function spaces; Galerkin method; finite element method; examples of finite elements; error analysis.

Aims:
The aim of this module is to provide an introduction to the analysis and design of numerical methods for solving partial differential equations of elliptic, hyperbolic and parabolic type.

Objectives:
Students who have successfully taken this module should be aware of the issues around the discretization of several different types of pdes, have a knowledge of the finite element and finite difference methods that are used for discretizing, be able to discretise an elliptic partial differential equation using finite element and finite difference methods, carry out stability and error analysis for the discrete approximation to elliptic, parabolic and hyperbolic equations in certain domains.

Books:
Background reading:

Stig Larsson and Vidar Thomee, *Partial differential equations with numerical methods*, Springer Texts in Applied Mathematics Volume 45 (2005).
K W Morton and D F Mayers, *Numerical solution of partial differential equations: an introduction* Cambridge University Press Second edition (2005).

Additional Resources

Archived Pages: 2011 2012 2014 2015

Year 1 Modules

Year 1 regs and modules
G100 G103 GL11 G1NC

Year 2 Modules

Year 2 regs and modules
G100 G103 GL11 G1NC

Year 3 Modules

Year 3 regs and modules
G100 G103

Year 4 Modules

Year 4 regs and modules
G103

Exam Information

Past Exams
Core module averages

MA3H2 Markov Processes and Percolation Theory

(https://warwick.ac.uk/fac/sci/maths/undergrad/ughandbook/year3/ma3h2)
Lecturer: Dr. Agelos Georgakopoulos
Term(s): Term 2

Status for Mathematics students: List A

Commitment: 30 lectures

Assessment: 3 hour exam 85%, assignments 15%

Prerequisites: As a prerequisite module students should have done MA359 Measure Theory or one of the following modules, MA253 Probability and Discrete Mathematics or ST213 Mathematics of random events. Alternatively, the students need to know the following basic key facts: probability measure , expectation and variance, law of large numbers, and Probability A module [as Probability A is a core module there are no further compulsory prerequisites].

Leads To: MA482 Stochastic Analysis,MA4F7 Brownian Motion, and MA4H3 Interacting Particle Systems, ST406 Applied Stochastic Processes with Advanced Topics, CO905 Stochastic models of complex systems and MA4L3 Large Deviation theory.

Content: This module provides an introduction to continuous-time Markov processes and percolation theory, which have numerous applications: random growth models (sand-pile models), Markov decision processes, communication networks.

The module first introduces the theory of Markov processes with continuous time parameter running on graphs. An example of a graph is the two-dimensional integer lattice and an example of a Markov process is a random walk on this lattice. Very interesting problems of such processes involve spatial disorder and dependencies (e.g. burning forests). Therefore, after the main part, an elementary introduction to percolation theory will be given which can be used to study such questions.

Percolation is a simple probabilistic model for spatial disorder, and in physics, chemistry and materials science, percolation concerns the movement and filtering of fluids through porous materials. Recent applications include for example percolation of water through ice which is important for the melting of the ice caps.

Let us briefly explain the mathematical setting. Percolation is a simple probabilistic model which exhibits a phase transition. The simplest version of percolation takes place on $\mathbb{Z}^2$, which we view as a graph with edges between neighbouring vertices. All edges of $\mathbb{Z}^2$ are, independently of each other, chosen to be open with probability p and closed with probability $1-p$. A basic question in this model is `What is the probability that there exists an open path from the origin to the exterior of the square $S_n = [-n,n]^2$?' A limit as $n \to \infty$ of the question raised above is `What is the probability that there exists an open path from 0 to infinity?' This probability is called the percolation probability and is denoted by $\theta(p)$. Clearly $\theta(0)=0$ and $\theta(1)=1$, since there are no open edges at all when $p=0$ and all edges are open when $p=1$. For some models there is a $0<p_c<1$ such that the global behaviour of the system is quite different for $p<p_c$ and for $p>p_c$. Such a sharp transition in global behaviour of a system at some parameter value is called a phase transition or a critical phenomenon, and the parameter value at which the transition takes place is called a critical value.

The basic mathematical methods and techniques of random processes and an overview of the most important applications will enable the student to use analytical techniques and models to study questions in modern applications in biological and physical systems, communication networks, financial market, decision processes.

Books:

We will not follow a particular book.

H.O. Georgii: *Stochastics: introduction to probability theory and statistics*, de Gruyter (2008). [basic introduction to stochastics and Markov chains (discrete time)]

J. Norris: *Markov chains*, Cambridge University Press [standard reference treating the topic with mathematical rigor and clarity, and emphasizing numerous applications to a wide range of subjects]

G. Grimmett, D. Stirzaker: *Probability and Random Processes*, OUP Oxford (2001) [chapter 6 on Markov chains]

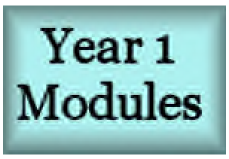
G. Grimmett: *Probability on Graphs*, Cambridge University Press (2010). [Available Online, contains a nice introduction to processes on graphs and percolation]

B. Bollabás, O. Riordan: *Percolation*, Cambridge University Press (2006). [a modern treatment of percolation. The introduction and the chapter on basic techniques are relevant for the lecture]

G. Grimmett: *Percolation*, 2nd ed., Springer (1999). [the standard reference on percolation. It contains much more than covered in the lecture. The first two chapters are relevant for the lecture]

Additional Resources

Archived Pages: 2011 2012 2013 2014 2015 2016 2017



Year 1 regs and modules
G100 G103 GL11 G1NC

MA3H6 Algebraic Topology

(https://warwick.ac.uk/fac/sci/maths/undergrad/ughandbook/year3/ma3h6)
Lecturer: David Mond

Term(s): Term 2

Status for Mathematics students: List A

Commitment: 30 hours

Assessment: 3 hour examination (85%), assessed work (15%)

Prerequisites: MA3F1 Introduction to Topology

Prerequisite for: MA4J7 Cohomology and Poincaré Duality

Leads To: MA4A5 Algebraic Geometry, MA5Q6 Graduate Algebra

Content: Algebraic topology is concerned with the construction of algebraic invariants (usually groups) associated to topological spaces which serve to distinguish between them. Most of these invariants are ``homotopy'' invariants. In essence, this means that they do not change under continuous deformation of the space and homotopy is a precise way of formulating the idea of continuous deformation. This module will concentrate on constructing the most basic family of such invariants, *homology groups*, and the applications of these homology groups.

The starting point will be *simplicial complexes* and *simplicial homology*. An *n-simplex* is the n-dimensional generalisation of a triangle in the plane. A simplicial complex is a topological space which can be decomposed as a union of simplices. The simplicial homology depends on the way these simplices fit together to form the given space. Roughly speaking, it measures the number of p-dimensional "holes'' in the simplicial complex. For example, a hollow 2-sphere has one 2-dimensional hole, and no 1-dimensional holes. A hollow torus has one 2-dimensional hole and two 1-dimensional holes. Singular homology is the generalisation of simplicial homology to arbitrary topological spaces. The key idea is to replace a simplex in a simplicial complex by a continuous map from a standard simplex into the topological space. It is not that hard to prove that singular homology is a homotopy invariant but very hard to compute singular homology directly from the definition. One of the main results in the module will be the proof that simplicial homology and singular homology agree for simplicial complexes. This result means that we can combine the theoretical power of singular homology and the computability of simplicial homology to get many applications. These applications will include the Brouwer fixed point theorem, the Lefschetz fixed point theorem and applications to the study of vector fields on spheres.

Aims: To introduce homology groups for simplicial complexes; to extend these to the singular homology groups of topological spaces; to prove the topological and homotopy invariance of homology; to give applications to some classical topological problems.

Objectives: By the end of the module the student should be able to:

Give the definitions of simplicial complexes and their homology groups and a geometric understanding of what these groups measure
Use standard techniques for computing these groups

Give the extension to singular homology
Understand the theoretical power of singular homology
Develop a geometric understanding of how to use these groups in practice

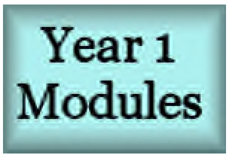
Text:
The course is based on chapter 2 of Allen Hatcher's book:
Algebraic Topology, CUP. (Available free from Hatcher's website).

Strongly recommended preliminary reading
Ideal for the summer holidays, and a good preparation also for MA3F1 Introduction to Topology:
David Richeson, *Euler's Gem*, Princeton, 2008
Jeffrey Weeks, *The Shape of Space*, Marcel Dekker, 2001

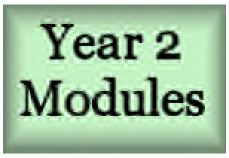
Additional references:
JW Vick, *Homology Theory: an introduction to algebraic topology*, Academic Press.
MA Armstrong, *Basic Topology*, Undergraduate Texts in Mathematics, Springer Verlag
Maunder, *Algebraic Topology*, Cambridge University Press.
A Dold, *Lectures on Algebraic Topology*, Springer-Verlag.

Additional Resources

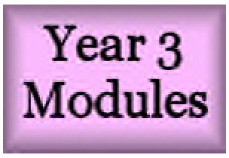
Archived Pages: Module Forum 2014 2015 2016 2017



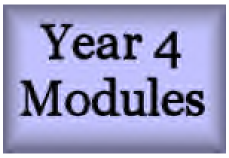
Year 1 regs and modules
G100 G103 GL11 G1NC



Year 2 regs and modules
G100 G103 GL11 G1NC



Year 3 regs and modules
G100 G103



Year 4 regs and modules
G103

Exam Information

Past Exams

Core module averages

MA3H8 Equivariant Bifurcation Theory

(https://warwick.ac.uk/fac/sci/maths/undergrad/ughandbook/year3/ma3h8)

Not Running 2016/17

Lecturer: David Wood

Term(s): Term 1

Status for Mathematics students: List A

Commitment: 30 hours

Assessment: 3 hour examination (100%)

Prerequisites: MA133 Differential Equations, aspects of MA249 Algebra II and MA225 Differentiation, MA254 Theory of ODEs useful but not essential

Content: Equivariant Bifurcation Theory is the study of systems of equations which have an inherent symmetry within them, it is a perfect fusion of pure and applied mathematics, leading to some quite powerful and aesthetically pleasing results. The module will concentrate primarily on systems of ordinary differential equations, and both steady-state and periodic solutions that are formed through bifurcations as a parameter is varied, but the theory can also be applied to discrete systems and systems of partial differential equations.

Essential background required includes solving systems of first order differential equations from Differential Equations, and knowledge of symmetry groups from Algebra II: in particular we concentrate on those that have physical symmetry interpretations such as permutation groups (S_n), symmetries of regular n-gons (D_n) and circle group symmetries ($O(2)$ and $SO(2)$). Additional knowledge from the second year Theory of ODEs or third year Qualitative Theory of ODEs will help but not having taken neither should not prove a major obstacle.

The module should appeal to both students who wish to study applications of mathematics, and those who enjoy the beauty of mathematics for its own sake.

In more detail the topics to be covered will include:

0. **Overview:** Basic bifurcation theory (standard one parameter bifurcations) and symmetry groups (essentially revision).

1. **Steady-State Bifurcation:** Symmetries of ODEs, Liapunov Schmidt reduction, Equivariant Branching Lemma, applications (inc. coupled cell networks and speciation).

2. **Linear Stability:** Symmetry of the Jacobian, Hilbert Bases and Equivariant Mappings, examples of Dn Steady State Bifurcations and Sn Invariant Theory.

3. **Time Periocicity and Spatio-Temporal Symmetry**: Animal gaits, characterization of possible spatio-temporal symmetries, rings of cells, coupled cell networks.

4. **Hopf Bifurcation with Symmetry:** linear analysis, the Equivariant Hopf Theorem, Poincaré-Birkhoff Normal Form, Hopf Bifurcation in Coupled Cell Networks (esp Dn), mode interactions.

