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Course Regulations for Year 3

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

MATHEMATICS BSC. G100

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

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

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

MASTER OF MATHEMATICS MMATH G103

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

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

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

Comments

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

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

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

Maths Modules

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

hide

Term	Code	Module	CATS	List
Term 1	MA241	Combinatorics	12	List A
	MA243	Geometry	12	List A
	MA359	Measure Theory	15	List A
	MA390	Topics in Mathematical Biology	15	List A
	MA397	Consolidation	7.5	Unusual (by invite only)

	MA398	Matrix Analysis and Algorithms	15	List A
	MA3A6	Algebraic Number Theory	15	List A
	MA3D9	Geometry of Curves and Surfaces	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
	MA3H2	Markov Processes and Percolation Theory	15	List A
	MA3H5	Manifolds	15	List A
	MA3K1	Maths of Machine Learning	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
	MA377	Rings and Modules	15	List A
	MA3B8	Complex Analysis	15	List A
	MA3D1	Fluid Dynamics	15	List A
	MA3D4	Fractal Geometry	15	List A
	MA3D5	Galois Theory	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
	MA3H3	Set Theory	15	List A
	MA3H6	Algebraic Topology	15	List A
	MA3H7	Control Theory	15	List A
	MA3J2	Combinatorics II	15	List A
	MA3J3	Bifurcations, Catastrophes and Symmetry	15	List A

	MA3J9	Historical Challenges in Mathematics	15	List A
Term 3	MA209	Variational Principles	6	List A

Interdisciplinary Modules (IATL and GSD)

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

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

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

hide

Term	Code	Module	CATS	List
Term 1	IL005	Applied Imagination (term 2 in 20/21)	12/15	Unusual
	GD305	Challenges of Climate Change	7.5/15	Unusual
Term 2	IL016	The Science of Music (won't be running 20/21)	7.5/12/15	Unusual
	IL023	Genetics: Science and Society	12/15	Unusual

Statistics Modules

hide

Term	Code	Module	CATS	G100	G103
Term 1	ST220	Introduction to Mathematical Statistics (from 2021 this will have code ST226 for finalists).	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.

hide

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

hide

Term	Code	Module	CATS	G100	G103
Term 1	CS301	Complexity of Algorithms	15	List A	List B
	CS324	Computer Graphics	15	List B	List B
	CS325	Compiler Design	15	List B	List B
	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

hide

Term	Code	Module	CATS	G100	G103
Term 1	PX350	Weather and the Environment	7.5	List B	List B
	PX308	Physics in Medicine	7.5	List B	List B
	PX366	Statistical Physics	7.5	List A	List B
	PX382	Quantum Physics of Atoms	7.5	List B	List B
	PX384	Electrodynamics	7.5	List A	List B
	PX390	Scientific programming	15	List A	List B
	PX392	Plasma Electrodynamics	7.5	List A	List B
	PX397	Galaxies	7.5	List B	List B
	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	PX370	Optoelectronics and Laser Physics	7.5	List B	List B
	PX387	Astro Physics	15	List B	List B
	PX389	Cosmology	7.5	List B	List B
	PX396	Nuclear Physics	7.5	List B	List B

Engineering

hide

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

Warwick Business School

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

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.

PLEASE NOTE: From 2020/21 all 2nd year WBS modules will only be available at 15 CATS not 12, and similarly 3rd year modules from 2021/22.

hide

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

Philosophy

hide

Term	Code	Module	CATS	G100	G103
Term 1	PH210	Logic II: Metatheory	15	List B	List B
Term 2	PH342	Philosophy of Mathematics	15	List B	List B

Centre for Education Studies

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

hide

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

Languages

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

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

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

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

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

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

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

Information on 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

MA359 Measure Theory

(https://warwick.ac.uk/fac/sci/maths/undergrad/ughandbook/year3/ma359/)
Lecturer: John Smillie

Term(s): Term 1

Status for Mathematics students: List A

Commitment: 30 hours

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

Prerequisites: MA132 Foundations or MA138 Sets and Numbers, MA260 Norms, Metrics and Topology or MA222 Metric Spaces, MA244 Analysis III or MA258 Mathematical Analysis III.

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

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

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

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

The Module will cover the following topics: Definition of a measurable space and σ-additive measures, Construction of a measure 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 avaliable from Warwick Library.

Additional Resources

Archived Pages: 2012 2013 2014 2015 2016 2017

Year 1 regs and modules
G100 G103 GL11 G1NC

Year 2 regs and modules
G100 G103 GL11 G1NC

Year 3 regs and modules
G100 G103

Year 4 regs and modules
G103

Exam information
Core module averages

MA372 Reading Course

(https://warwick.ac.uk/fac/sci/maths/undergrad/ughandbook/year3/ma372/)
Term(s): There are no 3rd year Reading Modules running 2020/21

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

Archived Pages: 2011 2013 2016 2017

Year 1 regs and modules
G100 G103 GL11 G1NC

Year 2 regs and modules
G100 G103 GL11 G1NC

Year 3 regs and modules
G100 G103

Year 4 regs and modules
G103

Exam information
Core module averages

MA377 Rings and Modules

(https://warwick.ac.uk/fac/sci/maths/undergrad/ughandbook/year3/ma377/)
Lecturer: Samir Siksek

Term(s): Term 2

Status for Mathematics students: List A

Commitment: 30 lectures

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

Prerequisites: MA136 Introduction to Abstract Algebra, MA106 Linear Algebra, MA251 Algebra I: Advanced Linear Algebra, MA249 Algebra II: Groups and Rings

Leads To:

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

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

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

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

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

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

Additional Resources

Archived Pages: 2011 2015 2016 2017

Year 1 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/undergrad/ughandbook/year3/ma390/)
Lecturer: Professor Nigel Burroughs

Term(s): Term 1

Status for Mathematics students: List A

Commitment: 10 on-line live lectures, additional videos, 10 on-line live examples classes

Assessment: 3 hour examination (100%)

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

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

1. Virus dynamics and mutation, including HIV/AIDS and basic immunology (ODEs, phase plane analysis - linearisation and stability analysis,).

