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Course Regulations for Year 3

(https://warwick.ac.uk/fac/sci/maths/currentstudents/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. Please also see note in following box.

Third year students obtaining an end of year average (with adjustment where there is overcatting) of 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.

Year 4 (MA4xx) Maths Modules: advice for MMath Students

As above, 3rd Year MMath students can take, towards their course requirements, some MA4 modules. We also allow 3rd year BSc students who would have fulfilled the requirements to be on the 3rd year of the MMath (and only these) to take up to two MA4 modules as Unusual Options. In the list of such modules on the Year 4 page, an asterix (*) suggests modules that the lecturer thinks may be particularly suitable for doing this since they mostly rely on pre-requisites that can be completed before the module starts (e.g. either second year modules or, for Term 2 modules, third year modules running in Term 1). Before choosing an MA4 module you should however consider the below, and discuss with your Personal Tutor:

- Modules that have an asterix should not be seen as "easier" MA4 modules, all fourth year modules are a step up again from 3rd year ones and are meant to be hard, they should be chosen with caution and after carefully reading the pre-requisites on the module page.
- Data presented at the exam boards consistently show that 3rd years on MA4 modules, on average, perform significantly worse on them than 4th years. That extra year of experience and mathematical maturity can make a big difference.
- Taking another MA3 module instead of an MA4 one can help to build a better, and broader, mathematical background in readiness for your 4th year which could be beneficial. Again, discuss with your Personal Tutor.
- If you are a strong (80% plus) student, and already have some idea of the direction you'd like to go in for a 4th year Research Project, taking a relevant 4th year module may be beneficial, but could still be left to year 4 if the timing is right. It would be worth chatting with potential project supervisors early for advice.
- Remember that if you commenced your degree in 2020/21 or later, all level 7 modules (e.g. MA4xx. PX4xx, ST4xx etc.) will have a pass mark of 50% not 40%.

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.

Term	Code	Module	CATS	List
Term 1	MA241	Combinatorics	12	List A
	MA243	Geometry	12	List A
	MA359	Measure Theory	15	List A
	MA390	Topics in Mathematical Biology	15	List A
	MA397	Consolidation (by invitation only)	7.5	Unusual
	MA398	Matrix Analysis and Algorithms	15	List A
	MA3A6	Algebraic Number Theory	15	List A
	MA3B8	Complex Analysis	15	List A
	MA3E1	Groups and Representations	15	List A
	MA3F1	Introduction to Topology	15	List A
	MA3G6	Commutative Algebra	15	List A
	MA3G7	Functional Analysis I	15	List A
	MA3H3	Set Theory	15	List A
	MA3H5	Manifolds	15	List A
	MA3J2	Combinatorics II	15	List A
	MA3J4	Mathematical Modelling and PDEs	15	List A
	MA3J9	Historical Challenges in Mathematics	15	List A
	MA3K0	High-dimensional Probability	15	List A
	MA3K4	Introduction to Group Theory	15	List A
Terms 1 & 2	MA372	Reading Module	15	List A
	MA395	Essay	15	List A

Term 2	MA250	Introduction to Partial Differential Equations	12	List A
	MA252	Combinatorial Optimization	12	List A
	MA254	Theory of ODEs	12	List A
	MA257	Introduction to Number Theory	12	List A
	MA261	Differential Equations: Modelling and Numerics	12	List A
	MA269	Asymptotics and Integral Transforms	12	List A
	MA377	Rings and Modules	15	List A
	MA3D1	Fluid Dynamics	15	List A
	MA3D4	Fractal Geometry	15	List A
	MA3D5	Galois Theory	15	List A
	MA3D9	Geometry of Curves and Surfaces	15	List A
	MA3E7	Problem Solving	15	List A (G100), List B (G103)
	MA3G1	Theory of PDEs	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
	MA3J3	Bifurcations, Catastrophes and Symmetry	15	List A
	MA3K1	Mathematics of Machine Learning	15	List A
	MA3K6	Boolean Functions	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 GD305 Challenges of Climate Change , 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:

Term	Code	Module	CATS	List
Term 1	IIL115	Applied Imagination	15	Unusual
	GD305	Challenges of Climate Change (also runs again in Term 2)	15	Unusual

Term 2	IL118	Reinventing Education	15	Unusual
	IL131	Serious Tabletop Game Design and Development	10/15	Unusual
	IL116	The Science of Music	15	Unusual
	IL123	Genetics: Science and Society	15	Unusual

Statistics Modules

Term	Code	Module	CATS	G100	G103
Term 1	ST226	Introduction to Mathematical Statistics (from 2021 this this is new code for finalists taking ST220).	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
	ST323	Multivariate Statistics	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
Term 2	ST305	Designed Experiments	15	List B	List B
	ST318	Probability Theory	15	List A	List A
	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

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.

Term	Code	Module	CATS	List
Term 1	EC220	Mathematical Economics 1A	15	List B but must have taken EC106 or EC107
Term 2	EC221	Mathematical Economics 1B	15	List B but must have taken EC106 or EC107

Computer Science

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
	CS409	Algorithmic Game Theory	15	List A	List B
Term 2	CS349	Principles of Programming Languages	15	List B	List B
	CS356	Approximation and Randomised Algorithms	15	List B	List B

Physics

Term	Code	Module	CATS	G100	G103

Term 1	PX366	Statistical Physics	7.5	List A	List B
	PX390	Scientific programming	15	List A	List B
	PX399	The Earth and its Atmosphere	15	List B	List B
	PX3A6	Galaxies and Cosmology	15	List B	List B
	PX408	Relativistic Quantum Mechanics	7.5	List A	List C
	PX420	Solar Magnetohydrodynamics	7.5	List A	List B
	PX425	High Performance Computing in Physics	7.5	List A	List C
	PX430	Gauge Theories for Particle Physics	7.5	List A	List C
	PX436	General Relativity	15	List A	List C
Term 2	PX3A4	Plasma Physics and Fusion	15	List B	List B
	PX3A9	Black Holes, White Dwarfs and Neutron Stars	15	List B	List B
	PX443	Planets, Exoplanets and Life	15	List B	List B

Engineering

Term	Code	Module	CATS	G100	G103
Term 1	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.

You will need to register for modules through MRM and through myWBS. When registering with myWBS you will need to do his in the Spring of the previous academic year to ensure you have secured a place.

Term	Code	Module	CATS	List
Term 1	IB253	Principles of Finance I	15	List B
	IB313	Business Studies I	15	List B
Term 2	IB254	Principles of Finance II	15	List B
	IB320	Simulation	15	List B

Philosophy

Term	Code	Module	CATS	List
Term 1	PH210	Logic II: Metatheory	15	List B
Terms 1 & 2	PH201	History of Modern Philosophy	30	List B
Term 2	PH342	Philosophy of Maths	15	List B

Centre for Education Studies

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

Term	Code	Module	CATS	List
Term 2	EP304	Introduction to Secondary Maths Teaching	15	List B
	EP304	Introduction to Secondary Maths Education	30	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 Transnational Resources Centre provides resources in the FAB building for all students registered with the Language Centre, more information can be found here.

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 laguages modules can be found on the Laguange Centre webpage

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

Exam information
Core module averages

MA3K4 Introduction to Group Theory

(https://warwick.ac.uk/fac/sci/maths/currentstudents/ughandbook/year3/ma3k4/)
Lecturer: Gareth Tracey

Term(s): Term 1

Status for Mathematics students: List A but note that this module cannot be taken by students who have previously taken MA442 Group Theory (Pre 2022)

Commitment: 30 lectures

Assessment: 100% 3 hour examination

Formal registration prerequisites: None

Assumed knowledge:

- MA251 Algebra I: Advanced Linear Algebra
- MA249 Algebra II: Groups and Rings

Useful background: Interest in Algebra

Synergies: This module will go well with:

- MA3E1 Groups and Representations
- MA3D5 Galois Theory

Leads to: The following modules have this module listed as **assumed knowledge** or **useful background:**

- MA442 Group Theory

Content: The main emphasis of this course will be on finite groups. However, results will be stated for infinite groups too whenever possible. In this course we will study group actions, Sylow's theorem and its various proofs, study direct and semidirect products of groups, use those to identify up to isomorphism various groups of relatively small orders, study the notion of soluble groups, state and prove Jordan-Holder Theorem.

This module will focus on laying the foundation for the study of modern group theory. The notions of group actions fundamental to the subject will be investigated in depth.
You will become familiar with different classes of groups such as finite groups, dihedral groups, simple groups,
soluble groups. Techniques will include the theorems of Sylow and Jordan-Holder, which will be proved in the module.
Distinct proofs of these results will demonstrate different technical approaches. The module will give some of the flavour of the modern group theory.

Aims: Students taking the module will learn some of the techniques required for working on a large-scale research project. These techniques are partly theoretical and partly computational. By the end of the module, students should be able to:

- Understand the notion of group actions
- Be able to state Sylow's Theorem and provide distinct proofs of this theorem
- Be able to apply Sylow's Theorems and its corollaries to show that A_n, n>4, is simple
- Use Sylow Theorems to demonstrate that certain finite groups are not simple
- Understand the notions of direct and semidirect products
- Be able to identify (up to isomorphisms) certain finite groups
- Understand the notion of soluble groups
- State and prove Jordan-Holder Theorem

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

Exam information
Core module averages

MA3K6 Boolean Functions

(https://warwick.ac.uk/fac/sci/maths/currentstudents/ughandbook/year3/ma3k6/)
Lecturer: Vadim Lozin

Term(s): Term 2

Status for Mathematics students: List A

Commitment: 30 lectures

Assessment: 85% 3 hour examination, 15% coursework

Formal registration prerequisites:

Assumed knowledge:

- MA241 Combinatorics

Useful background:

- MA252 Combinatorial Optimisation

Content: Boolean functions, named after an English mathematician George Boole, are {0,1}-valued functions of {0,1}-valued variables. They are the most fundamental objects studied in pure and applied mathematics. This module is a comprehensive introduction to the theory of Boolean functions with an emphasis on structural and combinatorial properties. We will also discuss connections of Boolean functions with other combinatorial structures, such as graphs, hypergraphs, set systems, matroids, as well as applications of Boolean functions in data analysis and optimisation.