Further topics from (depending on time and interest): Forced symmetry breaking, Euclidean Equivariant systems (example of liquid crystals), bifurcation from group orbits (Taylor Couette), heteroclinic cycles, symmetric chaos, Reaction-Diffusion equations, hidden symmetries, networks of cells (groupoid formalism).

Aims:

Objectives:

Books: Printed lecture notes will be made available as the module progresses, but other good textbooks for reference:

The Symmetry Perspective, Golubitsky and Stewart, 2002
Singularities and Groups in Bifurcation Theory Vol 2, Golubitsky/Stewart/Schaeffer 1988
Pattern Formation, Hoyle 2006.

For more general background of relevant ODE theory:

Nonlinear Oscillations, Dynamical Systems, and Bifurcations of Vector Fields, Guckenheimer/Holmes 1983

Additional Resources

ST218: Mathematical Statistics Part A

(https://warwick.ac.uk/fac/sci/maths/undergrad/ughandbook/year3/st218)
Lecturer(s): Dr Zorana Lazic

Important: This module is for students from the Statistics department only. Students from other departments should take ST220 Introduction to Mathematical Statistics.

Prerequisite(s): ST115 Introduction to Probability.

Commitment: 3 lectures/week, 1 tutorial/fortnight. This module runs in Term 1.

Aims: To build the necessary probability background for mathematical statistics.

Content:

1. Discrete and continuous multivariate distributions. Marginal distributions.
2. Jacobian transformation formula.
3. Conditional distributions, conditional expectation and properties.
4. Moment generating functions for multivariate random variables.
5. Multivariate Gaussian distribution and properties.
6. Distributions related to Gaussian distribution: the Chi-squared, Student's and Fisher distributions.
7. Convergence in distribution, convergence in probability and almost sure convergence. Examples.
8. Laws of large numbers.
9. Central limit theorem.

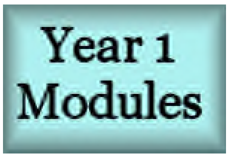
Books:

- A. Gut: An Intermediate Course in Probability
- Casella and Berger: Statistical Inference
- Suhov and Kelbert: Probability and Statistics by Example: Basic Probability and Statistics
- J. Pitman: Probability

Assessment: 90% by 2 hour examination in January, 10% by coursework.

Deadlines: Assignment 1: week 3, Assignment 2: week 5, Assignment 3: week 7 and Assignment 4: week 9.

Feedback: You will hand in answers to selected questions on the fortnightly exercise sheets. Your work will be marked and returned to you in the tutorial taking place the following week when you will have the opportunity to discuss it. The results of the January examination will be available in week 10 of term 2.



Year 1 regs and modules
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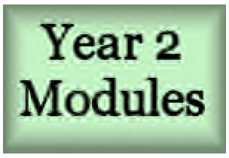
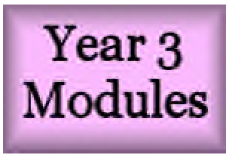
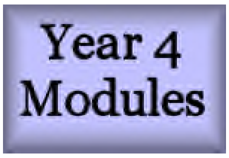


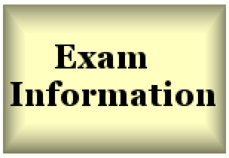
Year 2 regs and modules
G100 G103 GL11 G1NC



Year 3 regs and modules
G100 G103



Year 4 regs and modules
G103



Past Exams
Core module averages

ST301 Bayesian Statistics

(https://warwick.ac.uk/fac/sci/maths/undergrad/ughandbook/year3/st301)
Lecturer(s): Dr Ric Crossman

Important: If you decide to take ST301 you cannot then take ST413. Bear this in mind when planning your module selection. Recall: an integrated Masters student must take at least 120 CATS, of level 4+ modules over their 3rd & 4th years.

Prerequisite(s): Either ST218/219 Mathematical Statistics A&B or ST220 Introduction to Mathematical Statistics

Commitment: 3 lectures per week and one tutorial each in weeks 3, 7, and 9.This module runs in Term 1.

Content: Bayesian statistics is one of the fastest growing areas in statistics. With the advance of computer technology it is now a highly practical methodology for addressing many important high dimensional decision problems as well as being underpinned by a sound mathematical foundation. It is especially useful when some of the components of uncertainty have only sparsely collected data associated with them, so that expert judgements need to be incorporated. The course first introduces the central concepts of Bayesian decision analysis through a selection of simple examples. Various methodologies are then presented for:

- Structuring a decision problem – for example by decision trees and influence diagrams.
- Eliciting probability distributions over many variables – using the concepts of irrelevance and the Belief net.
- Eliciting the objectives and preferences of the client – developing the ideas of m.u.i.a. and value independence and the use of the decision conference.

The formal methodologies are illustrated through a wide range of examples for health, the environment, finance and public sector administration. Some of the examples build on the practical experience of the module's original creator as an active Bayesian decision analyst.

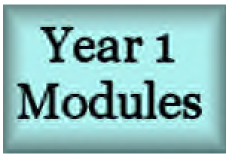
Aims:

- To demonstrate how to build statistical models of non-trivial problems when data is sparse and expert judgements need to be incorporated.
- To give ways to represent the pertinent features of a decision problem.
- To give practical algorithms for finding decision rules which the client can expect will best satisfy pre-specified objectives.
- To train the student in the rudiments of decision analysis.

Objectives:

- The student will gain an appreciation of the importance of conditional independence in subjective (Bayesian) statistical modelling and be introduced to the DAG as an efficient representation of collections of conditional independence statements as they arise in practice.
- The student will be provided with techniques for eliciting subjective probability distributions over many variables.
- The student will be provided with techniques for eliciting quantitative preference structures from a client which may involve competing objectives.
- The student will obtain an appreciation of the foundational arguments that justify expected utility maximisation as a paradigm for rational action.
- The student will obtain practice in implementing these techniques.
- The student will learn the bases of fast algorithms for the calculation of probabilities needed in such maximisation.

Assessment: 100% by 2-hour examination.



Year 1 regs and modules
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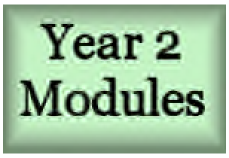
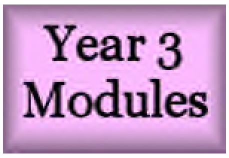
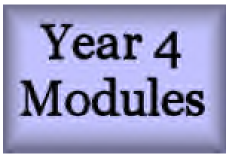


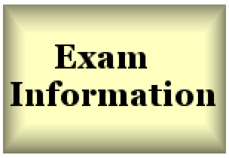
Year 2 regs and modules
G100 G103 GL11 G1NC



Year 3 regs and modules
G100 G103



Year 4 regs and modules
G103



Past Exams
Core module averages

ST305 Designed Experiments

(https://warwick.ac.uk/fac/sci/maths/undergrad/ughandbook/year3/st305)
Lecturer(s): Dr John Fenlon

Important: If you decide to take ST305 you cannot then take ST410. Bear this in mind when planning your module selection. Recall: an Integrated Masters student must take at least 120 CATS, of level 4+ modules over their 3rd & 4th years.

Prerequisite(s): Either ST218/219 Mathematical Statistics A&B or ST220 Introduction to Mathematical Statistics

Commitment: 30 one-hour lectures, plus weekly one-hour seminars / practicals. This module runs in Term 2.

Background: Designed experiments are used in industry, agriculture, medicine and many other areas of activity to test hypotheses, to learn about processes and to predict future responses. The primary purpose of experimentation is to determine the relationship between a response variable and the settings of a number of experimental variables (or factors) that are presumed to affect it. Experimental design is the discipline of determining the number and order (spatial or temporal) of experimental runs, and the setting of the experimental variables.

Content: This is a first course in designed experiments. The elementary theory of experimental design relies on linear models, while the practice involves important eliciting and communication skills. In this course we shall see how the theory links common designs such as the randomised complete block and split-plot to the underlying model. The course will commence with a review of linear model theory and some simple designs; we shall then examine the basic principles of experimental design and analysis, e.g. the concepts of randomisation and replication together with the blocking in designs and the combination of experimental treatments (factorial structure). Classical design structures are developed through the separate consideration of block and treatment structure, and the use of analysis of variance to explore differences between treatments for different types of design is explored. Throughout, diagnostic and analysis methods for the examination of practical experiments will be developed. A significant part of the course will be spent developing aspects of factorial design theory, including the theory and practice of confounding and of fractional designs. We will see how the exigencies of design in an industrial context have led to further theory and different emphases from classical design. This will include the use of regression in response surface modelling. Further topics such as repeated measures, non-linear design and optimal design theory may be included if time allows. Practical examples from many different application areas will be given throughout, with an emphasis on analysis using R.

Aims: This course aims to give students a sound understanding of experimental design, both theoretical and practical. The course will explore the method of analysis of variance and show how it is structurally linked to particular types of design. The combinatoric properties of designs will be explored, and the impact of computers on classical design considered. Some exploration of the matrix theory of design will also be undertaken.

Objectives: By the end of the course students will be able to:

- Describe the basic principles behind designed experiments
- Show the relationship between a designed experiment, the underlying linear model and the analysis of the resulting data
- Construct the design matrix for a simple experiment and estimate the model parameters
- Perform an analysis of variance on standard experimental designs
- Distinguish between different types of design and recognise their efficiency / utility
- Perform diagnostic tests on the results from a designed experiment.
- Explain the underlying theory of 2"/3" factorial designs, and implement such designs in practice.

Books:

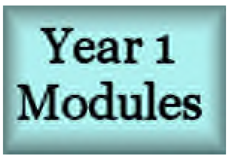
- G Clarke & R Kempson, Introduction to the Design and Analysis of Experiments, Arnold, 1996.
- DC Montgomery, Design and Analysis of Experiments, Wiley, 2005, 2009, 2012.

  Other books will be referred to through the module.

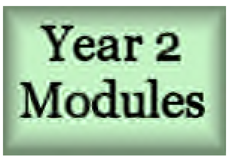
Assessment: Two assignments worth 10% each and 80% by 2-hour examination.

Deadlines: Assignment 1: Week 7 of Term 2. Assignment 2: Week 1 of Term 3. Other exercises will be provided and discussed during the seminars.

Feedback: Feedback on both assignment 1 and 2 will be returned after 2 weeks, following submission. Students will also receive feedback to worksheet examples during practical classes.



Year 1 regs and modules
G100 G103 GL11 G1NC



Year 2 regs and modules
G100 G103 GL11 G1NC

ST323: Multivariate Statistics

(https://warwick.ac.uk/fac/sci/maths/undergrad/ughandbook/year3/st323)
Lecturer(s): Dr Shahin Tavakoli

Important: If you decide to take ST323 you cannot then take ST412. Bear this in mind when planning your module selection. Recall: an integrated Masters student must take at least 120 CATS, of level 4+ modules over their 3rd & 4th years.

***Prerequisite(s)**:*

- Statistics students: ST115 Introduction to Probability, ST218 Mathematical Statistics A, ST219 Mathematical Statistics B.
- Non-Statistics students: ST111/112 Probability A&B, ST220 Introduction to Mathematical Statistics.

The coursework uses the statistical software package R, so basic knowledge in R such as covered in ST104 Statistical Laboratory I or ST952 Introduction to Statistical Practices is helpful.

Commitment: 30 lectures. This module runs in Term 1.

Aims: Multivariate data arises whenever several interdependent variables are measured simultaneously. Such high-dimensional data is becoming the rule, rather than the exception in many areas: in medicine, in the social and environmental sciences and in economics. The analysis of such multidimensional data often presents an exciting challenge that requires new statistical techniques which are usually implemented using computer packages. This module aims to give you a good understanding of the geometric and algebraic ideas that these techniques are based on, before giving you a chance to try them out on some real data sets.

Objectives: By the end of the course students will be able to:

- Construct and interpret graphical representations of multivariate data
- Carry out a principal components and canonical correlation analysis to summarise high dimensional data
- Perform clustering analysis to discover and characterize subgroups in the population
- Use classification and discrimination methods to assign individuals into groups
- Assess multivariate normality and do multivariate tests for comparing means across groups
- Understand any additional topics covered in the lectures. Time permitting lectures will cover one or two additional topics such as Factor Analysis, Multidimensional Scaling, Random Forests, Bagging, sparse multivariate methods, Gaussian graphical models, multiple testing, Functional Data Analysis, spatial statistics.

Books:

- James, G., Witten, D., Hastie, T., & Tibshirani, R. (2013). An introduction to statistical learning (Vol. 112). New York: Springer.
- Johnson, R. A., & Wichern, D. W. (2007). Applied Multivariate Statistical Analysis.: Pearson Prentice Hall. Upper Saddle River, NJ.
- Friedman, J., Hastie, T., & Tibshirani, R. (2009). The elements of statistical learning (second edition). New York: Springer.
- Efron, B., & Hastie, T. (2016). Computer age statistical inference (Vol. 5). Cambridge University Press.
- Hastie, T., Tibshirani, R., & Wainwright, M. (2015). Statistical learning with sparsity: the lasso and generalizations. CRC press.

Assessment: Two assignments worth 10% each; 80% by 2-hour examination in June.

Deadlines: Assignment 1: week 5 and Assignment 2: week 2 (Term 2).

Feedback: Feedback on both assignments will be returned after 2 weeks, following submission.

Year 1 Modules

Year 1 regs and modules
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Year 2 Modules

Year 2 regs and modules
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Year 3 Modules

Year 3 regs and modules
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Year 4 Modules

Year 4 regs and modules
G103

Exam Information

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Core module averages

ST329: Topics in Statistics A

(https://warwick.ac.uk/fac/sci/maths/undergrad/ughandbook/year3/st329)
Lecturer(s): Dr Paul Chleboun, Professor Xavier Didelot, Dr Ioannis Kosmidis,

Prerequisite(s): Either ST218/219 Mathematical Statistics A&B or ST220 Introduction to Mathematical Statistics

Content: Three self-contained sets of ten lectures. For a description of the topics see below. Please note that the topics covered in this module may change from year to year.

Commitment: 3 x 10 lectures in term 2, plus 1 revision class per topic in term 3.

Assessment: 100% by 2-hour examination.

Topic: Generalized Linear Models with large data sets

Lecturer: Dr Ioannis Kosmidis

Aims: To introduce core methods and software tools for tackling regression problems that involve large data sets either in terms of number of observations or in terms of explanatory variables.

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

- Define linear and generalized linear models for a data set at hand, fit them, and interpret the output of key methods for regression modelling in R
- Identify least squares as a core optimization problem for fitting linear and generalized linear models, and classify the various methods for its solution in terms of complexity, memory usage and accuracy
- Describe a range of incremental bounded-memory algorithms and stochastic gradient descent algorithms for large regression problems, and contrast them in terms of their relative merits
- Use ready software and tools for estimating linear and generalized linear models from large data sets
- Implement new algorithms for handling large data sets with more complex regression models (e.g. generalized non-linear models or extensions with smooth terms) and alternative estimation techniques (e.g. ridge regression), using new R functionality (if time).

Recommended: Familiarity with principles of linear regression and R programming is desirable.

Topic: Hidden Markov Models

Lecturer: Dr Xavier Didelot

Aims: To introduce Hidden Markov Models as a powerful, popular and flexible statistical methodology of analysis for sequential data.

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

- Define Hidden Markov Models
- Describe and implement the algorithms for computing the likelihood, estimating parameters, decoding and forecasting
- Select and test a Hidden Markov Model for a given sequential dataset
- Integrate Hidden Markov Models within a Bayesian analysis
- Describe typical applications of Hidden Markov Models, for example to speech recognition or genetic data analysis

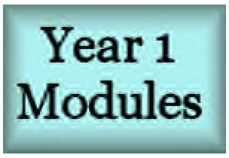
Topic: Combinatorial Stochastic Process

Lecturer: Dr Paul Chleboun

Aims: Combinatorics is an integral part of probability theory. In this course we will discuss generating functions, Bell polynomials and its applications to counting partitions and objects with composite sturctures.

Objectives: At the end of the course students should be able to use generating functions for counting and for identifying distributions.

Recommended: Basic knowledge of Probability Theory (Expectation, independence).



Year 1 regs and modules
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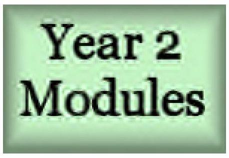

Year 2 regs and modules
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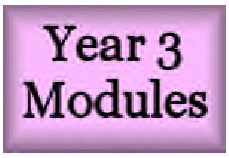
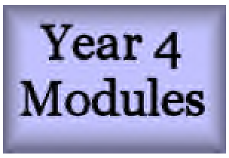
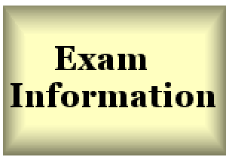


Year 3 regs and modules
G100 G103



Year 4 regs and modules
G103



Past Exams
Core module averages

ST333: Applied Stochastic Processes

(https://warwick.ac.uk/fac/sci/maths/undergrad/ughandbook/year3/st333)
Lecturer(s): **Dr Larbi Alili**

Important: If you decide to take ST333 you cannot then take ST406. Bear this in mind when planning your module selection. Recall: an integrated Masters student must take at least 120 CATS of level 4+ modules over their 3^{rd} & 4^{th} years.

Commitment: 3 lectures per week, 1 example class per fortnight. This module runs in Term 1.

Prerequisite(s): ST202 Stochastic Processes.

Aims: To provide an introduction to concepts and techniques which are fundamental in modern applied probability theory and operations research:

- Models for queues, point processes, and epidemics.
- Notions of equilibrium, threshold behaviour, and description of structure.

These ideas have a vast range of applications, for example routing algorithms in telecommunications (queues), assessment of apparent spatial order in astronomical data (stochastic geometry), description of outbreaks of disease (epidemics). We will only be able to introduce each area - indeed each area could easily be the subject of a course on its own! But the introduction will provide you with a good base to follow up where and when required. (For example: a MORSE student graduating in 1996 found the next year their firm was asking them to address problems in queuing theory, for which ST333 provided the basis.) We will discuss these and other applications and show how the ideas of stochastic process theory help in formulating and solving relevant questions.

Objectives: At the end of the course students will:

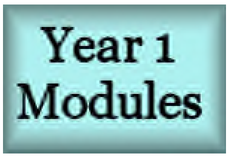
- Be able to formulate continuous-time Markov chain models for applied problems.
- Be able to use basic theory to gain quick answers to important questions (for example, what is the equilibrium distribution for a specific reversible Markov chain?).
- Be able to solve for the transition probabilities for Markov chains on a finite state space.

Assessment: 10% by class tests, 90% by examination.

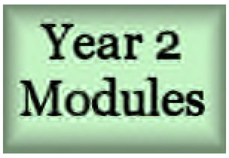
There will be support classes associated with the course, and students will be expected to attend.

Class Tests: Class tests are scheduled for **weeks 5 and 9** and will take place in one of the lectures.

Feedback: Feedback on class tests will be returned after 2 weeks, following each test.



Year 1 regs and modules
G100 G103 GL11 G1NC



Year 2 regs and modules
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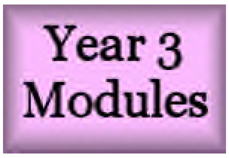

Year 3 regs and modules
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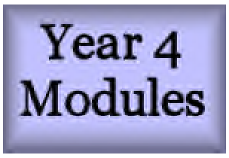
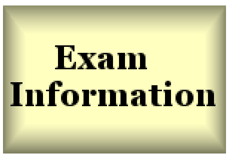


Year 4 regs and modules
G103



Past Exams
Core module averages

ST339: Financial Mathematics

(https://warwick.ac.uk/fac/sci/maths/undergrad/ughandbook/year3/st339)

Lecturer(s): Dr Martin Herdegen

Prerequisites:

- Students must have done either ST218 Mathematical Statistics A or ST220 Introduction to Mathematical Statistics.
- It is *strongly recommended* to take either MA359 Measure theory or ST342 Mathematics of Random Events alongside this module.

Restrictions:

- Statistics students may take *at most one* of the following:
  - ST339 Introduction to Mathematical Finance
  - EC333 Topics in Financial Economics: Theories and International Finance
  - IB253 Principles of Finance 1
- Moreover, Statistics students who have taken ST339 Introduction to Mathematical Finance *may not take* IB254 Principles of Finance 2.

Commitment:

- 3 hours of lectures per week. 5 example classes per term. This module runs in Term 1.

Aims:

- To provide an introduction to Mathematical Finance in discrete time and cover the discrete part of the CT8 actuarial syllabus.
- The Actuarial profession has agreed to grant an exemption to their professional examination CT8 to students who perform sufficiently well in the examinations *for both* ST339 and ST401.
- This module serves as a prerequisite for ST401, and for the following WBS finance modules:
  - IB357 Investment Management
  - IB359 Derivatives and Risk Management
  - IB394 International Financial Management.
- It is also a prerequisite (acting as an alternative to EC333) for the module EC334 Topics in Financial Economics: Corporate Finance and Markets.

Content:

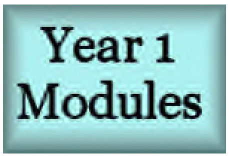
- Arbitrage theory
- Mean-variance portfolio selection and the Capital Asset Pricing Model
- Utility theory and Risk measures
- Pricing and Hedging in discrete time, Binomial Model

Assessment:

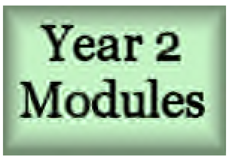
- 2-hour exam in Summer.

Illustrative Bibliography:

- H. Föllmer and A. Schied: *Stochastic Finance. An Introduction in Discrete Time*, 4th ed., de Gruyter, 2016.
- S.F. LeRoy and J. Werner: *Principles of Financial Economics*, 2nd ed., Cambridge University Press, 2014.
- S.E. Shreve: *Stochastic Calculus for Finance 1*: The Binomial Asset Pricing Model, Springer, 2003.
- J. Jacod and P. Protter: *Probability Essentials*, Springer, 2003.



Year 1 regs and modules
G100 G103 GL11 G1NC



Year 2 regs and modules
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ST407: Monte Carlo Methods

(https://warwick.ac.uk/fac/sci/maths/undergrad/ughandbook/year3/st407)
Lecturer(s): Dr Pieralberto Guarniero

Commitment: 3 lectures per week, 1 computer practical per week starting in week 2.

Pre-requisite(s):

- ST115 Introduction to Probability or ST111/112 Probability A & B or equivalent.
- ST218/ST219 Mathematical Statistics A & B or ST220 Introduction to Mathematical Statistics equivalent.

Desirable Background:
A basic knowledge of the statistical programming language R or SPLUS. Coursework will be based on R.

Aims: This module will provide students with the tools for advanced statistical modelling and associated estimation procedures based on computer-intensive methods known as Monte Carlo techniques.

Content: When modelling real world phenomena statisticians are often confronted with the following dilemma: should we choose a standard model that is easy to compute with or use a more realistic model that is not amenable to analytic computations such as determining means and p-values. We are faced with such choice in a vast variety of application areas, some of which we will encounter in this module. These include financial models, genetics, polymer simulation, target tracking, statistical image analysis and missing data problems. With the advent of modern computer technology we are no longer restricted to standard models as we can use simulation-based inference. Essentially we replace analytic computation with sampling of probability models and statistical estimation. In this module we discuss a variety of such methods, their advantages, disadvantages, strengths and pitfalls.

Learning Outcomes:

- Knowledge of a collection of simulation methods including Markov chain Monte Carlo (MCMC); understanding of Monte Carlo procedures.
- Ability to develop and implement an MCMC algorithm for a given probability distribution
- Ability to evaluate a stochastic simulation algorithm with respect to both its efficiency and the validity of the inference results produced by it.
- Ability to use Monte Carlo methods for scientific applications.