Aims: The module will include a brief introduction to the basic concepts of Boolean functions, and it will then be structured around the following topics:

1. Foundations:

- Representations of Boolean functions: Boolean expressions, binary decision diagrams, decision trees, geometric interpretation
- Normal forms, prime implicants
- Duality theory
- Functional completeness, Post's Theorem

2. Classes of Boolean functions:

- Quadratic functions
- Horn functions
- Threshold functions
- Read-once functions

3. Generalizations and applications:

- Partially defined Boolean functions and logical analysis of data
- Pseudo-Boolean functions and pseudo-Boolean optimisation

Learning outcomes: At the end of the module, students will be able to:

- Understand the notion of Boolean function and various ways of representing them
- State Post's Theorem and compute Post classes generated by given functions
- Recognize special classes of Boolean functions, such as quadratic, Horn, threshold, read-once, etc
- Be able to apply partially defined Boolean functions to logical analysis of data
- Understand pseudo-Boolean functions in the context of pseudo-Boolean optimisation

Books:

Crama, Yves; Hammer, Peter L., *Boolean Functions. Theory, Algorithms and applications. Encyclopaedia of Mathematics and its Applications, 142.* Cambridge University Press, Cambridge, 2011. xxii+687 pp. ISBN: 978-0-521-84751-3

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

MA359 Measure Theory

(https://warwick.ac.uk/fac/sci/maths/currentstudents/ughandbook/year3/ma359/)
Lecturer: Josephine Evans

Term(s): Term 1

Status for Mathematics students: List A

Commitment: 30 hours

Assessment: 85% Examination, 15% Assignments

Formal registration prerequisites: None

Assumed knowledge:

MA244 Analysis III or MA258 Mathematical Analysis III:

- Riemann Integration
- Uniform Convergence
- Uniform Continuity

MA260 Norms, Metrics and Topologies or MA222 Metric Spaces:

- Definition of a topology
- Open and closed sets
- Norms

Useful background: Good knowledge of core analysis courses including material about continuity and convergence.

Synergies: The following modules go well together with Measure Theory:

- MA3G7 Functional Analysis I
- MA3G8 Functional Analysis II
- MA254 Theory of ODEs
- MA250 Introduction to PDEs
- MA3G1 Theory of PDEs

Leads to: The following modules have this module listed as **assumed knowledge** or **useful background:**

- MA3G8 Functional Analysis II
- MA3H2 Markov Processes and Percolation Theory
- MA3D4 Fractal Geometry
- MA3K1 Mathematics of Machine Learning
- MA433 Fourier Analysis
- MA4L2 Statistical Mechanics
- MA4A2 Advanced Partial Differential Equations
- MA427 Ergodic Theory
- MA4F7 Brownian Motion
- MA4J0 Advanced Real Analysis
- MA482 Stochastic Analysis
- MA4L3 Large Deviation Theory
- MA4L9 Variational Analysis and Evolution Equations
- MA4M9 Mathematics of Neuronal Networks

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 from 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 available from Warwick Library.

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

Exam information
Core module averages

MA372 Reading Course

(https://warwick.ac.uk/fac/sci/maths/currentstudents/ughandbook/year3/ma372/)
Term(s): There is one 3rd year Reading Module running 2022/23

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, this exam is almost always in the exam session immediately after Easter vacation, regardless of the term(s) in which the particular reading module is carried out.

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

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
Core module averages

MA377 Rings and Modules

(https://warwick.ac.uk/fac/sci/maths/currentstudents/ughandbook/year3/ma377/)
Lecturer: Rob Silversmith

Term(s): Term 2

Status for Mathematics students: List A

Commitment: 30 lectures

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

Formal registration prerequisites: None

Assumed knowledge: The ring theory part of the second year Maths core:

MA251 Algebra I: Advanced Linear Algebra:

- Jordan normal forms
- Smith normal forms over integers
- Classification of finitely generated abelian groups

MA249 Algebra II: Groups and Rings:

- Rings
- Domains (UFD, PID, ED)
- Chinese remainder theorem
- Gauss lemma
- Eisenstein criterion

Useful background: Interest in Algebra and good working knowledge of Linear Algebra

Synergies: The following modules go well together with Rings and Modules:

- MA3G6 Commutative Algebra
- MA3E1 Groups and Representations

Leads to: The following modules have this module listed as **assumed knowledge** or **useful background:**

- MA4J8 Commutative Algebra II
- MA453 Lie Algebras
- MA4M6 Category Theory
- MA4H8 Ring Theory

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

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
Core module averages

MA390 Topics in Mathematical Biology

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

Term(s): Term 1

Status for Mathematics students: List A

Commitment: Up to 30 lectures over the term and support classes.

Assessment: 100% 3 hour examination

Formal registration prerequisites: None

Assumed knowledge:

- MA133 Differential Equations or MA113 Differential Equations A: basic understanding of solving ODEs
- ST111 Probability A and ST112 Probability B: random variables, probability distributions

Useful background:

- MA256 Introduction to Mathematical Biology: all the assumed knowledge is rehearsed in this module
- MA250 Introduction to Partial Differential Equations: we will introduce the methods of characteristics from first principles but it is previously studied in this module
- MA254 Theory of ODEs: we will introduce phase planes, stability analysis and bifurcation theory from first principles but they are previously studied in this module

Synergies:

- MA261 Differential Equations: Modelling and Numerics
- ST202 Stochastic Processes
- MA3J3 Bifurcations, Catastrophes and Symmetry
- MA3J4 Mathematical Modelling with PDE
- MA3G1 Theory of Partial Differential Equations
- MA3H7 Control Theory

Leads to: The following modules have this module listed as **assumed knowledge** or **useful background:**

- MA4E7 Population Dynamics: Ecology & Epidemiology
- MA4M1 Epidemiology by Example

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

- Virus dynamics and mutation, including HIV/AIDS and basic immunology (ODEs, phase plane analysis - linearisation and stability analysis)
- Small gene circuits (bifurcations, stochastic modelling using master equations and solving them with method of characteristics (PDEs reduced to ODEs))
- Cancer modelling (branching processes, solutions with method of characteristics)
- Cancer treatment (possibly including game theory and control theory)

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 and cancer; to consolidate basic mathematical techniques used in these approaches, such as ODEs, PDEs, control theory, probability theory, branching processes and Markov Chains.

Books:
There is no dedicated text. A classic text (only deterministic modelling, I is predominantly ODEs and of more relevance to course, 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], *Virus dynamics : mathematical principles of immunology and virology.* Martin Nowak and Robert May. 2000. OUP, *Methods and Models in Mathematical Biology*, Müller, Johannes, Kuttler, Christina, Lecture Notes in Mathematical Modelling in the Life Sciences, Springer. ISBN 978-3-642-27251-6.

Additional Resources

MA395 Essay

(https://warwick.ac.uk/fac/sci/maths/currentstudents/ughandbook/year3/ma395/)
Organiser: Markus Kirkilionis

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 Moodle 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.

Additional Resources

MA397 Consolidation

(https://warwick.ac.uk/fac/sci/maths/currentstudents/ughandbook/year3/ma397/)
Lecturer: Andrew Brendon-Penn

Term(s): Term 1

Status for Mathematics students: Unusual option for third year maths students by invitation only. 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.

Formal registration prerequisites: None

Assumed knowledge: None

Useful background: None

Synergies: Covers second year material useful for third year core 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

Exam information
Core module averages

MA398 Matrix Analysis and Algorithms

(https://warwick.ac.uk/fac/sci/maths/currentstudents/ughandbook/year3/ma398/)
Lecturer: Randa Herzallah

Term(s): Term 1

Status for Mathematics students: List A

Commitment: 30 lectures

Assessment: Written exam 85%, Assignments 15%

Formal registration prerequisites: None

Assumed knowledge: The following core first and second year modules are particularly important:

- MA106 Linear Algebra - providing methodological foundations
- MA124 Mathematics by Computer - being a useful introduction to some of the scientific computing aspects and programming elements of the module
- MA251 Algebra 1: Advanced Linear Algebra - developing more complex techniques in matrix classification and their properties in particular mathematical settings of interest
- MA259 Multivariable Calculus - providing the language and concepts needed for some of the typical proofs we will encounter.

Useful background: Some knowledge of numerical concepts such as accuracy, iteration and stability as provided in MA261 Differential Equations: Modelling and Numerics will become important in the context of this module. General interdisciplinary curiosity will also be supported through interactions with areas such as medical imaging and data science.

Synergies: The following modules link up well with Matrix Analysis and Algorithms, either through methodology, computational or application-oriented content:

- MA3K1 Mathematics of Machine Learning
- MA3H0 Numerical Analysis and PDEs
- MA4G7 Computational Linear Algebra and Optimisation
- PX390 Scientific Computing
- PX425 High Performance Computing in Physics

Leads to: The following modules have this module listed as **assumed knowledge** or **useful background:**

- MA4M4 Topics in Complexity Science
- MA4J5 Structures of Complex Systems

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:

- Various matrix factorisations as the theoretical basis for algorithms
- Assessing algorithms with respect to computational cost
- Conditioning of problems and stability of algorithms
- 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

Year 1 regs and modules
G100 G103 GL11 G1NC

Year 2 regs and modules
G100 G103 GL11 G1NC

MA3A6 Algebraic Number Theory

(https://warwick.ac.uk/fac/sci/maths/currentstudents/ughandbook/year3/ma3a6/)
Lecturer: Simon Myerson

Term(s): Term 1

Status for Mathematics students: List A

Commitment: 30 one-hour lectures

Assessment: 85% 3 hour examination, 15% Assignments

Formal registration prerequisites: None

Assumed knowledge:

It is an extremely good idea to revise finitely generated abelian groups (Algebra I) and ideals (Algebra II) before starting this course.