Syllabus:

1. Introduction and Examples: The need for Monte Carlo Techniques; history; example applications.
2. Basic Simulation Principles: Rejection method; variance reduction; importance sampling.
3. Markov chain theory: convergence of Markov chains; detailed balance; limit theorems.
4. Basic MCMC algorithms: Metropolis-Hastings algorithm; Gibbs sampling.
5. Implementational issues: Burn In; Convergence diagnostics, Monte Carlo error.
6. More advanced algorithms: Auxiliary variable methods; simulated and parallel tempering; simulated annealing; reversible jump MCMC.

Assessment: 20% by coursework (assignment 1 10%, assignment 2 10%) and 80% by exam in April.

Books:

- C.P.Robert and G.Casella, Monte Carlo Statistical Methods (2nd Ed.), Springer, 2004.
- J. Voss "An introduction to Statistical Computing: A Simulation-Based Approach"

- J.S. Liu, Monte Carlo Strategies in Scientific Computing, Springer, 2001.

Deadline: Assignment 1: Week 5. Assignment 2: Week 10.

Feedback: Feedback on assignments will be returned after 2 weeks, following submission.

ST318: Probability Theory

(https://warwick.ac.uk/fac/sci/maths/undergrad/ughandbook/year3/st318)
Lecturer(s): Prof Vassili Kolokoltsov

Prerequisite(s): ST342 Mathematics of Random Events or MA359 Measure Theory.

Commitment: 3 lectures/week, 1 tutorial/fortnight. This module runs in Term 2.

Content: Independence and conditioning, probability measures on metric spaces, types of probabilistic convergence, an introduction to martingales.

Aims: This course aims to give the student a rigorous presentation of some fundamentalresults in measure theoretic probability and an introduction to the theory of discrete time martingales. In so doing it aims to provide a firm basis for advanced work on probability and its applications.

Objectives: The objectives of the course are as follows: at the end of the course the student will:

- Understand the ideas relating to independence and zero-one laws and be able to apply these ideas in simple contexts.
- Understand the different modes of convergence for sequences of random variables (more generally random elements) and the relationship between these different modes.
- Be able to state and prove the Central Limit Theorem and understand how this result can be applied.
- Understand some basic results on discrete time martingales.

Assessment: 100% by 2-hour examination.

Course Material: Lecture notes, example sheets, and other module material are to be found at the Module Resources page. Note that lecture notes are made available progressively throughout the module.

ST332: Medical Statistics

(https://warwick.ac.uk/fac/sci/maths/undergrad/ughandbook/year3/st332)
Lecturer(s): **Professor Jane Hutton**

Important: If you decide to take ST332 you cannot then take ST409. Bear this in mind when planning your module selection. Recall: an integrated Masters student must take at least 120 CATS of level 4+ modules over their 3rd & 4th years.

Commitment: 3 lectures/week. This module runs in Term 2.

Prerequisite(s): Either ST218/219 Mathematical Statistics A&B or ST220 Introduction to Mathematical Statistics

Content: Modern applications of statistics to medicine are highly developed. A look at almost any medical journal reveals that a substantial proportion of medical research papers employ statistical techniques. Large numbers of statisticians are employed in medical research establishments, particularly in the pharmaceutical companies and the medical schools, and medical statistics continues to be the most buoyant area for statistical recruitment. Although the course will cover some topics of a specifically medical nature, much of the work will be discussing basic statistical techniques as applied to medical data, but which could equally well be applied to data arising in other applications. Thus, whilst medicine provides the focus of the course, it could also be viewed as a more general applied statistics course. The course will explain why and how statistics is used in medicine, and study some of the statistical methods commonly used in medical research. Examples and case studies in areas such as cancer, heart disease and psychiatry will be discussed.

- *Generalised linear models:* linear models as an extension of linear regression; analysis of binary data by logistic regression; analysis of counts and proportions. Two by two tables.
- *Study designs:* cohort, case-control and survey designs; randomised clinical trials; sample size and power; conditioning and covariance adjustment.
- *Analysis of censored survival data:* life tables; hazard and survival functions; Kaplan-Meier survival curves; parametric survival models, the proportional hazards regression model.

Aims: To introduce applications of statistics in medicine, and some of the statistical methods commonly used in medical research.

Objectives:

- To appreciate the role of statistics in medical research.
- To understand some of the statistical principles of good practice in medical investigations.

- To understand how to use and interpret some of the statistical techniques used in medical data analysis.

Books:

- A.J.Dobson, "An introduction to generalised linear models";
- D.G.Altman, "Practical statistics for medical research";
- D.Collett, "Modelling survival data in medical research". (All Chapman & Hall)

Assessment: One assignment worth 10%, one group project worth 10%, 80% by examination

Deadline: Individual Assignment - Term 2 Week 6 and Group Project - Term 3 Week 2

Feedback: Feedback will be returned within 20 working days.

Year 1 Modules

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Year 2 Modules

Year 2 regs and modules
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Year 3 Modules

Year 3 regs and modules
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Year 4 Modules

Year 4 regs and modules
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Exam Information

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Core module averages

ST337: Bayesian Forecasting and Intervention

(https://warwick.ac.uk/fac/sci/maths/undergrad/ughandbook/year3/st337)
Lecturer(s): Dr Jeremie Houssineau

Important: If you decide to take ST337 you cannot then take ST405. Bear this in mind when planning your module selection. Recall: an integrated Masters student must take at least 120 CATS of level 4+ modules over their 3rd & 4th years.

Prerequisite(s): Either ST218/219 Mathematical Statistics A&B or ST220 Introduction to Mathematical Statistics

This module runs in Term 2.

Rationale: Forecasting is a vital prerequisite to decision making. This course is concerned with the theory and practice of short-term forecasting, using both data and subjective information. The course focuses on Dynamic Linear Models (DLM). DLM's are a class of Bayesian Forecasting Models which generalise linear regression models and static statistical linear models. The course offers a very powerful fundamental probabilistic approach to forecasting, controlling and learning about uncertain commercial, financial, economic, production, environmental and medical dynamic systems.

Contents:

- State space modelling

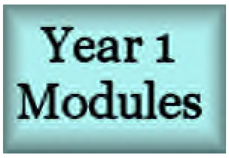
- Bayesian updating of beliefs
- Specifying Dynamic Linear Models
- Updating Dynamic Linear Models, forecasting
- Building Dynamic Linear Models, accommodating external information
- ARIMA models, stationarity

The theory will be illustrated by real examples from industry, marketing, finance, government, agriculture etc.

Books: Printed course notes will be available.

- Mike West & Jeff Harrison, "Bayesian Forecasting and Dynamic Models", 1997 (2nd edn.) Springer - Verlag.
- Andy Pole, Mike West & Jeff Harrison, "Applied Bayesian Forecasting and Time Series Analysis", 1994 Chapman and Hall.

Assessment: 100% by 2-hour examination.



Year 1 regs and modules
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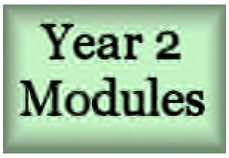

Year 2 regs and modules
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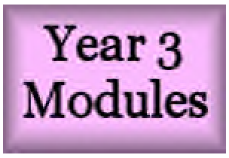
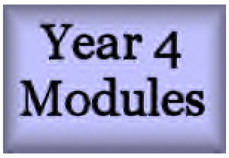


Year 3 regs and modules
G100 G103



Year 4 regs and modules
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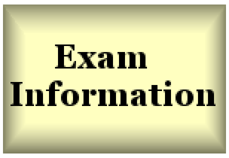


Past Exams
Core module averages

ST343 Topics in Data Science

(https://warwick.ac.uk/fac/sci/maths/undergrad/ughandbook/year3/st343)
Lecturer(s): Dr Paul Jenkins , Dr Theo Damoulas and Dr Adam Johansen

Please note that the topics covered in this module may change from year to year.

Prerequisite(s): Either ST219 Mathematical Statistics B, ST220 Introduction to Mathematical Statistics or CS260 Algorithms.

Commitment: 3 lectures per week for 10 weeks. This module runs in Term 2.

Content: Three self-contained sets of ten lectures in term 2.

Title: Artificial Neural Networks

Lecturer: Dr Paul Jenkins

Aims: Artificial neural networks (NNs) are a class of learning algorithms for regression, classification, and unsupervised learning that mimic real neural networks. They are very flexible and have become hugely popular in recent years. This topic will provide an introduction to the theory and practice of artificial NNs for supervised learning, building up from simple single layer feed-forward networks to complex multi-layer 'deep' architectures. We will cover some theory such as universal approximation theorems, as well as practicalities like training and regularization. We will also cover extensions including recurrent NNs, convolutional NNs, and (time-permitting) unsupervised NNs.

Objectives: By the end of the course students should be able to (1) explain the key concepts of artificial NNs, such as activation functions, layers, weights; (2) describe and implement a gradient descent algorithm for fitting a NN; (3) discuss the issues arising in training NNs, such as overfitting, instability, and computational cost.

References: Goodfellow et al. “Deep learning”. MIT Press, 2017.

Title: Introduction to Reinforcement Learning

Lecturer: Dr Theo Damoulas

Aims: Reinforcement Learning (RL) is one of the main subfields of machine learning, alongside supervised and unsupervised learning, that focuses on decision making under implicit feedback. As such, it is heavily employed and developed in areas such as robotics and AI enginges in games like Go and Chess. This topic will introduce the field of RL and standard agent-environment framework, covering Bellman's equations, dynamic programming, Monte Carlo and Temporal-Difference learning.

Objectives: By the end of the topic students should be able to (1) explain key concepts in RL such as the exploration-expolitation trade-off, discounting, MDPs, Policy iteration, Bellman's equations, TD and Q-learning; (2) implement basic RL algorithms; (3) have an understanding of basic issues such as the curse of dimensionality and differences between on and off-policy control.

References: Reinforcement Learning: An Introduction, S.Sutton and A.G.Barto (2002)

Title: Modelling the Written Word: Compression and Human-Computer-Interfaces

Lecturer: Dr Adam Johansen

Aims: Modelling of written words, viewed as streams of symbols from a finite alphabet, is a rich field with an extensive literature. This topic will provide an introduction to some probabilistic approaches to this problem and will show how these models can be used to efficiently store written text and also to provide efficient mechanisms for entry of text into computer systems which can be used without mastering the keyboard.

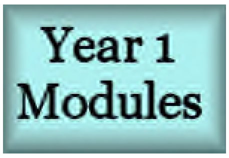
Objectives: By the end of the course students should be able to

(1) train and use simple probabilistic models for strings of characters to describe written languages;
(2) describe and implement simple symbol- and stream- coding and decoding algorithms (such as Huffman coding and arithmetic coding);
(3) explain the connection between data compression and data entry and hence how to use simple probabilistic models of written language to facilitate efficient entry of text into a computer system.

References:

- Information Theory, Inference, and Learning Algorithms, D. J. C. MacKay, Cambridge University Press (2003).
- Non-uniform Random Variate Generation, L. Devroye, Springer-Verlag (1986).
- Fast Hands-free writing by Gaze Direction, D. J. Ward and D. J. C. MacKay, Nature 418(6900):838.

Assessment: 100% by 2-hour examination.



Year 1 regs and modules
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CS301 Complexity of Algorithms

(https://warwick.ac.uk/fac/sci/maths/undergrad/ughandbook/year3/cs301)

Academic Aims

To learn the notions of the complexity of algorithms and the complexity of computational problems. To learn various models of computation. To understand what makes some computational problems harder than others. To understand how to deal with hard/intractable problems.

Learning Outcomes

Students will learn to analyse the intrinsic difficulty of various computational challenges, and how to specify useful variations that may be more tractable.

Content

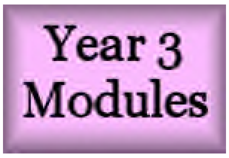
In this module, the notions of complexity of algorithms and of computational problems will be studied. Students will learn how to design efficient algorithms, what makes an algorithm efficient, and what makes a problem hard (so that it has no fast algorithm).