- MA251 Algebra I: Advanced Linear Algebra: Finitely generated abelian groups, especially: generating sets, free basis, change of basis, classification of Finitely Generated Abelian Groups, subgroups of free abelian groups.
- MA249 Algebra II: Groups and Rings: Rings, fields, ideals, factorisation of polynomials, Gauss' Lemma, Eistenstein's Criterion, the First Isomorphism Theorem for rings, the Third Isomorphism Theorem for groups, Domains (Integral Domains, UFDs, PIDs).
- MA132 Foundations or MA138 Sets and Numbers: This course is always assumed knowledge! But modular arithmetic and solving congruences in the integers are particularly relevant here.

Useful background:

- MA257 Introduction to Number Theory: Prime factorisations in the integers. Solving congruences in integers. The Gaussian integers, potentially Minkowski's theorem on lattices if we have time.
- MA249 Algebra II: Groups and Rings: As well as the assumed knowledge, you might have seen an example of an integral domain that's not a UFD; that's nice motivation for this course. The Chinese Remainder Theorem might also come up.

Synergies:

- MA3D5 Galois Theory: Like this course, Galois Theory studies algebraic numbers; if you're interested in one you will probably enjoy the other as well. Some results will be stated without proof in this course, and proved in Galois Theory. The two courses have a lot of overlap in the pre-requisites, especially around polynomial rings and factorising integer polynomials.

Leads to: The following modules have this module listed as **assumed knowledge** or **useful background:**

- MA4J8 Commutative Algebra II
- MA4M3 Local Fields
- MA4L7 Algebraic Curves

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 factorisation 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 factorisations into irreducibles:

$$6 = 2 \times 3$$

and

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

However, we do get a unique factorisation 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.
- Factorisation of algebraic integers into irreducibles, Euclidean and principal ideal domains.
- Ideals, and the prime factorisation of ideals.
- Minkowski's Theorem.
- The ideal class group.
- Units; the unit group of a quadratic field.
- Using the class group and unit group to solve Mordell and Pell equations in rational integers.

Aims:

- To demonstrate that uniqueness of factorisation into irreducibles can fail in rings of algebraic integers, but that it can be replaced by the uniqueness of factorisation into prime ideals.
- To apply the techniques in the course to solve Mordell and Pell equations.

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 algebraic number fields;
- Be able to factorise ideals into prime ideals in algebraic number fields in straightforward examples;
- Understand the use of the class group and unit group to solve Mordell and Pell equations in rational integers.

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

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
Core module averages

MA3B8 Complex Analysis

(https://warwick.ac.uk/fac/sci/maths/currentstudents/ughandbook/year3/ma3b8/)

Lecturer: Peter Topping

Term(s): Term 1

Status for Mathematics students: List A

Commitment: 30 one-hour lectures

Assessment: 3 hour examination (100%).

Formal registration prerequisites: None

Assumed knowledge:

- MA244 Analysis III
- MA259 Multivariable Calculus
- MA260 Norms Metrics and Topologies or MA222 Metric Spaces

Please note that MA258 Mathematical Analysis III is NOT equivalent to MA244 Analysis III for the purposes of this course.

Useful knowledge: The "assumed knowledge" (and their prerequisites) will be enough.

Synergies: This course connects with virtually every other domain in both pure and applied mathematics.

Leads to: The following modules have this module listed as **assumed knowledge** or **useful background:**

- MA3D1 Fluid Dynamics
- MA475 Riemann Surfaces
- MA4H9 Modular Forms
- MA4L6 Analytic Number Theory
- MA426 Elliptic Curves
- MA4L7 Algebraic Curves
- MA448 Hyperbolic Geometry
- MA4M7 Complex Dynamics

Content: The module 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 second year core. Our goal will be to push the theory further, hopefully revealing a very beautiful classical subject.

In the early part of the module we will see some of the complex analysis topics from MA244 Analysis III, typically in greater depth and/or generality. This includes complex differentiability, the Cauchy-Riemann equations, complex power series, Cauchy's theorem, Taylor's and Liouville's theorem etc. Most of the course will be new topics. We will cover Möbius transformations, the Riemann sphere, winding numbers, generalised versions of Cauchy's theorem, Morera's theorem, zeros of holomorphic functions, the identity theorem, the Schwarz lemma, the classification of isolated singularities, the Weierstrass-Casorati theorem, meromorphic functions, Laurent series, the residue theorem (and applications to integration), Rouché's theorem, the Weierstrass convergence theorem, Hurwitz's theorem, Montel's theorem, and the remarkable Riemann mapping theorem (with proof) that ties the whole module together.

Books: Please see the Talis-aspire web page of this module for the latest recommended books.

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

Exam information
Core module averages

MA3D1 Fluid Dynamics

(https://warwick.ac.uk/fac/sci/maths/currentstudents/ughandbook/year3/ma3d1/)
Lecturer: Ferran Brosa Planella

Term(s): Term 2

Status for Mathematics students: List A

Commitment: 30 lectures

Assessment: 100% 3 hour examination

Formal registration prerequisites: None

Assumed knowledge:

MA259 Multivariable Calculus:

- Multivariate scalar and vector functions
- Differential identities
- Integral theorems
- Ability to perform line, surface and volumetric integrals

MA250 Introduction to Partial Differential Equations:

- Derivation and solution of various differential equations as applied to fluid dynamics, most notably Laplace equations
- Heat equation
- Understanding of appropriate boundary conditions that accompany the equations
- Methods of solution, including separation of variables and fundamental solution

Useful background:

MA3B8 Complex Analysis:

- Cauchy-Riemann conditions
- Holonomic functions
- Complex integration
- Conformal maps

Synergies: Those who enjoy fluid dynamics may be interested in the following modules:

- MA269 Asymptotics and Integral Transforms
- MA3H0 Numerical Analysis and PDEs
- MA4J1 Continuum Mechanics
- MA4L0 Advanced Fluid Dynamics

Leads to: The following modules have this module listed as **assumed knowledge** or **useful background:**

- MA4J1 Continuum Mechanics
- MA4L0 Advanced Topics in Fluids

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 and 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

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
Core module averages

MA3D4 Fractal Geometry

(https://warwick.ac.uk/fac/sci/maths/currentstudents/ughandbook/year3/ma3d4/)
Lecturer: Mark Pollicott

Term(s): Term 2

Status for Mathematics students: List A

Commitment: 30 one hour lectures

Assessment: 100% by 3 hour Examination

Formal registration prerequisites: None

Assumed knowledge:

- MA260 Norms, Metrics and Topologies or MA222 Metric Spaces

Useful background:

- MA359 Measure Theory

Synergies:

- MA424 Dynamical Systems

Leads to: The following modules have this module listed as **assumed knowledge** or **useful background:**

- MA4M7 Complex Dynamics

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

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
Core module averages

MA3D5 Galois Theory

(https://warwick.ac.uk/fac/sci/maths/currentstudents/ughandbook/year3/ma3d5/)
Lecturer: Gavin Brown

Term(s): Term 2

Status for Mathematics students: List A

Commitment: 30 lectures plus assessment sheets

Assessment: 85% 3 hour examination, 15% best 3 out of 4 assessed worksheets

Formal registration prerequisites: None

Assumed knowledge:

- MA106 Linear Algebra: Linear independences, bases of vector spaces, dimension, linear maps, rank-nullity formula
- MA132 Foundations or MA138 Sets and Numbers: Factorisation of polynomials, long division and the Euclidean algorithm
- MA249 Algebra II: Groups and Rings: Fields, rings and ideals, quotient rings and the first isomorphism theorem - especially polynomial rings and their quotient rings by ideals. Groups and homomorphisms, normal subgroups and quotient groups and the isomorphism theorems.

Useful background: Whilst we do use the technical machinery described as assumed knowledge, at some level this module is extremely hands on, and you will benefit by practising the Euclidean algorithm for polynomials, working with permutations (in permutation groups), and manipulating complex numbers (inverses, solving quadratic polynomials, and especially the roots of unity).

Synergies:

- MA3A6 Algebraic Number Theory:

Although each subject is more general in differing respects, the fundamental objects of study in each module include fields that contain the rational numbers and are finite dimensional as a vector space over them - the set of all complex numbers you can write using rationals and the square root of 2 is an example. In Galois theory we study the symmetries of such fields, while in Algebraic Number Theory the focus is on number-theoretic questions, such as questions about factorisation.

- MA3K4 Introduction to Group Theory:

Galois Theory uses groups of permutations and their subgroups as fundamental objects that capture the symmetry of field extensions and of solutions of polynomials. Any familiarity with permutations and groups is good, and in particular soluble groups appear in both modules: in Galois Theory they capture the symmetries that arise when you repeatedly extract square roots, cube roots and higher.

Leads to: The following modules have this module listed as **assumed knowledge** or **useful background:**

- MA4J8 Commutative Algebra II
- MA453 Lie Algebras
- MA4M3 Local Fields
- MA4L7 Algebraic Curves
- MA4H8 Ring Theory

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:

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

Books: DA Cox, *Galois Theory*, Wiley (second edition 2012).

IN Stewart, *Galois Theory*, CRC Press (e.g. fourth edition 2015, or any other edition).

DJH Garling, *A Course in Galois Theory*, CUP (there must be later editions than my 1986 one).

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

Exam information
Core module averages

MA3D9 Geometry of Curves and Surfaces

(https://warwick.ac.uk/fac/sci/maths/currentstudents/ughandbook/year3/ma3d9/)
Lecturer: Felix Schulze

Term(s): Term 2

Status for Mathematics students: List A

Commitment: 30 lectures

Assessment: 100% 3-hour examination

Formal registration prerequisites: None

Assumed knowledge:

- MA244 Analysis III or MA258 Mathematical Analysis III
- MA259 Multivariable Calculus

Useful background: Some familiarity with MA260 Norms, Metrics and Topologies or MA222 Metric Spaces and MA254 Theory of ODEs may be useful.

Synergies: This module goes well with the following modules:

- MA3H5 Manifolds
- MA3F1 Introduction to Topology
- MA3B8 Complex Analysis
- MA3H6 Algebraic Topology
- MA3G1 Theory of Partial Differential Equations
- PX436 General Relativity

Leads to: The following modules have this module listed as **assumed knowledge** or **useful background:**

- MA4C0 Differential Geometry

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

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
Core module averages

MA3E1 Groups & Representations

(https://warwick.ac.uk/fac/sci/maths/currentstudents/ughandbook/year3/ma3e1/)
Lecturer: Samir Siksek

Term(s): Term 1

Status for Mathematics students: List A

Commitment: 30 one-hour lectures

Assessment: Homework 15%, 3 hour written exam 85%

Formal registration prerequisites: None

Assumed knowledge:

- MA132 Foundations or MA138 Sets and Numbers
- MA136 Introduction to Abstract Algebra
- MA106 Linear Algebra
- MA251 Algebra I: Advanced Linear Algebra
- MA249 Algebra II: Groups and Rings

Useful background: Only the above

Synergies: This module goes well with other third year algebra modules, particularly Group Theory.

Leads to: The following modules have this module listed as **assumed knowledge** or **useful background:**

- MA453 Lie Algebras
- MA4M6 Category Theory

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
- 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

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
Core module averages

MA3E7 Problem Solving

(https://warwick.ac.uk/fac/sci/maths/currentstudents/ughandbook/year3/ma3e7/)
Lecturer: Mark Cummings

Term(s): Term 2

Status for Mathematics students: List A for 3rd year G100 (and 4th year G101), List B for 3rd year G103 (G105). If numbers permit, 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 and 10 one hour seminars (including some assessed problem solving)

Assessment: 10% from weekly problem-solving seminars, 40% from take home assignment, 50% two hour examination in June

Formal registration prerequisites: None

Assumed knowledge: None

Useful background: General interest in mathematics outside of university modules (e.g. Numberphile or other maths YouTube channels, Martin Gardner's puzzles).

Synergies: This module is very different from your usual theorem-proof module. It will get you to think about mathematical problem solving in a new way. This module is particularly useful if you are considering a career in teaching.

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.

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

- Use an explicit problem solving *rubric* to organise and facilitate mathematical problem solving
- Explain the role played by different phases of problem solving
- Critically evaluate your own problem solving practice
- Be aware of key literature on mathematical problem solving

Organisation: The module runs in term 2, weeks 1-10. Typically there will be a weekly session for completing the problems counting towards 10% of the module (see below) and a second, longer session discussing the theory a working through problems together. You are expected to attend all timetabled hours.

Assessment Details:

- 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%
- A take home assignment (40%) due in March
- A 2 hour examination in June (50%)

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

Exam information
Core module averages

MA3F1 Introduction to Topology

(https://warwick.ac.uk/fac/sci/maths/currentstudents/ughandbook/year3/ma3f1/)
Lecturer: Luke Peachey

Term(s): Term 1

Status for Mathematics students: List A

Commitment: 30 one-hour lectures

Assessment: 85% 3 hour examination, 15% assignments

Formal registration prerequisites: None

Assumed knowledge:

MA260 Norms, Metrics and Topologies or MA222 Metric Spaces:

- Topological spaces
- Continuous functions
- Homeomorphisms
- Compactness
- Connectedness

MA136 Introduction to Abstract Algebra:

- Groups
- Subgroups
- Homomorphisms and Isomorphisms

Useful background:

- Interest in geometry e.g., MA243 Geometry
- More experience with groups e.g., MA251 Algebra I: Advanced Linear Algebra or MA249 Algebra II: Groups and Rings

Synergies: The following modules go well together with Introduction to Topology:

- MA3H5 Manifolds
- MA3D9 Geometry of Curves and Surfaces

Leads to: The following modules have this module listed as **assumed knowledge** or **useful background:**

- MA3H6 Algebraic Topology
- MA475 Riemann Surfaces
- MA4H4 Geometric Group Theory
- MA4J7 Cohomology and Poincare Duality
- MA4M6 Category Theory
- MA4M7 Complex Dynamics

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 (e.g. compact but not connected or connected but not path connected).

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

For more reading, see the Moodle Pages (link below). MA Armstrong, *Basic Topology* Springer (recommended but not essential).

MA3F2 Knot Theory

(https://warwick.ac.uk/fac/sci/maths/currentstudents/ughandbook/year3/ma3f2/)

Not Running 2019/20

Lecturer:

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 2018

Year 1 regs and modules
G100 G103 GL11 G1NC

MA3G1 Theory of Partial Differential Equations

(https://warwick.ac.uk/fac/sci/maths/currentstudents/ughandbook/year3/ma3g1/)
Lecturer: Matteo Mucciconi

Term(s): Term 2

Status for Mathematics students: List A

Commitment: 30 lectures

Assessment: Exam 100%

Formal registration prerequisites: None

Assumed knowledge:

- MA259 Multivariable Calculus
- MA244 Analysis III or MA258 Mathematical Analysis III
- MA250 Introduction to Partial Differential Equations

Useful background:

- MA260 Norms Metrics and Topologies or MA222 Metric Spaces

Synergies:

- MA3H0 Numerical Analysis and Partial Differential Equations

Leads to: The following modules have this module listed as **assumed knowledge** or **useful background:**

- MA4A2 Advanced Partial Differential Equations
- MA4J1 Continuum Mechanics
- MA482 Stochastic Analysis
- MA4L3 Large Deviation Theory
- MA4L9 Variational Analysis and Evolution Equations
- MA4M9 Mathematics of Neuronal Networks

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 module MA250 Introduction to Partial Differential Equations, 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

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
Core module averages

MA3G6 Commutative Algebra

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

Term(s): Term 1

Status for Mathematics students: List A

Commitment: 30 one hour lectures

Assessment: 85% 3 hour examination, 15% coursework

Formal registration prerequisites: None

Assumed knowledge: The ring theory part of the second year Maths core:

MA251 Algebra I: Advanced Linear Algebra:

- Jordan Normal Forms
- Classification of Finitely Generated Abelian Groups

MA249 Algebra II: Groups and Rings:

- Domains (UFD, PID, ED)
- Chinese Remainder Theorem
- Gauss Lemma

Useful background: Besides the general interest in Algebra, the following could be useful:

MA257 Introduction to Number Theory:

- Factorisation
- Divisibility
- Euclidean Algorithm
- Elementary factorization algorithms

MA260 Norms, Metrics and Topologies or MA222 Metric Spaces

Synergies: The following modules go well together with Commutative Algebra:

- MA3A6 Algebraic Number Theory
- MA377 Rings and Modules (which concentrates more on non-commutative theory)
- MA3D5 Galois Theory

Leads to: The following modules have this module listed as **assumed knowledge** or **useful background:**

- MA4J8 Commutative Algebra II
- MA4A5 Algebraic Geometry
- MA453 Lie Algebras
- MA4M3 Local Fields
- MA4M6 Category Theory
- MA4L7 Algebraic Curves

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*, (Volumes I and II). Springer 1975-6. [QA251.3.Z2]

Additional Resources

MA3G6 Forum 2016

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

8 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

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MA3G7 Functional Analysis I

(https://warwick.ac.uk/fac/sci/maths/currentstudents/ughandbook/year3/ma3g7/)
Lecturer: Jan Grebik

Term(s): Term 1

Status for Mathematics students: List A

Commitment: 30 lectures

Assessment: 100% exam

Formal registration prerequisites: None

Assumed knowledge:

- MA244 Analysis III or MA258 Mathematical Analysis III
- MA260 Norms, Metrics, & Topologies or MA222 Metric Spaces

Useful background:

- MA259 Multivariable Calculus

Synergies:

- MA359 Measure Theory

Leads To: The following modules have this module listed as **assumed knowledge** or **useful background:**

- MA3G8 Functional Analysis II
- MA427 Ergodic Theory
- MA433 Fourier Analysis
- MA4A7 Quantum Mechanics: Basic Principles and Probabilistic Methods
- MA4A2 Advanced Partial Differential Equations
- MA4J0 Advanced Real Analysis
- MA4L3 Large Deviation Theory
- MA4M2 Mathematics of Inverse Problems
- MA4L9 Variational Analysis and Evolution Equations

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: An obvious recommendation would be:
JC Robinson, *An Introduction to Functional Analysis*, Cambridge University Press, 2020.
The module will follow parts of this book quite closely. However, if you want a different take on the material,
the book BP Rynne & MA Youngson, *Linear Functional Analysis*, Springer-Verlag, London, 2000 is very good.