Various models of computation will be discussed, in particular, the models of classical deterministic computations, non-deterministic computations, and also of randomized computations, approximation algorithms, parallel computations, and on-line computations will be presented.

Some part of the module will be devoted to the discussion of what makes some computational problems harder than others, how to classify well-defined computational problems into levels of hardness, and how to deal with problems that are hard and intractable.

Year 1 Modules
Year 1 regs and modules
G100 G103 GL11 G1NC

Year 2 Modules
Year 2 regs and modules
G100 G103 GL11 G1NC



Year 3 regs and modules
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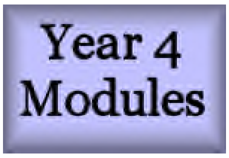

Year 4 regs and modules
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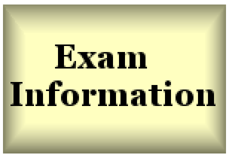


Past Exams
Core module averages

CS324 Computer Graphics

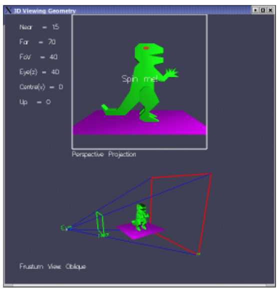
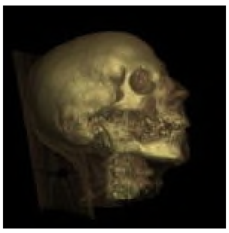
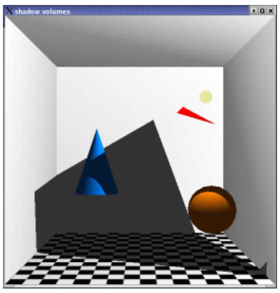
(https://warwick.ac.uk/fac/sci/maths/undergrad/ughandbook/year3/cs324)
This course is a solid introduction to computer graphics, from how we see, display devices, and how computer graphics are generated by modern graphics processing units (GPUs).

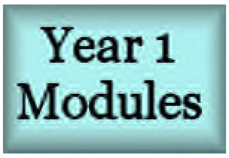
With plenty of visual examples and demos, the lectures covers, step-by-step:

- the graphic generation process and viewing geometry
- three-dimensional objects,
- parametric representations such as spline curves and surfaces,
- display lists and drawing primitives
- rasterisation onto a two-dimensional frame-buffer

On the way, we look at how realism is achieved by the clever use of texture-mapping and the approximation of lighting and shading, including shadow generation. We also look at ray-casting techniques, global illumination and volume rendering.

The course will assume you have some background in vector and linear algebra.



Year 1 regs and modules
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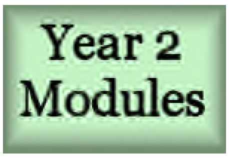

Year 2 regs and modules
G100 G103 GL11 G1NC

CS325 Compiler Design

(https://warwick.ac.uk/fac/sci/maths/undergrad/ughandbook/year3/cs325)

Academic Aims

The module will provide a through introduction to the principles of compiler design, with an emphasis on general solutions to common problems as well as techniques for putting the extensive theory into practice.

Learning Outcomes

A successful student will have acquired the skills to understand, develop, and analyze recognizers for programming languages. The student will also be able to deploy efficient and methodical techniques for integrating semantic analysis into the afore-mentioned recognizers, and generate low-level code for most constructs that characterise imperative and functional programming languages.

Content

- Languages and Grammars: regular expressions, context-free grammars, BNF.
- Parsing: top-down and bottom-up techniques.
- Semantic Analysis: attribute grammars, translation schemes, type inference, symbol tables.
- Code Generation: run-time environment, intermediate code, register allocation, optimization.
- Programming Paradigms: issues in the compilation of imperative, functional, and object-oriented languages.

15 CATS (7.5 ECTS)
Term 2
Organiser:
Dr Gihan Mudalige

Syllabus
Online material

Year 2 Modules

Year 2 regs and modules
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Year 3 Modules

Year 3 regs and modules
G100 G103

Year 4 Modules

Year 4 regs and modules
G103

Exam Information

Past Exams
Core module averages

CS332 Programming Language Design and Semantics

(https://warwick.ac.uk/fac/sci/maths/undergrad/ughandbook/year3/cs332)
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Year 1 Modules

Year 1 regs and modules
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Year 2 Modules

Year 2 regs and modules
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Year 3 Modules

Year 3 regs and modules
G100 G103

Year 4 Modules

Year 4 regs and modules
G103

Exam Information

Past Exams

Core module averages

PX350 Weather and the Environment

(https://warwick.ac.uk/fac/sci/maths/undergrad/ughandbook/year3/px350)

Lecturer: David Leadley

Weighting: 7.5 CATS

The diffusion, convection, chemical reactions and the interaction with living organisms, which take place in or at the boundaries of the atmosphere, determine the weather patterns we observe. The module looks at some of these processes. The module also treats the phenomenon of cloud-formation and the role of the earth's rotation in determining flow patterns in the atmosphere.

Aims:

To show how the troposphere 'works'. To show how, with only very simple ideas from mechanics and thermodynamics, one can explain most of what we call 'weather'.

Objectives:

By the end of the module you should:

- be able to describe the structure and composition of the earth's atmosphere and how it developed.
- appreciate how motion in the troposphere is driven by the (differential) heating of the earth by the sun.
- understand how the troposphere transfers heat and matter by convection-generated flows and the effect on these flows of the earth's rotation
- understand the mechanisms that lead to precipitation
- be aware of the influence of human activity on the atmosphere and climate

The module is quite descriptive. You will need to develop your ability to be precise and accurate when writing about and describing phenomena, even when not referring to a quantitative theory.

Syllabus:

Description of the atmosphere
Composition: permanent and variable gases
Layer profile: troposphere, stratosphere (ozone layer), mesosphere and beyond
Atmospheric energy balance: surface temperature, albedo and greenhouse effect
Origin of the earth's atmosphere and the role of life in determining past and future climates
Vertical motion and role of water
Atmospheric stability: dry and saturated adiabatic lapse rates
Water vapour: relative humidity, evaporation and condensation
Cloud formation: condensation nuclei, growth by diffusion and accretion
Precipitation: warm rain, the three-stage process
Atmospheric electricity: lightning
Flow Patterns - wind and weather
Pressure gradients and their origins: sea breezes
Mechanics in a rotating frame: Coriolis force, geostrophic wind
Circulation on a global scale: prevailing winds, jet streams
Synoptic scale motion: air masses, fronts, cyclones and accompanying weather patterns
Mesoscale and microscale motion: planetary boundary layer.
Influence of the oceans: El Niño, Gulf Stream.

Commitment: 15 Lectures + examples sheets

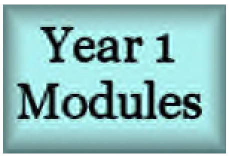
The examples sheets are designed to take you through (usually) very simple arguments which explain a number of surprising and familiar phenomena from everyday experience, *eg* the size of raindrops, why smoke sometimes rises vertically and sometimes is advected downstream by the wind, why the wind direction rotates with height, the relative sizes of the gravitational, Coriolis and other horizontal forces.

This module has its own home page.

Assessment: 1.5 hour examination

Recommended Text: JFR McIlveen, *Fundamentals of Weather and Climate*, 2nd Ed., Oxford, 2010;
or 1st Ed., *Fundamentals of Weather and Climate* Chapman & Hall, 1992;
John M. Wallace and Peter V. Hobbs, *Atmospheric science : an introductory survey (2nd ed)*, Academic Press, 2006.

Leads from: The module has no real prerequisites, but draws on some elementary concepts discussed in: PX148 Classical Mechanics and Relativity, PX264 Physics of Fluids



Year 1 regs and modules
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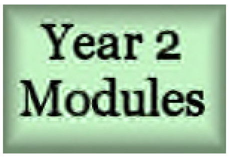

Year 2 regs and modules
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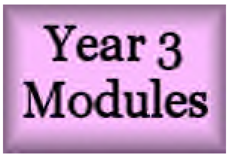

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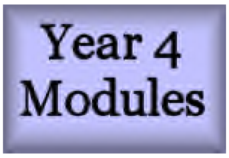

Year 4 regs and modules
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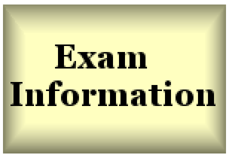


Past Exams
Core module averages

PX366 Statistical Physics

(https://warwick.ac.uk/fac/sci/maths/undergrad/ughandbook/year3/px366)

Lecturer: Marco Polin

Weighting: 7.5 CATS

Fluctuations play an essential role in nature. Statistical mechanics is, in essence, a description of the role played by these fluctuations. The module studies the physics of such seemingly diverse problems as diffusion, phase transitions and Fermi-Dirac and Bose-Einstein statistics. It also uses examples from Polymer physics where the behaviour of the polymer chains is driven by configurational entropy, rather than energy.

Aims:
To illustrate the important concepts of modern statistical physics using simple examples. It should give an appreciation of the fundamental role played by fluctuations in nature.

Objectives:
At the end of the module you should

- Have been reminded about aspects of equilibrium thermodynamics
- Have been introduced to the statistical mechanics of long chain molecules (polymers) and understand why they are examples of systems driven by configurational entropy rather than energy
- Appreciate the importance of phase transitions, primarily the paramagnetic-ferromagnetic transition
- Understand the motivation behind the Ginzburg-Landau theory of continuous symmetry breaking phase transitions
- Understand the physics of diffusive processes. Know the origin of the Langevin and diffusion equations
- Understand the origin of the law of equipartition of energy and see how it may be used to solve real problems where we are interested in the statistics of fluctuations

Syllabus:

Review of the fundamental principles underlying conventional statistical mechanics and thermodynamics.

Introduction to phase transitions I: thermodynamic description. PVT system: coexistence lines, triple point, critical point, Gibbs phase rule. First order transitions (latent heat) and continuous phase transitions (no latent heat, divergence of susceptibilities). Gas-liquid coexistence region, lever rule, metastable states and spinodal decomposition.

Introduction to phase transitions II: mean-field description. Introduction to the idea of universality, importance of symmetries, concept of order parameter and spontaneous symmetry breaking. Ferromagnetic Ising model: mean field theory, Curie temperature and emergence of spontaneous magnetisation. Introduction to the concept of critical exponent. Ginzburg-Landau description of phase transitions (continuous and first order). Failure of mean field and concept of critical dimension. Polymers. Motivate a treatment of polymers based on statistical physics emphasising an insensitivity to the chemistry. Difference between ideal and non-ideal chains. Critical review of different models for ideal chain -Gaussian chain, lattice chain, freely jointed chain-. Master equation and derivation of diffusion equation. Restricted ideal polymers: entropic elasticity of a single chain (both linear and nonlinear); polymers confined by one wall (polymer brush) and two walls (disjoining pressure).

Brownian motion I: macroscopic description. Introduction to the concept of Brownian motion and its physical origin. Typical orders of magnitude and diffusion timescales. Conservation equation, Fick's law and its microscopic motivation. Derivation of Fokker-Planck equation; fluctuation-dissipation theorem. Simple solutions to Fokker-Planck equation (free diffusion and link to ideal polymers; one absorbing wall; communicating reservoirs) and discussion of physical meaning of different boundary conditions.

Brownian motion II: microscopic description. Difference between macroscopic and microscopic description, concept of ensemble average. Langevin equation, origin and properties of Brownian noise. Massless diffusion (overdamped case): formal solution; concept of a Markov process; mean square displacement; how to establish the properties of Brownian noise; velocity autocorrelation and diffusivity. Brownian particle in a potential (Ornstein-Uhlenbeck process): autocorrelation and memory of the process; mean square displacement and caging. Free diffusion with mass (underdamped case) and connection with Ornstein-Uhlenbeck process. Issues with Langevin equation at short timescales (hydrodynamic memory).