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

Exam information
Core module averages

MA3G8 Functional Analysis II

(https://warwick.ac.uk/fac/sci/maths/currentstudents/ughandbook/year3/ma3g8/)
Lecturer: Dr Andras Mathe

Term(s): Term 2

Status for Mathematics students: List A

Commitment: 30 lectures

Assessment: 100% 3 hour examination

Formal registration prerequisites: None

Assumed knowledge:

MA3G7 Functional Analysis I:

- Normed spaces
- Banach spaces
- Lebesgue spaces
- Hilbert spaces
- Dual spaces
- Linear operators

MA260 Norms, Metrics & Topologies or MA222 Metric Spaces:

- Normed spaces
- Metric spaces
- Continuity
- Topological spaces

- Compactness
- Completeness

Useful background:

MA260 Norms, Metrics & Topologies and MA222 Metric Spaces:

- Nowhere dense sets
- Baire category theorem

MA359 Measure Theory:

- Lebesgue measure
- Measurable functions
- Integral with respect to a measure

Synergies: The following modules go well together with Functional Analysis II:

- MA3G7 Functional Analysis I
- MA359 Measure Theory

Leads To: The following modules have this module listed as **assumed knowledge** or **useful background:**

- MA427 Ergodic Theory
- MA433 Fourier Analysis
- MA4A7 Quantum Mechanics: Basic Principles and Probabilistic Methods
- MA4A2 Advanced Partial Differential Equations
- MA4J0 Advanced Real Analysis
- MA4M2 Mathematics of Inverse Problems
- MA4L9 Variational Analysis and Evolution Equations

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

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
Core module averages

MA3H0 Numerical Analysis and PDEs

(https://warwick.ac.uk/fac/sci/maths/currentstudents/ughandbook/year3/ma3h0/)
Lecturer: Markus Kirkilionis

Term(s): Term 2

Status for Mathematics students: List A

Commitment: 30 lectures

Assessment: 85% 3 hour exam, 15% Assignments

Formal registration prerequisites: None

Assumed knowledge:

- Basic understanding of partial differential equations and their solutions, as covered in MA250 Introduction to Partial Differential Equations
- Differentiable functions and modes of convergence, as covered in MA244 Analysis III or MA258 Mathematical Analysis III

Useful background:

- Good working knowledge of partial derivatives and calculus for functions of multiple variables, as covered in MA259 Multivariable Calculus
- Discretisation, stability and convergence; programming in Python. All are covered in MA261 Differential Equations: Modelling and Numerics

Synergies: The following year 3 modules link up well with Numerical Analysis and PDEs, either through the use of numerical analysis, or by covering various aspects of partial differential equations:

- MA398 Matrix Analysis and Algorithms
- MA3D1 Fluid Dynamics
- MA3J4 Mathematical Modelling with PDE
- MA3G1 Theory of Partial Differential Equations
- MA3G7 Functional Analysis I

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 able to:

- Become aware of the issues around the discretization of several different types of PDEs
- Gain 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

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
Core module averages

MA3H1 Topics in Number Theory

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

Not Running in 2019/20

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 regs and modules
G100 G103 GL11 G1NC

MA3H2 Markov Processes and Percolation Theory

(https://warwick.ac.uk/fac/sci/maths/currentstudents/ughandbook/year3/ma3h2/)
Lecturer: Oleg Zaboronski

Term(s): Term 2

Status for Mathematics students: List A

Commitment: 30 lectures

Assessment: 3 hour exam 100%

Formal registration prerequisites: None

Assumed knowledge: MA359 Measure Theory and ST342 Mathematics of Random Events. Alternatively, the students need to know the following basic facts: probability measure and expectation (including conditional expectation); convergence of random variables; the law of large numbers and central limit theorems; basic theory of Markov chains and random walks; relevant theorems of analysis such the Fubini's theorem, the dominated and the monotone convergence theorems. Most of the above facts are summarised on the course's Moodle page and covered by Chapter 1 and the Appendix of Rick Durret's book 'Probability: theory and examples'.

Useful background: This module provides an introduction to phase transitions for Markov processes and Bernoulli percolation models. Phase transitions are ubiquitous in Nature: freezing and evaporation of water and spontaneous magnetisation of a ferromagnet are some of the most familiar examples. However the rigorous mathematical theory of phase transition is both exciting and hard. One source of difficulty is the non-analytical dependence of the observables detecting the phase transition (e. g. magnetisation) on the parameters controlling the phase (e. g. temperature). In the course we will treat rigorously two of the simplest models exhibiting phase transition: firstly, we will investigate the extinction phase transition for the well know Galton-Watson branching process from population dynamics, secondly - the percolation transition for Bernoulli percolation model on tree graphs and $\mathbb{Z}^d$.

Galton-Watson branching process was introduced in the 19th century to investigate the chance of the perpetual survival of aristocratic families in Victorian Britain and has since became both a useful model for population dynamics and an interesting probabilistic model in its own right. Bernoulli percolations were introduced in the late 1950's to model the propagation of fluid through porous media and gained. Probabilistically it is the simplest model of spatial disorder. Each of the models is very easy to define, yet there are still many open research questions concerning both the branching process and the percolation model. For example, there have been already two Fields medals awarded in the 21st century for studying percolations (Smirnov and Duminil-Copin). Yet there are still some fundamental unresolved questions (e, g. the continuity of the percolation function), which will certainly bring you the Fields medal if you can answer them before you are 40!

The beauty of the models we are studying in the course is in the possibility to understand them using elementary probabilistic methods. This is in part due to simplified proofs due to Duminil-Copin, Hofstadt, Heydenreich and many others which appeared only in the last decade. Thus the course will equip you with modern tools for studying probabilistic models of phase transitions. The acquired knowledge will allow you understand research papers on branching processes and percolations and will be applicable to the study phase transitions in applications such as biological and physical systems, communication networks and financial markets.

Synergies: The following modules go well together with Markov Processes:

- MA482 Stochastic Analysis
- MA4F7 Brownian Motion

Leads to: The following modules have this module listed as **assumed knowledge** or **useful background:**

- MA4L2 Statistical Mechanics
- MA4L3 Large Deviation Theory

Content:

Let us briefly explain the mathematical setting using the example of Bernoulli percolation. 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.

Books:

We will not follow a particular book. However, there are several sets of lecture notes used in the course, which can be downloaded from the Moodle page. The list below is a selection of books for a much deeper study of the subject.

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

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
Core module averages

MA3H3 Set Theory

(https://warwick.ac.uk/fac/sci/maths/currentstudents/ughandbook/year3/ma3h3/)
Lecturer: Dr Adam Epstein

Term(s): Term 1

Status for Mathematics students: List A

Commitment: 30 lectures

Assessment: 100% 3 hour exam

Formal registration prerequisites: None

Assumed knowledge: Elementary set theory and Proof by induction, as covered in:

- MA132 Foundations
- MA138 Sets and Numbers

Useful background: Set theoretic reasoning in topology, as in:

- MA260 Norms, Metrics and Topologies
- MA222 Metric Spaces

Synergies:

- MA359 Measure Theory
- PH210 Logic II: Metatheory
- PH340 Logic III: Incompleteness and Undecidability

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

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
Core module averages

MA3H4 Random Discrete Structures

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

Not Running in 2019/20

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

Exam information
Core module averages

MA3H5 Manifolds

(https://warwick.ac.uk/fac/sci/maths/currentstudents/ughandbook/year3/ma3h5/)
Lecturer: Damiano Testa

Term(s): Term 1

Status for Mathematics students: List A

Commitment: 30 hours

Assessment: 100% 3 hour examination

Formal registration prerequisites: None

Assumed knowledge:

MA259 Multivariable Calculus:

- Basic theory of differentiation, including statements (though not proofs) of Inverse and Implicit Function Theorems

MA260 Norms, Metrics and Topologies or MA222 Metric Spaces:

- Integrations in several variables and familiarity with basic notions of point-set topology and metric spaces
- Topologies
- Continuity
- Compactness
- Connectedness
- Completeness

Useful background: MA254 Theory of ODEs - We will use some results about the existence, uniqueness and dependence on parameters of solutions to ODEs in one or two places of the course. These results will be stated and could be taken on faith, but some prior acquaintance might be useful.

Synergies: The theory of manifolds is fundamental in many areas of modern mathematics. Modules that go well with this Module are (of course some choice should be made depending on whether your tastes are more analytic, geometric or topological):

- MA3D9 Geometry of Curves and Surfaces
- MA3F1 Introduction to Topology
- MA3B8 Complex Analysis
- MA3H6 Algebraic Topology
- MA3G1 Theory of Partial Differential Equations

Leads to: The following modules have this module listed as **assumed knowledge** or **useful background:**

- MA4C0 Differential Geometry
- MA4E0 Lie Groups
- MA424 Dynamical Systems
- MA4A5 Algebraic Geometry

Content: The course will start by introducing the concept of a manifold (without recourse to an embedding into an ambient space). In the words of Hermann Weyl (Space, Time, Matter, paragraph 11):

"The characteristic of an n-dimensional manifold is that each of the elements composing it (in our examples, single points, conditions of a gas, colours, tones) may be specified by the giving of n quantities, the "co-ordinates," which are continuous functions within the manifold. This does not mean that the whole manifold with all its elements must be represented in a single and reversible manner by value systems of n co-ordinates (e.g. this is impossible in the case of the sphere, for which n = 2); it signifies only that if P is an arbitrary element of the manifold, then in every case a certain domain surrounding the point P must be representable singly and reversibly by the value system of n co-ordinates."

Thus the points on the surface of a sphere form a manifold. The possible configurations of a double pendulum (one pendulum hung off the pendulum bob of another) is a manifold that is nothing but the surface of a two-torus: the surface of a donut (a triple pendulum would give a three-torus etc.) The possible positions of a rigid body in three-space form a six-dimensional manifold. Colour qualities form a two-dimensional manifold (cf. Maxwell's colour triangle).