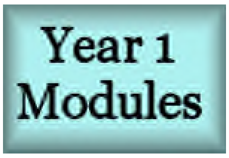
Commitment: 15 Lectures

Assessment: 1.5 hour examination

Recommended Texts: F. Mandl, *Statistical Physics*, Wiley; David Chandler, *Introduction to Modern Statistical Mechanics*, OUP; P de Gennes *Scaling Concepts in Polymer Physics*, Cornell Univ. Press

This module has its own home page.

Leads from: PX265 Thermal Physics II



Year 1 regs and modules
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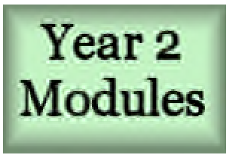

Year 2 regs and modules
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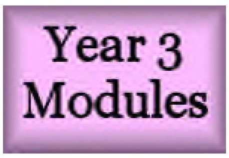

Year 3 regs and modules
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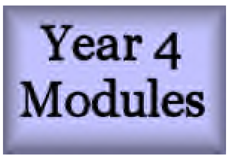


Year 4 regs and modules
G103

Exam Information

Past Exams

Core module averages

PX382 Quantum Physics of Atoms

(https://warwick.ac.uk/fac/sci/maths/undergrad/ughandbook/year3/px382)

Lecturer: Martin Lees

Weighting: 7.5 CATS

The principles of quantum mechanics are applied to a range of phenomena in atomic physics including the operation of a laser. The intrinsic property of spin is described and its relation to the indistinguishability of identical particles in quantum mechanics discussed. Perturbation theory and variational methods are described and applied to several problems. The hydrogen and helium atoms are analysed and the ideas that come out from this work are used to obtain a good qualitative understanding of the periodic table.

Aims:

To develop the ideas of quantum theory and apply these to atomic physics

Objectives:
At the end of the module you should:

- Have developed an understanding of the approximate methods of quantum theory – perturbation theory (time-dependent and time-independent), variational methods
- Understand the role of spin and the Pauli exclusion principle
- Be able to explain atomic spectra and the structure of the periodic table
- Have an understanding of lasers

Syllabus:

Review of Second Year Quantum Mechanics

Approximation methods in quantum mechanics
Time-independent perturbation theory.
• Non-degenerate case, ground state of helium atom.
• Degenerate case, Stark effect in hydrogen.
Variational methods: Rayleigh - Ritz, ground state of helium atom.

Spin-orbit coupling and the Zeeman effect
Effects of spin-orbit coupling, and the strong and weak field Zeeman effect using time-independent perturbation theory.

Many electron effects-indistinguishability of identical particles
Identical particles and spin.
Symmetric and anti-symmetric states.
Discussion of periodic table, ionisation energies.

Time-dependent perturbation theory and the lasers
Derivation of Fermi's golden rule.
Radiation from atoms.
Operation of the laser including stimulated emission and population inversion.

Commitment: 15 lectures

Assessment: 1.5 hour examination (85%) + assessed work (15%).

This module has a home page.

Recommended Texts: S.M. McMurry, *Quantum Mechanics*, Addison-Wesley 1994
F Mandl, *Quantum Mechanics*, Wiley A.I.M. Rae, *Quantum Mechanics*, IOP, 2002; S. Gasiorowicz, *Quantum Physics*, Wiley, 2003;

Leads from: PX262 Quantum Mechanics and its Applications;
Leads to: Other modules on quantum theory and quantum phenomena.

PX389 Cosmology

(https://warwick.ac.uk/fac/sci/maths/undergrad/ughandbook/year3/px389)

Lecturer: Grant Kennedy

Weighting: 7.5 CATS

Questions about the origin of the Universe, where it is going and how it may get there are the domain of cosmology. One of the questions addressed in the module is whether the Universe will continue to expand or ultimately contract. Relevant experimental data include those on the Cosmic Microwave Background radiation, the distribution of galaxies and the distribution of mass in the Universe. The module discusses the implications of these in some detail. Starting from fundamental observations such as that the night sky is dark and, by appealing to principles from Einstein's General Theory of Relativity, the module develops a description of the Universe. This leads to the Friedmann equation, Hubble's law, the cosmological redshift and eventually to the Big Bang Model, with singular behaviour at the origin of the Universe. The module also discusses the evolution of the primeval fireball, the synthesis of Helium and the origin of structure.

Aims:
To present the credentials of the Universe as we know it (via experiment) and introduce the simplest models which can describe it. The module should stress the role of experimental data and emphasize the need to distinguish between cosmology as a physical science, which makes testable predictions, and untestable pseudo-cosmologies which may claim to give appealing and all-encompassing accounts of the universe but are untestable.

Objectives:
By the end of the module, you should:

- have a good qualitative appreciation of the current status of cosmology
- recognise the importance of observations in constraining possible cosmological theories
- understand the idea of metrics used to describe local and global physics
- be critically aware of some of the aspects of cosmology where more work is needed to reconcile theory and observations

Syllabus:

1. The history and foundations of modern cosmology: Olber’s Paradox, Hubble’s Law and the Cosmological Principle.

2. Describing the evolution of the Universe: basics of space time and relativity, curvature, Friedmann equation, fluid and acceleration equations.
3. Model universes: describing the evolution when dominated by single component and multiple-components - the standard cosmological (benchmark) model.
4. Key properties of our Universe: tests of the standard cosmological model, evidence for dark matter; models for dark matter, origin of structure.
5. The early Universe: the Big Bang, connection to elementary particle physics and grand-unified field theories (GUTS), inflation, Big Bang nucleosynthesis, formation of the cosmic background radiation.

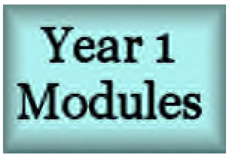
Commitment: 15 Lectures

Assessment: 1.5 hour examination.

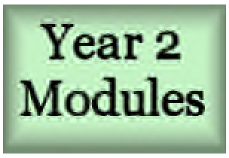
This module has a home page.

Recommended Texts: Please see homepage

Leads to: PX436 General Relativity



Year 1 regs and modules
G100 G103 GL11 G1NC



Year 2 regs and modules
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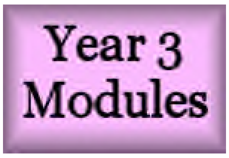
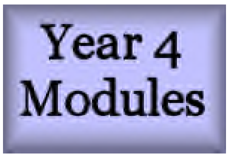


Year 3 regs and modules
G100 G103



Year 4 regs and modules
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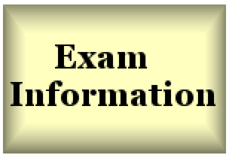


Past Exams
Core module averages

PX390 Scientific Programming

(https://warwick.ac.uk/fac/sci/maths/undergrad/ughandbook/year3/px390)

Organiser: Ben McMillan

Weighting: 15 CATS

This module should help you develop C programming skills. The module will consist of some lectures and a series of programming exercises designed to illustrate important aspects of program design. The module will also cover some important numerical techniques used in data processing in physics. Aspects relating to the reliability, accuracy and efficiency of these techniques will be discussed, as well as other issues such as making software user friendly, and data transfer between platforms. The module will be assessed on the basis of the exercises completed during the module and some project work.

Aims:
To develop proficiency in the solution of physics problems and to understand the fundamentals of numerical computation using the C programming

language, which underpins modern software.

Objectives:
You should

- Be able to program in the C language, and be familiar with the development cycle and debugging tools.
- Understand how computer hardware implements numerical operations and the implications for numerical software
- Select appropriate algorithms to solve physics problems
- Implement software to solve physics problems, including those that involve partial differential equations
- Be able to test your code and determine the size of numerical errors.

Syllabus:

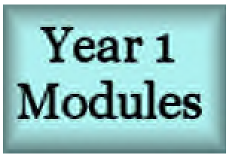
1. The C Syntax and the development cycle. The underlying representation of data in hardware will be discussed, and the methods by which the C language reveals this low-level description through the use of pointers.
2. Tools for debugging and verifying C programs will be introduced, and coding standards and effective programming techniques introduced to reinforce the concepts of modularity and clarity in code writing.
3. Numerical representation of mathematical objects, and, in particular, multi-dimensional functions, will be introduced. Numerical integration will be used to illustrate concepts of numerical accuracy and the relationship of numerical methods to function properties.
4. Algorithms for solving chaotic and stochastic differential equations will be explored, and robustness and reproducibility will be quantified.
5. The finite difference method will be explained, along with concepts of numerical convergence and stability.
6. Minimisation techniques and the use of the weak form of equations will be used to introduce finite-element and variational approaches.
7. Data structures, and in particular lists and tree algorithms. Use of these in physics problems, in particular, n-body codes.

Commitment: 10 lectures + 15 2 hour workshops.

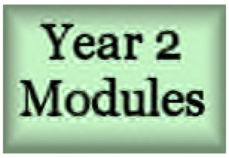
Assessment: The module is 100% assessed. 6 assignments with weightings 10%, 10%, 20%, 20%, 20% and 20%.

This module has a home page.

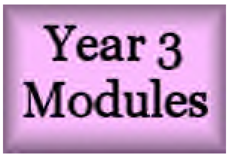
Leads from: PX277 Computational Physics
Leads to: PX425 High Performance Computing in Physics



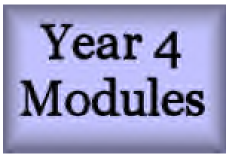
Year 1 regs and modules
G100 G103 GL11 G1NC



Year 2 regs and modules
G100 G103 GL11 G1NC



Year 3 regs and modules
G100 G103



Year 4 regs and modules
G103

PX384 Electrodynamics

(https://warwick.ac.uk/fac/sci/maths/undergrad/ughandbook/year3/px384)

Lecturer: Robin Ball

Weighting: 7.5 CATS

The module starts by revising the magnetic vector potential, A, which is defined so that the magnetic field B=curl A. We will see that this is the natural quantity to consider when exploring how electric and magnetic fields transform under Lorentz transformations (special relativity).

The radiation (EM-waves) emitted by accelerating charges will be described using retarded potentials (these are the time-dependent analogs of the usual electrostatic potential and the magnetic vector potential) and have the wave-like nature of light built in. The scattering of light by free electrons (Thompson scattering) and by bound electrons (Rayleigh scattering) will also be described. Understanding the bound electron problem led Rayleigh to his celebrated explanation of why the sky is blue and why sunlight appears redder at sunrise and sunset.

Aims:

To introduce the magnetic vector potential and to show that electromagnetism is Lorentz invariant. To discuss particle dynamics in plasmas.

Objectives:
At the end of the module, you should:

- Be familiar with the vector potential and Lorentz invariant form of Maxwell's equations
- Be able to manipulate Maxwell's equations and solve representative problems using 4-vectors
- Understand the physics of EM radiation and scattering and be able to describe the propagation of EM waves through free space
- Know how Maxwell's equations can be solved to calculate the EM field from known source distributions.

Syllabus:

1. Revision of special relativity. Revision of Maxwell's Equations in vacuum and in a macroscopic medium. Simple models of polarization. Displacement current; Potentials ϕ and $\boldsymbol{A}$. Coulomb and Lorenz gauge. Laplace's and Poisson's equations and the solution of Maxwell's equations. Retarded potentials.
2. Lorentz invariance of Maxwell's equations. Four vectors. Covariant and contravariant representation (examples, exercises on-line). Minkovsky's metric tensor (exercises on-line). Four vector formulation of Maxwell's equation (examples, exercises on-line).
3. Generation of EM waves and retarded potentials. The power radiated by accelerating charges.
4. The scattering of EM waves. Rayleigh scattering and Thompson scattering.

Commitment: 15 Lectures

Assessment: 1.5 hour examination (85%), coursework (15%)

Recommended Text: IS Grant and WR Phillips, *Electromagnetism*, Wiley

This module has a home page.