It becomes clear that manifolds are ubiquitous in mathematics and other sciences: in mechanics they occur as phase-spaces; in relativity as space-time; in economics as indifference surfaces; whenever dynamical processes are studied, they occur as "state-spaces" (in hydrodynamics, population genetics etc.)

Moreover, in the theory of complex functions, the problem of extending one function to its largest domain of definition naturally leads to the idea of a Riemann surface, a special kind of manifold.

Although it seems so natural from a modern vantage point, it took some time and quite a bit of work (by Gauss, Riemann, Poincare, Weyl, Whitney, …) till mathematicians arrived at the concept of a manifold as we use it today. It is indispensable in most areas of geometry and topology as well as neighbouring fields making use of geometric methods (ordinary and partial differential equations, modular and automorphic forms, Arakelov theory, geometric group theory…)

Some buzz words suggesting topics which we plan to cover include:

- The notion of a manifold (in different setups), examples of constructions of manifolds (submanifolds, quotients, surgery)
- The tangent space, vector fields, flows/1-parameter groups of diffeomorphisms
- Tangent bundle and vector bundles
- Tensor and exterior algebras, differential forms
- Integration on manifolds, Stokes' theorem
- de Rham cohomology, examples of their computation (spheres, tori, real projective spaces...)
- Degree theory, applications: argument principle, linking numbers, indices of singularities of vector fields.

We will also discuss a lot of concrete and interesting examples of manifolds in the lectures and work sheets, such as for example: tori, n-holed tori, spheres, the Moebius strip, the (real and complex) projective plane, higher-dimensional projective spaces, blow-ups, Hopf manifolds…

The nature of the material makes it inevitable that considerable time must be devoted to establishing the foundations of the theory and defining as well as clarifying key concepts and geometric notions. However, to make the content more vivid and interesting, we will also seek to include some attractive and non-obvious theorems, which at the same time are not too hard to prove and natural applications of the techniques introduced, such as, for instance, Ehresmann's theorem on differentiable fibrations, or that a sphere cannot be diffeomorphic to a product of (positive-dimensional) manifolds.

This Module is mathematically closely related to, but formally completely independent of MA3D9 Geometry of Curves and Surfaces.

Books:

Frank W. Warner, *Foundations of Differentiable Manifolds and Lie Groups*, Springer (1983) (esp. Chapters 1, 2, 4)

M. Berger, B. Gostiaux, *Differential Geometry: Manifolds, Curves, and Surfaces*, Springer (1988) (esp. Chapters 2-6)

Spivak, *A Comprehensive Introduction to Differential Geometry*, vol. 1, Publish or Perish, Inc. (2005) (esp. Chapters 1-8)

John Lee, *Introduction to Smooth Manifolds*, Springer (2012)

Loring W. Tu, *An Introduction to Manifolds*, Springer (2011)

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

Exam information
Core module averages

MA3H6 Algebraic Topology

(https://warwick.ac.uk/fac/sci/maths/currentstudents/ughandbook/year3/ma3h6/)
Lecturer: Martin Gallauer

Term(s): Term 2

Status for Mathematics students: List A

Commitment: 30 hours

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

Formal registration prerequisites: None

Assumed knowledge: Introductory topology and second year abstract algebra:

- MA260 Norms, Metrics and Topologies or MA222 Metric Spaces
- MA3F1 Introduction to Topology
- MA249 Algebra 2: Groups and Rings

Useful background: Familiarity with abelian groups: subgroups, quotient groups, and the structure theorem for finitely generated abelian groups, as taught in MA251 Algebra 1: Advanced Linear Algebra.

Synergies: This module goes well with MA3H5 Manifolds

Leads to: The following modules have this module listed as **assumed knowledge** or **useful background:**

- MA4E0 Lie Groups
- MA4J8 Commutative Algebra II
- MA4J7 Cohomology and Poincare Duality
- MA4M6 Category Theory

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

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

MA3H7 Control Theory

(https://warwick.ac.uk/fac/sci/maths/currentstudents/ughandbook/year3/ma3h7/)
Lecturer: Tim Sullivan

Term(s): Term 2

Status for Mathematics students: List A

Commitment: 30 one hour lectures

Assessment: 100% 3-hour written examination

Formal registration prerequisites: None

Assumed knowledge:

- MA106 Linear Algebra
- MA133 Differential Equations or MA113 Differential Equations A
- MA244 Analysis III or MA258 Mathematical Analysis III

Useful background:

- ST112 Probability B
- MA254 Theory of ODEs
- MA259 Multivariable Calculus

Synergies:

- MA254 Theory of ODEs
- MA261 Differential Equations: Modelling and Numerics
- MA4K0 Introduction to Uncertainty Quantification
- MA4M2 Mathematics of Inverse Problems

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.

- Introduction to key concepts
- Background material
- Controllability
- Stabilization
- Observability and filtering
- 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 analyse 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.

MA3J1 Tensors, Spinors and Rotations

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

Not Running 2019/20

Lecturer:

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 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
Core module averages

MA3J2 Combinatorics II

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

Term(s): Term 1

Status for Mathematics students: List A

Commitment: 30 Lectures

Assessment: 100% Examination

Formal registration prerequisites: None

Assumed knowledge:

MA241 Combinatorics I:

- Graph theory
- Hall's Theorem
- Graph colouring

MA260 Norms, Metrics and Topology or MA222 Metric Spaces:

- Norms on Euclidean space
- Open and closed sets
- Compactness

MA249 Algebra II: Groups and Rings:

- Basic examples of finite fields

ST111 Probability A:

- Events
- Probabilities
- Random variables

Useful background:

ST112 Probability B:

- Poisson distribution
- Chebyshev's inequality

- The Central Limit Theorem

MA243 Geometry:

- Projective geometry

Synergies: The following module goes well together with Combinatorics II:

MA3G7 Functional Analysis I

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

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
Core module averages

MA3J3 Bifurcations, Catastrophes and Symmetry

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

Term(s): Term 2

Status for Mathematics students: List A

Commitment: 30 Lectures

Assessment: 100% exam

Formal registration prerequisites: None

Assumed knowledge: This module will assume knowledge from core mathematics modules, in particular the whole of MA133 Differential Equations (although MA113 Differential Equations A will be sufficient provided the following is also covered), and bits of both MA249 Algebra II and MA259 Multivariable Calculus. In more detail:

MA249 Algebra II: Groups, in particular permutation groups and groups and groups of non-singular matrices (Dihedral groups especially). Quotient Groups, isomorphism theorems and orbit-stabilizer.

MA259 Multivariable Calculus: Differentiable functions, Inverse Function Theorem and Implicit Function Theorem.

Useful background: Having taken MA254 Theory of ODEs (or taking in parallel) will be beneficial, but not essential.

Synergies: Although containing a fair amount of "pure" maths, this is largely applying those theories and so this sits well beside modules such as MA256 Introduction to Mathematical Biology, MA390 Topics in Mathematical Biology, MA4E7 Population Dynamics, MA3J4 Mathematical Modelling with PDEs and MA4M1 Epidemiology by Example. It will also add extra context for modules such as MA3H5 Manifolds, MA3E1 Groups and Representations and MA4E0 Lie Groups, although here we only intersect with the basics of those.

Leads to: This module doesn't formally lead to any further modules, but sits alongside, and gives useful context to, many of the modules in "Synergies" above.

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:

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:

- Catastrophe Theory and its Applications, Poston and Stewart, 1978
- Singularities, Bifurcations and Catastrophes, Montaldi, 2021
- 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.
- Nonlinear Oscillations, Dynamical Systems and Bifurcations of Vector Fields, Guckenheimer/Holmes 1983

Additional Resources

Year 1 regs and modules
G100 G103 GL11 G1NC

MA3J4 Mathematical Modelling with PDE

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

Term(s): Term 1

Status for Mathematics students:

Commitment: 30 Lectures

Assessment: 3 hour exam 100%

Formal registration prerequisites: None

Assumed knowledge:

- MA250 Introduction to PDEs

Useful background:

- MA254 Theory of ODEs
- MA261 Differential Equations: Modelling and Numerics

Synergies: The following modules go well together with Mathematical Modelling:

- MA3G1 Theory of PDEs
- MA261 Differential Equations: Modelling and Numerics

Leads to: The following modules have this module listed as **assumed knowledge** or **useful background:**

- MA4M1 Epidemiology by Example
- MA4L0 Advanced Topics in Fluids

Content:

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

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

Transport and flows:

- Conservation of mass, momentum and energy
- Euler and Navier-Stokes equations

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 necessary 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

Year 4 regs and modules
G103

Exam information
Core module averages

MA3J8 Approximation Theory and Applications

(https://warwick.ac.uk/fac/sci/maths/currentstudents/ughandbook/year3/ma3j8/)
Lecturer: Professor Christoph Ortner

Term(s): Not running 2020/21

Status for Mathematics students: List A

Commitment: 30 lectures

Assessment: 100% Exam

Prerequisites: There are no formal prerequisites beyond the core module MA260 Norms, Metrics and Topology but any programming module and any of the following modules would be useful complements: MA228 Numerical Analysis, MA261 Differential Equations: Modelling and Numerics, 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 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
Core module averages

MA3J9 Historical Challenges in Mathematics

(https://warwick.ac.uk/fac/sci/maths/currentstudents/ughandbook/year3/ma3j9/)

Lecturer: Damiano Testa

Term(s): Term 1

Status for Mathematics students:

Commitment: 30 lectures, support classes

Assessment: 3 hour exam 85% and Assignments 15%

Formal registration prerequisites: None

Assumed knowledge: Core Maths modules in Year 2 especially MA249 Algebra II: Groups and Rings and MA251 Algebra 1: Advanced Linear Algebra.

Useful background: Throughout the module, we will work with Abelian groups (finite, finitely generated, free, though also not satisfying any of the previous assumptions), Polynomials and rational functions, extending a field by adding a square root of one of its elements (we will review this in class).

Synergies: Depending on the week, the material that we will cover leads to the following modules:

- MA3A6 Algebraic Number Theory
- MA3G6 Commutative Algebra
- MA257 Introduction to Number Theory
- MA3D5 Galois Theory
- MA3H3 Set Theory though we will introduce everything that we use from these modules.

Content:

The module will cover several topics each year. Below is a list of possible topics:

- Sample Topic 1: Fermat's little theorem and RSA Cryptography
- Residue classes modulo primes, Fermat's little theorem, Cryptographic applications. May include Elliptic Curve factorisation
- Sample Topic 2: Hilbert's 10th problem and Undecidability
- Decidability, recursively enumerable set and Diophantine sets, Computing and algorithms
- Sample Topic 3: Hilbert's 3rd problem and Dehn invariants
- Scissor congruence in the plane, Scissor congruence in R^n and Hilbert's 3rd problem, Dehn invariant for R^3
- Sample Topic 4: Four colour theorem
- Graphs, colourings, Five colour theorem, the role of computers

Aims:

To show how a range of problems both theoretical and applied can be modelled mathematically and solved using tools discussed in core modules from years 1 and 2.

Objectives:

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

- For each of the topics discussed appreciate their importance in the historical context, and why mathematicians at the time were interested in it.
- For each of the topics discussed understand the underlying theory and statement of the result, and where applicable how the proof has been developed (or how a proof has been attempted in the case of unsolved problems).
- For each of the topics discussed understand how to apply the theory to similar problems/situations (where applicable).
- For each of the topics discussed understand the connections between the results/proofs in question and the core mathematics modules that the student has studied.

Books:

Depending on the topics, different sources will be used. Most will be available online or with provided lecture notes.

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

MA3K0 High Dimensional Probability

(https://warwick.ac.uk/fac/sci/maths/currentstudents/ughandbook/year3/ma3k0/)
Lecturer: Stefan Adams

Term(s): Term 1

Status for Mathematics students:

Commitment: 10 x 3 hour lectures + 9 x 1 hour support classes

Assessment: Assessed homework sheets (15%) and Summer exam (85%)

Formal registration prerequisites: None

Assumed knowledge: Basic probability theory: random variables, law of large numbers, Chebycheff inequality, distribution functions, expectation and variance, Bernoulli distribution, normal distribution, Poisson distribution, exponential distribution, de Moivre Laplace theorem e.g. ST111 Probability A & ST112 Probability B.

Some basic skills in analysis: MA258 Mathematical Analysis III or MA259 Multivariate Calculus or ST208 Mathematical Methods or MA244 Analysis III. The module works in Euclidean vector space R^n , so norm, basic inequalities, scalar product, linear mappings and matrix algebra (eigenvalues, eigenvectors, singular values etc) are relevant.

Useful background: Know what a a probability measure/distribution is. Earlier probability modules will be of some use but not necessary. The framework is some mild probability theory (e.g. ST202 Stochastic Processes). Know what the Central Limit Theorem is (de Moirvre Laplace for general random variables).

Synergies: In general the module is a mathematical basis for machine learning, data science and random matrix theory. The following modules provide some synergies and connections:

- MA359 Measure Theory
- MA3K1 Maths of Machine Learning
- MA3H2 Markov Processes and Percolation Theory

There are also strong links and thus suitable combinations to the following modules:

- MA4K4 Topics in Interacting Particle Systems
- MA4F7 Brownian Motion
- MA482 Stochastic Analysis
- MA427 Ergodic Theory
- MA424 Dynamical Systems
- MA4L2 Statistical Mechanics
- MA4L3 Large Deviation Theory

Leads to: The following modules have this module listed as **assumed knowledge** or **useful background:**

- MA3K1 Mathematics of Machine Learning

Content:

- Preliminaries on Random Variables (limit theorems, classical inequalities, Gaussian models, Monte Carlo)
- Basic Information theory (entropy; Kull-Back Leibler information divergence)
- Concentrations of Sums of Independent Random Variables
- Random Vectors in High Dimensions
- Random Matrices
- Concentration with Dependency structures
- Deviations of Random Matrices and Geometric Consequences
- Graphical models and deep learning

Aims:

- Concentration of measure problem in high dimensions

- Three basic concentration inequalities
- Application of basic variational principles
- Concentration of the norm
- Dependency structures
- Introduction to random matrices

Objectives:

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

- Understand the concentration of measure problem in high dimensions
- Distinguish three basic concentration inequalities
- Distinguish between concentration for independent families as well as for various dependency structures
- Understand the basic concentrations of the norm
- Be familiar with random matrices (main properties)
- Be able to understand basic variational problems
- Be familiar with some application of graphical models

Books:

We won't follow a particular book and will provide lecture notes. The course is based on the following three books where the majority is taken from [1]:

[1] Roman Vershynin, *High-Dimensional Probability: An Introduction with Applications in Data Science*, Cambridge Series in Statistical and Probabilistic Mathematics, (2018).

[2] Kevin P. Murphy, *Machine Learning - A Probabilistic Perspective*, MIT Press (2012).

[3] Simon Rogers and Mark Girolami, *A first course in Machine Learning*, CRC Press (2017).

[4] Alex Kulesza and Ben Taskar, *Determinantal point processes for machine learning*, Lecture Notes (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

Year 4 regs and modules
G103

Exam information
Core module averages

MA3K1 Mathematics of Machine Learning

(https://warwick.ac.uk/fac/sci/maths/currentstudents/ughandbook/year3/ma3k1/)
Lecturer: Martin Lotz

Term(s): Term 2

Status for Mathematics students:

Commitment: 10 x 3 hour lectures with support classes

Assessment: 85% 3 hour Examination, 15% Assignments

Formal registration prerequisites: None

Assumed knowledge: The module assumes good working knowledge of MA106 Linear Algebra, MA259 Multivariable Calculus and ST111 Probability Part A, as provided by the compulsory modules in the first two years for Maths programmes. In addition MA260 Norms, Metrics and Topologies or MA222 Metric Spaces - Notion of norm, metric, topology and convergence, open and closed sets as well as compactness.

Useful background: The Term 1 modules MA359 Measure Theory and MA3K0 High Dimensional Probability will provide useful background. Programming skills and knowledge of Numerical Analysis (as covered in MA261 Differential Equations: Modelling and Numerics) are beneficial but not required.

Synergies: The module combines well with MA3K0 High Dimensional Probability.

Content:

Fundamentals of statistical learning theory:

- Regression and classification
- Empirical risk minimization and regulation
- VC theory

Optimization:

- Basic algorithms (gradient descent, Newton's method)
- Convexity, Lagrange duality and KKT theory
- Quadratic optimization and support vector machines
- Subgradients and nonsmooth analysis
- Proximal gradient methods
- Accelerated and stochastic algorithms

Machine learning:

- Neural networks and deep learning
- Stochastic gradient descent
- Kernel methods and Gaussian processes
- Recurrent neural networks
- Applications (pattern recognition, time series prediction)

- Applications (pattern recognition, time series prediction)

Aims:

The aim of this course is to introduce Machine Learning from the point of view of modern optimization and approximation theory.

Objectives:

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

- Describe the problem of supervised learning from the point of view of function approximation, optimization, and statistics
- Identify the most suitable optimization and modelling approach for a given machine learning problem
- Analyse the performance of various optimization algorithms from the point of view of computational complexity (both space and time) and statistical accuracy
- Implement a simple neural network architecture and apply it to a pattern recognition task

Books:

1. Friedman, Jerome, Trevor Hastie, and Robert Tibshirani. *The elements of statistical learning*. Springer series in statistics, 2001.
2. Beck, Amir. *First-Order Methods in Optimization*. Vol. 25. SIAM, 2017.
3. Vapnik, Vladimir. *The nature of statistical learning theory*. Springer, 2013.
4. Cucker, Felipe, and Ding Xuan Zhou. *Learning theory: an approximation theory viewpoint*. Vol. 24. Cambridge University Press, 2007.

5. Higham, Catherine F. and Desmond J. Higham. *Deep Learning: An Introduction for Applied Mathematicians. arXiv preprint arXiv:1801.05894* (2018).

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

CS349 Principles of Programming Languages

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

CS349-15 Principles of Programming Languages

Academic year	**22/23**
Department	**Computer Science**
Level	**Undergraduate Level 3**
Module leader	**Sara Kalvala**
Credit value	**15**
Module duration	**10 weeks**
Assessment	**Multiple**
Study location	**University of Warwick main campus, Coventry**

Download as PDF

Description | Study | Assessment | Availability

Introductory description

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

Module aims

Understanding the foundations for formal descriptions of programming languages. Relating abstract concepts in the design of programming languages with real languages in use and pragmatic considerations. Exposure to a variety of languages through presentations by peers and evidence from literature surveys.

Outline syllabus

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

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

Learning outcomes

By the end of the module, students 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 about program behaviour.
- Implement program interpreters and type inference algorithms.

Indicative reading list

Please see Talis Aspire link for most up to date list.

View reading list on Talis Aspire

Research element

Literature review and critical analysis of a language of choice, and presenting both subjective and objective conclusions on the position of the language within the wider programming language landscape.

Subject specific skills

Putting formal logic systems into practice.
Understanding practical implementations of type systems.
Understanding issues in dynamic and static binding.
Survey of modern programming languages.