Leads from: PX263 Electromagnetic Theory and Optics

Leads to: Further modules on Classical Physics

PX392 Plasma Electrodynamics

(https://warwick.ac.uk/fac/sci/maths/undergrad/ughandbook/year3/px392)

Lecturer: Valery Nakariakov

Weighting: 7.5 CATS

Plasmas are 'fluids' of charged particles. The motion of these charged particles (usually electrons) is controlled by the electromagnetic fields which are imposed from outside and by the fields which the moving charged particles themselves set up. This module will cover the key equations which describe such plasmas. It will examine some predictions derived on the basis of these equations and compare these with results from laboratory experiments and with observations from in situ measurements of solar system plasmas and remote observations of astrophysical systems. It will also be important to look at instabilities in plasmas and how electromagnetic waves interact with the plasmas.

Aims:
The module should discuss particle dynamics in plasmas. The interaction of EM fields with a fully ionised fluid (plasma) should be considered in detail leading to ideas of magnetohydrodynamics.

Objectives:
At the end of the module, you should

- Be familiar with single particle dynamics, guiding centre motion and adiabatic invariants, the plasma approximation and waves in plasmas
- Understand the nature of bulk fluid-instabilities with application to confinement devices and astrophysics
- Be familiar with micro-instabilities and their description via distribution functions
- Understand the interaction of electromagnetic waves with plasmas.

Syllabus:

1. Single particle dynamics guiding centre motion and adiabatic invariants. The plasma approximation, waves in plasmas
2. Propagation of EM waves through plasmas
3. MHD description of plasmas and fluid like plasma instabilities
4. Vlasov's equation and micro-instabilities

Commitment: 15 lectures

Assessment: 1.5 hour examination.

This module has a home page.

Recommended Text: N.A. Krall and A.W. Trivelpiece, *Principles of Plasma Physics*, San Fransisco Press/McGraw Hill;
R. O. Dendy. *Plasma Dynamics*, OUP 1990.

Leads to: Other modules on Plasmas

PX396 Nuclear Physics

(https://warwick.ac.uk/fac/sci/maths/undergrad/ughandbook/year3/px396)

Lecturer: Michal Kreps

Weighting: 7.5 CATS

This module shows how the properties of the stable nucleus can be understood in terms of elementary models using basic physics from earlier modules, but with the introduction of the strong nuclear force. It is shown that the main features of the decay of unstable nuclei can also be understood on the basis of these ideas, but that a further interaction, the weak interaction, has to be postulated.

Aims:
To introduce the concepts and models of nuclear physics. To describe experimental methods used to probe nuclear properties.

Objectives:
At the end of the module, you should

- Be able to describe the properties and structure of stable nuclei
- Understand the properties of the nuclear force
- Be aware of the constraints on a quantum model of the nucleus
- Understand the shell model and be able to explain radioactive processes including beta decay and its properties

Syllabus:

Nuclear Properties (4L): Nuclear radius; distribution of nuclear matter; nuclear mass and binding energy
Nuclear force and the strong interaction (4L): Properties of the deuteron; nucleon-nucleon scattering; Isospin and the structure of nuclear forces
Nuclear models (3L): Nucleons in a central potential; the shell model
Radioactivity (2L): Radioactive decay, beta-decay and the weak interaction

Commitment: 15 Lectures

Assessment: 1.5 hour examination

This module has a home page.

Recommended Texts:

B.R. Martin, Nuclear and Particle Physics, Wiley, 2006

Leads from: Core modules on quantum physics.

Year 1 Modules

Year 1 regs and modules
G100 G103 GL11 G1NC

Year 2 Modules

Year 2 regs and modules
G100 G103 GL11 G1NC

Year 3 Modules

Year 3 regs and modules
G100 G103

Year 4 Modules

Year 4 regs and modules
G103

Exam Information

Past Exams
Core module averages

PX397 Galaxies

(https://warwick.ac.uk/fac/sci/maths/undergrad/ughandbook/year3/px397)

Lecturer: Matteo Brogi

Weighting: 7.5 CATS

The module illustrates how important physical principles, from different areas of physics, can be developed to yield a description of complex physical systems like galaxies. The module should explore some of the properties of galaxies, which yield insights into their formation, evolution and ongoing processes.

Aims:
To illustrate how important physical principles, from different areas of physics, can be developed to yield a description of complex physical systems like galaxies. The module should explore some of the properties of galaxies, which yield insights into their formation, evolution and ongoing processes.

Objectives:
By the end of the module, students should:

- be aware of the structure of our own Galaxy and how it fits into the 'zoo' of galaxies distributed through the Universe
- understand the physical principles behind the observations used to study galaxies
- be familiar with the standard models for galaxy formation, structure and evolution

- be aware of some of the outstanding, and only partially understood, problems in the study of galaxies including the nature of galaxy cores and the roles of dark matter and dust.

Syllabus:

The module describes both observational and theoretical classifications for different galaxy types and for our own Milky Way:

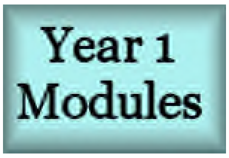
1. Galaxy classification; the Hubble Tuning Fork; elliptical and spiral galaxies; surface brightness profiles.
2. The Milky Way, its structure and properties; the role of stellar populations and the interstellar medium.
3. Galaxy populations; luminosity functions, star formation vs AGN, radio galaxies and seyferts.
4. Galaxy kinematics; Tully-Fisher relation; rotation curves; dark matter; virial mass
5. The origin and role of dust and gas in galaxies; ULIRGs; submillimeter galaxies; dust extinction laws.
6. Galaxy clusters; the local group and nearby superclusters

Commitment: 15 lectures

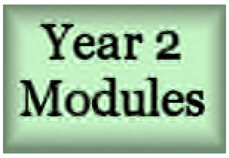
Assessment: 1.5 hour examination

This module has a home page.

Recommended texts: S Philipps, *The Structure and Evolution of Galaxies*, Wiley, 2005



Year 1 regs and modules
G100 G103 GL11 G1NC



Year 2 regs and modules
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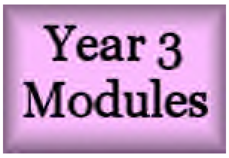

Year 3 regs and modules
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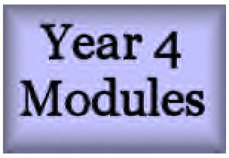
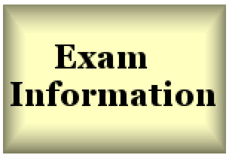


Year 4 regs and modules
G103



Past Exams
Core module averages

PX439 Statistical Mechanics of Complex Systems

(https://warwick.ac.uk/fac/sci/maths/undergrad/ughandbook/year3/px439)

Lecturer: Gareth Alexander

Weighting: 7.5 CATS

Aims:
This module aims to survey the tools of Statistical Mechanics and show examples of their use outside the traditional application domain.

Objectives:
At the end of this module you should:

- appreciate how inference underpins the modelling of multivariate complex systems in terms of fewer state variables.
- understand how fluctuations depend on system size, and limit of large numbers .
- be able to model emergent order in equilibrium systems.
- be able to construct transport models.
- be able to model emergent behaviour in non-equilibrium systems

Syllabus:

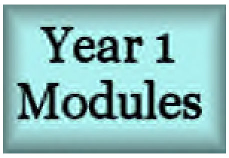
- Equilibrium
  - Statistical Mechanics from Bayesian inference and the maximum entropy principle
  - Fluctuations, the large number limit and thermodynamics
  - Equilibrium ordering and phase transitions
- Dynamics
  - Modelling non-equilibrium states. Examples in granular physics: the Edwards' ensemble of configurations.
  - Transport: fluxes and forces
  - Dynamical ordering: examples in collective biological motion, flocking, social ordering

Commitment: 10 x 2 hour lecture slots and optional classwork

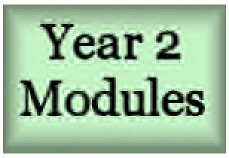
Assessment: 1.5 hour examination

Recommended Texts: JP Sethna, *Statistical Mechanics: Entropy, Order Pararmeters and Complexity*, OUP 2006

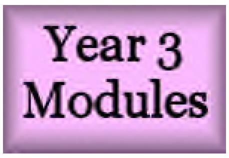
Leads from: PX366 Statistical Physics



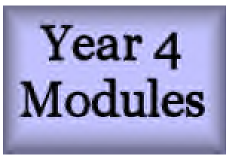
Year 1 regs and modules
G100 G103 GL11 G1NC



Year 2 regs and modules
G100 G103 GL11 G1NC



Year 3 regs and modules
G100 G103



Year 4 regs and modules
G103

PX308 Physics in Medicine

(https://warwick.ac.uk/fac/sci/maths/undergrad/ughandbook/year3/px308)

Lecturer: Michael Pounds

Weighting: 7.5 CATS

The application of physics and physical measurement techniques are essential to modern medicine. This module concentrates on five major areas of medical physics: plain film X-ray imaging, X-ray computer tomography, nuclear medicine, ultrasound in medicine, and radiotherapy. The aim of the module is to demonstrate the application of basic physical principles to these important areas of medical physics.

Aims:
To show how some of the physics learnt in a number of core modules may be applied in an important area outside of physics.

Objectives:
By the end of the module, you should be able to explain the physical principles underlying the five areas of the application of physics to medicine covered in the module. You should be able to discuss the advantages and drawbacks of each of these therapeutic or investigative techniques and have some understanding of the current research into ways in which they might be improved.

Syllabus:
An introduction to some of the applications of physics in medicine. Five major topics:

1. Plain film X-ray imaging
2. X-ray computer tomography
3. Nuclear medicine
4. Ultrasound in medicine
5. Radiotherapy

A companion module is Magnetic Resonance (PX388), where the syllabus includes one of the most important diagnostic tools in modern medicine, Magnetic Resonance Imaging (MRI).

Commitment: 15 Lectures

Assessment: 1.5 hour examination.

This module has a home page.

Recommended Texts:
S. Webb (Ed), *The Physics of Medical Imaging*, Hilger
B.H. Brown et. al., *Medical Physics and Biomedical Engineering* IOPP;
G. Steele, *Basic Clinical Radiobiology*, Arnold;
Bomford et. al., *Walter and Miller's textbook of radiotherapy*, Churchill.

PX370 Optoelectronics and Laser Physics

(https://warwick.ac.uk/fac/sci/maths/undergrad/ughandbook/year3/px370)

Lecturer: Steve Dixon

Weighting: 7.5 CATS

Lasers produce coherent light, which can be used to carry information and energy. Semiconductor lasers, in particular, have become very important in the field of communication. This module covers the basic physics of laser action in the various types of laser and describes their applications in optoelectronics.

Aims:
To provide an introduction to the physical principles upon which the laser and a number of other optoelectronic devices are based. To describe a number of different types of laser, second harmonic generation using lasers, modulators (both electro-opto and acousto-optic) and detectors such as the photodiode, avalanche photodiode and photomultiplier. To describe the properties of optical fibres and the likely requirements of an optical communication system.

Objectives:
At the end of the module you should:

- understand the essential requirements for laser action in a material and be able to describe different types of laser.
- be able to describe an optical modulator.
- be able to describe light detectors such as the photodiode, avalanche photodiode and photomultiplier and be aware of their relative merits.
- be able to describe optical fibres and to discuss which are the important parameters of these in an optical communications system.

Syllabus:

Lasers: Spontaneous and stimulated emission, Einstein A and B coefficients; optical cavities, Fabry Perot; inversion mechanisms; examples of different types of laser; gas lasers, solid state optically pumped lasers, dye lasers, homojunction and heterojunction semiconductor diode lasers. Q switching; second harmonic generation. Optical modulators, electro-optic modulators, acousto-optic modulators. Light detectors, semiconductor diode detectors, Avalanche Photodiodes. Optical Fibres. Optical communications.

Commitment: 15 Lectures

Assessment: 1.5 hour examination

Recommended Text: J Wilson and JFB Hawkes, *Optoelectronics, an Introduction*, Prentice-Hall;

This module has on-line information available.