Transferable skills

Presentation skills,
Library/ Literature Review skills
Technical Writing Skills

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
Core module averages

CS356 Approximation and Randomised Algorithms

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

CS356-15 Approximation and Randomised Algorithms

Academic year	**22/23**
Department	**Computer Science**
Level	**Undergraduate Level 3**
Module leader	**Sayan Bhattacharya**
Credit value	**15**
Module duration	**10 weeks**
Assessment	**Multiple**
Study location	**University of Warwick main campus, Coventry**

Download as PDF

Description | Study | Assessment | Availability

Introductory description

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.

Module aims

Students will learn the mathematical foundations underpinning the design and analysis of such algorithms.

Outline syllabus

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

- 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
  If time permits, more topics can be covered such as Tail inequalities for martingales, SDP based algorithms, local search algorithms, PTAS for Euclidean

TSP, metric embeddings, hardness of approximation, online algorithms or streaming.

Learning outcomes

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

- 1. Understand and use suitable mathematical tools to design approximation algorithms and analyse their performance.
- 2. Understand and use suitable mathematical tools to design randomised algorithms and analyse their performance.
- 3. 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.

Indicative reading list

Please see Talis Aspire link for most up to date list.

View reading list on Talis Aspire

Subject specific skills

1. Use of LP relaxations and related algorithm design paradigms in approximation algorithms
2. Use of Chernoff bounds and related tools from discrete probability in randomised algorithms
3. Systematic techniques for derandomising randomised algorithms

Transferable skills

1. Communication - Reading and writing mathematical proofs
2. Critical Thinking - Problem solving
3. Technical - Technological competence and staying current with knowledge

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
Core module averages

CS409 Algorithmic Game Theory

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

CS409-15 Algorithmic Game Theory

Academic year	**22/23**
Department	**Computer Science**
Level	**Undergraduate Level 4**
Module leader	**Marcin Jurdzinski**
Credit value	**15**
Module duration	**10 weeks**
Assessment	**Multiple**
Study location	**University of Warwick main campus, Coventry**

Download as PDF

Description | Study | Assessment | Availability

Introductory description

The focus of the module is on algorithmic and computational complexity aspects of game-theoretic models.

Module aims

To familiarise students with formal methods of strategic interaction, as studied in game theory. One of the aims will be to give a flavour of current research and most recent advances in the field of algorithmic game theory.

Outline syllabus

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

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 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.

Learning outcomes

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

- Understand the fundamental concepts of non-cooperative 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.

Indicative reading list

Osborne and Rubinstein, A Course in Game Theory;
Roughgarden, Selfish Routing and the Price of Anarchy;
Nisan, Roughgarden, Tardos and Vazirani (eds), Algorithmic Game Theory;
Selected research papers.

Subject specific skills

Advanced algorithmic techniques;

Transferable skills

Problem Solving;
Communication skills

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
Core module averages

PX408 Relativistic Quantum Mechanics

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

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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
Core module averages

PX420 Solar Magnetohydrodynamics

(https://warwick.ac.uk/fac/sci/maths/currentstudents/ughandbook/year3/px420/)
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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
Core module averages

PX425 High Performance Computing in Physics

(https://warwick.ac.uk/fac/sci/maths/currentstudents/ughandbook/year3/px425/)
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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
Core module averages

PX429 Scattering and Spectroscopy

(https://warwick.ac.uk/fac/sci/maths/currentstudents/ughandbook/year3/px429/)
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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
Core module averages

PX430 Gauge Theories for Particle Physics

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

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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
Core module averages

CS301 Complexity of Algorithms

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

CS301-15 Complexity of Algorithms

Academic year	**22/23**
Department	**Computer Science**
Level	**Undergraduate Level 3**
Module leader	**Matthias Englert**
Credit value	**15**
Module duration	**10 weeks**
Assessment	**Multiple**
Study location	**University of Warwick main campus, Coventry**

Download as PDF

Description | Study | Assessment | Availability

Introductory description

CS301 Complexity of Algorithms

Module 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.

Outline syllabus

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

In this module, the notions of complexity of algorithms and of computational problems will be studied. Students will learn how to design efficient algorithms for reducing computational problems to one another, 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, and approximation algorithms. Furthermore, parallel computations and on-line computations might 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.

Learning outcomes

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

- Know and understand a variety of complexity classes.
- Understand techniques for formally proving that a computational problem is solvable or not solvable.
- Understand techniques for formally proving something about the kind and amount of computational resources (e.g. processing time, memory requirements) that are required to solve a problem.
- Formulate more tractable variations of some computationally hard problems.

Subject specific skills

N/A

Transferable skills

Critical thinking

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
Core module averages

CS324 Computer Graphics

(https://warwick.ac.uk/fac/sci/maths/currentstudents/ughandbook/year3/cs324/)

CS324-15 Computer Graphics

Academic year	**22/23**
Department	**Computer Science**
Level	**Undergraduate Level 3**
Module leader	**Shan Raza**
Credit value	**15**
Module duration	**10 weeks**
Assessment	**Multiple**
Study location	**University of Warwick main campus, Coventry**

Download as PDF

Description | Study | Assessment | Availability

Introductory description

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.

Module aims

Graphical presentation of models of the physical world is an important aspect of current and future applications of computers. Students are introduced to the basic concepts of manipulating and modelling objects in 2D, 3D and 4D.
Techniques are introduced for realistically visualising models of objects in ways that exploit our visual senses.

Outline syllabus

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

Topics covered include:

- Graphics hardware
- Rendering processes
- Computational geometry of 2 and 3 dimensions
- Modelling and projection of 3 dimensional structures
- Spatial data structures
- Colour and texture
- Ray tracing
- 'Fractal' processes in graphics
- Demonstrations of graphics features will be given during the module.

Learning outcomes

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

- At the end of this module, a successful student will: - Understand the mathematics behind geometric transformations and techniques for modelling objects; .
- - Understand the techniques used to approximate the physical process of image generation.
- - Have an understanding of how these techniques are made available through graphical programming standards.

Indicative reading list

Please see Talis Aspire link for most up to date list.

[View reading list on Talis Aspire]

Subject specific skills

Understanding of human perception and digital display devices.
Knowledge of terminologies and concepts of basic algorithms behind graphics kernels for drawing 2D, 3D primitives, transformations, clipping, modeling and rendering.
Expertise in designing, modelling and manipulating graphics objects using OpenGL.

Transferable skills

Students will learn about displaying graphics objects and interaction on digital display devices. Computer graphics is multidisciplinary subject. The students will study skills for developing graphics user interfaces, engineering designs, data visualization, photo realism, computer generated imagery (CGI).

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
Core module averages

CS325 Compiler Design

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

CS325-15 Compiler Design

Academic year	**22/23**
Department	**Computer Science**
Level	**Undergraduate Level 3**
Module leader	**Gihan Mudalige**
Credit value	**15**
Module duration	**10 weeks**
Assessment	**Multiple**
Study location	**University of Warwick main campus, Coventry**

Download as PDF

Description | Study | Assessment | Availability

Introductory description

A compiler is a program that can read a program in one language - the source language -
and translate it into an equivalent program in another language - the target language

Module 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.

Outline syllabus

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

- 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

Learning outcomes

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

- A successful student will have acquired the skills to understand, develop, and analyse 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.

Indicative reading list

(a) Appell, Modern Compiler Implementation in Java, Cambridge University Press, 2003
(b) Watt and Brown, Programming Language Processors in Java, Prentice Hall, 2000
(c) Grune, Bal, Jacobs, and Langendoen, Modern Compiler Design, Wiley, 2000.
(d) Aho, Sethi and Ullman, Compilers Principles, Techniques and Tools, Addison-Wesley.

Subject specific skills

Develop an end-to-end compiler. Use of modern and industrial-grade compiler development software, techniques and tools.

Transferable skills

Technical - Programming. Following online tutorials. Version control and software development. Software testing and debugging.
Creativity - Designing tangible and strategic solutions (compilers).
Multitasking - Time management, organisation skills and meeting deadlines.
Critical thinking - Problem-solving, analysis of possible solutions.
Communication - Listening, writing, technical communication skills

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

Syllabus
Online material

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
Core module averages

PX308 Physics in Medicine

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

Exam information
Core module averages

PX350 Weather and the Environment

(https://warwick.ac.uk/fac/sci/maths/currentstudents/ughandbook/year3/px350/)
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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
Core module averages

PX366 Statistical Physics

(https://warwick.ac.uk/fac/sci/maths/currentstudents/ughandbook/year3/px366/)
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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
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Exam information
Core module averages

PX370 Optoelectronics and Laser Physics

(https://warwick.ac.uk/fac/sci/maths/currentstudents/ughandbook/year3/px370/)
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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

Exam information
Core module averages

PX382 Quantum Physics of Atoms

(https://warwick.ac.uk/fac/sci/maths/currentstudents/ughandbook/year3/px382/)
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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
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Exam information
Core module averages

PX387 Astrophysics

(https://warwick.ac.uk/fac/sci/maths/currentstudents/ughandbook/year3/px387/)

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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
Core module averages

PX389 Cosmology

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

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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
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Exam information
Core module averages

PX390 Scientific Programming

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

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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

Exam information
Core module averages

PX384 Electrodynamics

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

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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

Exam information
Core module averages

PX392 Plasma Electrodynamics

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

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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
Core module averages

PX396 Nuclear Physics

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

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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
Core module averages

PX397 Galaxies

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

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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
Core module averages

PX436 General Relativity

(https://warwick.ac.uk/fac/sci/maths/currentstudents/ughandbook/year3/px436/)

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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
Core module averages

PX439 Statistical Mechanics of Complex Systems

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

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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
Core module averages

ES3C8 Systems Modelling and Control

(https://warwick.ac.uk/fac/sci/maths/currentstudents/ughandbook/year3/es3c8/)

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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

Exam information
Core module averages