Leads from: PX263 Electromagnetic Theory and Optics

PX387 Astrophysics

(https://warwick.ac.uk/fac/sci/maths/undergrad/ughandbook/year3/px387)

Lecturer: Elizabeth Stanway

Weighting: 15 CATS

Aims:

To introduce the most important physical processes and detection methods required for understanding the broad band emission spectra of astrophysical objects from the radio regime to X-rays and gamma-rays, to provide a basis for further studies in observational astrophysics.

Objectives:

At the end of this module you should be:

- be able to identify the major emission mechanisms of astrophysical objects
- understand the physical basis of detection methods for UV-radiation and X-rays from astrophysical sources.
- understand how electromagnetic theory and quantum mechanics are used to predict the emission of radiation.
- be able to quantify physical conditions in a variety of astrophysical systems using measured data.
- understand how gravitational potential energy produces most of the high-energy radiation of the Universe through the process of accretion

Syllabus:

- Observational instrumentation, telescope design, detectors
- Accretion onto compact objects as a source of energy
- The Eddington limit: a maximum accretion rate
- The structure and the emission of accretion disks
- The occurence of jets in astrophysical objects
- Binary stars: configuration, evolution, stable and unstable mass transfer
- Accretion onto magnetic stars, Alven radius
- Radiation from free electrons, Larmor formula, synchrotron radiation, cyclotron radiation
- Thermal bremsstrahlung from hot accretion plasmas
- Stable and unstable nuclear shell burning in accreting white dwarfs and neutron stars
- Black holes of different masses
- Supernovae and gamma-ray burst: massive stars, exploding white dwarfs, merging neutron stars

- Pulsars: origin, emission, evolution

Commitment: 24 Lectures and 5 problem classes

Assessment: 2 hour examination

This module has a home page.

Recommended Texts: H Bradt, *Astronomy Methods: A Physical Approach to Astronomical Observations*, Cambridge University Press
J Frank, AR King and DJ Raine, *Accretion Power in Astrophysics*, CUP
C Hellier Cataclysmic Variables: How and why they vary, Springer

Leads to: 4th year modules on astrophysics

Year 1 Modules

Year 1 regs and modules
G100 G103 GL11 G1NC

Year 2 Modules

Year 2 regs and modules
G100 G103 GL11 G1NC

Year 3 Modules

Year 3 regs and modules
G100 G103

Year 4 Modules

Year 4 regs and modules
G103

Exam Information

Past Exams
Core module averages

PX436 General Relativity

(https://warwick.ac.uk/fac/sci/maths/undergrad/ughandbook/year3/px436)

Lecturer: Gareth Alexander

Weighting: 15 CATS

Einstein's general theory of relativity is the basis for our understanding of black holes and the Universe on its largest scales. In general relativity the Newtonian concept of a gravitational force is abolished, to be replaced by a new notion, that of the curvature of space-time. This leads in turn to predictions of phenomena such as the bending of light and gravitational time dilation that are well tested, and others, such as gravitational waves, which are only now coming into the regime of direct detection.

The module starts with a recap of Special Relativity, emphasizing its geometrical significance. The formalism of curved coordinate systems is then developed. Einstein's equivalence principle is used to link the two to arrive at the field equations of GR. The remainder of the module looks at the application of general relativity to stellar collapse, neutron stars and black-holes, gravitational waves, including their detection, and finally to cosmology where the origin of the "cosmological constant" -- nowadays called "dark energy" - becomes apparent.

Aims:

To present the theory of General Relativity and its applications in modern astronomy, and to give an understanding of black-holes.

Objectives:
At the end of this module you should:

- understand the metric nature of special and general relativity, how the metric determines the motion of particles
- be able to undertake elementary calculations involving the Schwarzschild metric
- be able to describe the key features of black-holes
- be able to demonstrate knowledge of current attempts to detect gravitational waves

Syllabus:

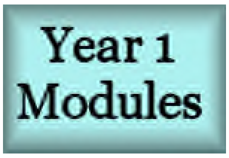
- The geometry of space-time and the invariant “interval” in special relativity; the 4-vector formulation of special relativity; the metric of special relativity
- The equivalence principle and local inertial frames; the motivation for considering curved space-time; vectors and tensors in curved coordinate systems
- Geodesics: how the metric determines equations of motion; motion in almost-flat space-time: the Newtonian limit
- The curvature and stress-energy tensors; how the metric is determined: Einstein's field equations
- The Schwarzschild metric; observable consequences; black-holes; stability of orbits; extraction of energy
- Gravitational radiation and its detection; cosmology: the Robertson-Walker metric

Commitment: 25 Lectures (and 5 problems classes)

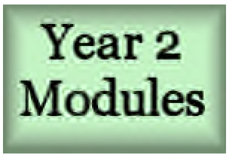
Assessment: 2 hour examination

The module has a website.

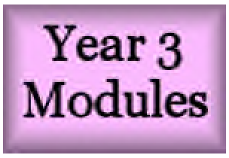
Recommended Texts: BF Schutz *A first course in general relativity*, Cambridge University Press,
M.P Hobson, G. Efstathiou, A.N. Lasenby, *General Relativity -- An Introduction for Physicists*, CUP.



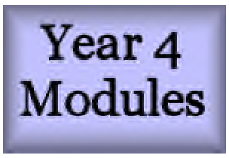
Year 1 regs and modules
G100 G103 GL11 G1NC



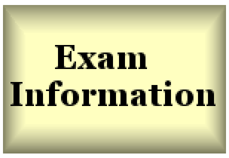
Year 2 regs and modules
G100 G103 GL11 G1NC



Year 3 regs and modules
G100 G103



Year 4 regs and modules
G103



Past Exams
Core module averages

ES3C8 Systems Modelling and Control

(https://warwick.ac.uk/fac/sci/maths/undergrad/ughandbook/year3/es3c8)

Module code: ES3C8

Module name: Systems Modelling and Control

Department: School of Engineering

Credit: 15

Content and teaching | Assessment | Availability

Module content and teaching

Principal aims

Most disciplines of the engineering profession require a sound understanding of the techniques used in the modelling and control of dynamic, multi-domain physical, and other, systems. The aims of this module are: to introduce techniques and computer tools for modelling, predicting and analysing the behaviour of dynamic systems; and to introduce concepts, principles and techniques employed in classical methods of single loop feedback control system design.

Principal learning outcomes

By the end of the module the student should be able to: 1. Develop mathematical models of physical systems (including non-linear) expressing with Ordinary Differential Equations, frequency domain and state-space techniques and representing in MATLAB/SIMULINK utilising engineering analogies to demonstrate commonality of behaviour. 2. Implement techniques of system identification (e.g. ARMAX, weiner-hopf filter, black box and grey box models) for data-driven dynamic models. 3. Utilise analytical, computational and numerical methods to analyse and predict dynamical (e.g. steady-state and transient response to a range of inputs) behaviour of physical systems including stability performance analysis for non-linear and discrete-time control systems. 4. Apply concepts and techniques to analyse the behaviour of open loop physical systems (including feasibility of end-user objectives), and to design feedback control systems (lead/lag, PID) using frequency domain and state-space techniques, and implement the solutions in MATLAB/SIMULINK and in the laboratory 5. Choose and evaluate theoretical and practical tools and methods for modelling, simulation, analysis and control of engineering systems

Timetabled teaching activities

28 x 1hr lectures 4 x 1hr example classes 2 x 1hr revision class 2 x 4hr laboratory sessions TOTAL 42 Hours

Departmental link

http://www2.warwick.ac.uk/fac/sci/eng/eso/modules/year3/es3c8

Other essential notes

Advice and feedback hours are available for answering questions on the module Student must pass the examination and the coursework.

Module assessment

Assessment group	Assessment name	Percentage
15 CATS (Module code: ES3C8-15)		
D1 (Assessed/examined work)	System Modelling and System Identification Assignment	20%
	Lab Assignment 1	10%
	Lab Assignment 2	10%
	2 hour examination (Summer)	60%
VA (Visiting students only)	100% assessed (part year) visiting	100%

Module availability

This module is available on the following courses:

Core

BEng Automotive Engineering (H330) - Year 3

MEng Automotive Engineering (H331) - Year 3

MEng Automotive Engineering with Year in Research (H333) - Year 3

MEng Automotive Engineering with Year in Research (H333) - Year 4

BEng Automotive Engineering with Intercalated Year (H339) - Year 4

BEng Systems Engineering (HH36) - Year 3

MEng Systems Engineering (HH63) - Year 3

MEng Systems Engineering with Intercalated Year (HH64) - Year 3

MEng Systems Engineering with Year in Research (HH65) - Year 3

MEng Systems Engineering with Year in Research (HH65) - Year 4

Optional Core

MEng Automotive Engineering with Intercalated Year (H332) - Year 3

MEng Automotive Engineering with Intercalated Year (H332) - Year 4

Optional

Undergraduate Mathematics (BSc) (G100) - Year 3

Undergraduate Mathematics with Intercalated Year (G101) - Year 4

Undergraduate Mathematics (MMath) (G103) - Year 3

Undergraduate Mathematics (MMath) (G103) - Year 4

Undergraduate Master of Mathematics (with Intercalated Year) (G105) - Year 3

Undergraduate Master of Mathematics (with Intercalated Year) (G105) - Year 4

Undergraduate Master of Mathematics (with Intercalated Year) (G105) - Year 5

Undergraduate Mathematics (MMath) with Study in Europe (G106) - Year 3

Undergraduate Mathematics (MMath) with Study in Europe (G106) - Year 4

Undergraduate Computer Systems Engineering (G406) - Year 3

Undergraduate Computer Systems Engineering (with Intercalated Year) (G407) - Year 4

Undergraduate Computer Systems Engineering (G408) - Year 3

Undergraduate Computer Systems Engineering (with Intercalated Year) (G409) - Year 4

BEng Engineering (H106) - Year 3

MEng Engineering (H107) - Year 3

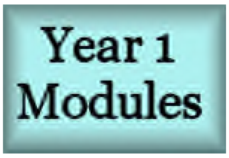
MEng Engineering with Intercalated Year (H109) - Year 3

MEng Engineering with Intercalated Year (H109) - Year 4

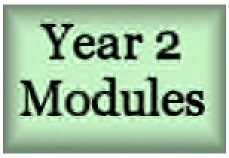
MEng Engineering with Year in Research (H110) - Year 3

MEng Engineering with Year in Research (H110) - Year 4

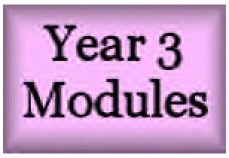
BSc Engineering (H112) - Year 3



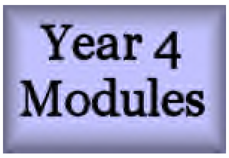
Year 1 regs and modules
G100 G103 GL11 G1NC



Year 2 regs and modules
G100 G103 GL11 G1NC



Year 3 regs and modules
G100 G103



Year 4 regs and modules
G103

Exam Information

Past Exams

Core module averages

PH210 Logic II Metatheory

(https://warwick.ac.uk/fac/sci/maths/undergrad/ughandbook/year3/ph210)

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Year 1 Modules

Year 1 regs and modules

G100 G103 GL11 G1NC

Year 2 Modules

Year 2 regs and modules

G100 G103 GL11 G1NC

Year 3 Modules

Year 3 regs and modules

G100 G103

Year 4 Modules

Year 4 regs and modules

G103

Exam Information

Past Exams

Core module averages

PH340 Logic III: Incompleteness and Undecidability

(https://warwick.ac.uk/fac/sci/maths/undergrad/ughandbook/year3/ph340)

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Year 1 Modules

Year 1 regs and modules

G100 G103 GL11 G1NC

Year 2 Modules

Year 2 regs and modules

G100 G103 GL11 G1NC

Year 3 Modules

Year 3 regs and modules

G100 G103

Year 4 Modules

Year 4 regs and modules

G103

Exam Information

Past Exams

Core module averages