2. Small gene circuits (bifurcations, stochastic modeling using master equations and solving them with method of characteristics (PDEs reduced to ODEs)).

3. Cancer modelling (branching processes, solutions with method of characteristics).

4. 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, 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

Archived Pages: Pre-2011 2011 2012 2013 2014 2015 2016 2018

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

MA395 Essay

(https://warwick.ac.uk/fac/sci/maths/undergrad/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 the Undergraduate Office by 12:00 noon on Thursday of the first week of Term 3. This deadline is enforced by the mechanism described in the Course Handbook section on Assessment. The oral presentation should be completed in week 3 or 4 of Term 3.

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

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

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

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

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

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

MA397 Consolidation

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

Term(s): Term 1

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

Commitment: Weekly meetings

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

Prerequisites: None

Leads To: 3rd year modules

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

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

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

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

Additional Resources

Year 1 regs and modules
G100 G103 GL11 G1NC

Year 2 regs and modules
G100 G103 GL11 G1NC

Year 3 regs and modules
G100 G103

Year 4 regs and modules
G103

Exam information
Core module averages

MA398 Matrix Analysis and Algorithms

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

Term(s): Term 1

Status for Mathematics students: List A

Commitment: 30 lectures

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

Prerequisites: Core module of the first and second year, in particular MA106 Linear Algebra and MA259 Multivariable Calculus are sufficient. Helpful but not mandatory is some knowledge of numerical concepts as accuracy, iteration, and stability as provided in MA228 Numerical Analysis or MA261 Differential Equations: Modelling and Numerics.

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

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

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

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

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

Books:

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

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

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

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

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

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

Additional Resources

Archived Pages: Pre-2011 2011 2012 2013 2014 2015

Year 1 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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Core module averages

MA3A6 Algebraic Number Theory

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

Term(s): Term 1

Status for Mathematics students: List A

Commitment: 30 one-hour lectures.

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

Prerequisites: MA251 Algebra I, MA249 Algebra II

Leads To:

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

$$x^n + a_{n-1}x^{n-1} \cdots + a_1 x + a_0$$

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

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

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

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

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

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

and

.

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

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

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

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

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

Objectives: By the end of the course students will:

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

Books:

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

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

Additional Resources

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Exam information
Core module averages

MA3B8 Complex Analysis

(https://warwick.ac.uk/fac/sci/maths/undergrad/ughandbook/year3/ma3b8/)
Lecturer: Peter Topping

Term(s): Term 2

Status for Mathematics students: List A

Commitment: 30 one-hour lectures

Assessment: 3 hour examination (100%).

Prerequisites: MA244 Analysis III, and MA259 Multivariable Calculus. MA3F1 Introduction to Topology would be helpful but not essential.

Leads To: MA475 Riemann Surfaces.

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

We will start with a review of elementary complex analysis topics from MA244 Analysis 3. This includes complex differentiability, the Cauchy-Riemann equations, Cauchy's theorem, Taylor's and Liouville's theorem etc. Most of the course will be new topics. This page will be updated in due course with the exact topics, but topics from previous years have included: Winding numbers, the generalized version of Cauchy's theorem, Morera's theorem, the fundamental theorem of algebra, the identity theorem, classification of singularities, the Riemann sphere and Weierstrass-Casorati theorem, meromorphic functions, Rouche's theorem, integration by residues.

Books: This list will be updated in due course.

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

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

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

Additional Resources

Archived Pages: 2011 2012 2013 2014 2015 2017 2018

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Year 2 regs and modules
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Exam information
Core module averages

MA3D1 Fluid Dynamics

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

Term(s): Term 2

Status for Mathematics students: List A

Commitment: 30 lectures

Assessment: 3 hour exam

Prerequisites: MA259 Multivariable Calculus and MA250 PDEs.
MA3B8 Complex Analysis is desirable.

Leads To:

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

The module will cover the following topics:

- ***Mathematical modelling of fluid flow.*** Specification of the flow by field variables; vorticity; stream function; strain tensor; stress tensor. Euler's equation. Navier-Stokes equation. Introduction of non-dimensional parameters
- ***Additional conservation laws***. Bernoulli's equations. Global conservation laws.
- ***Vortex dynamics***. Kelvin's circulation theorem. Helmholtz theorems. Cauchy-Lagrange theorem. 3D vorticity equation, vortex lines, vortex tubes and vortex stretching.
- ***2D flows***. Flow in a pipe. Shear flows. Jet flow by similarity solution. Round vortices.
- ***Irrotational 2D flows & classical aerofoil theory***. Complex analysis methods in Fluid Dynamics. Blasius theorem. Zhukovskii lift theorem. Force on a cylinder and force on an aerofoil.
- ***Rotating flows***. Navier-Stokes in a rotating frame. Rossby number. Taylor-Proudman theorem. Geophysical flow.
- ***Boundary layers.*** Prandtl's boundary layer theory. Ekman boundary layer in rotating fluids.
- ***Waves***. General theory of waves. Sound waves. Free-surface flows & surface tension. Gravity-capillary water waves.
- ***Instabilities.*** Rayleigh criterion. Orr-Sommerfeld equation. Kelvin-Helmholtz instability. Stability of parallel flows.

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

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

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

Further Reading:

A.R. Paterson, *A First Course in Fluid Dynamics*, CUP. (Easier than Acheson.)

L.D. Landau and E.M. Livshitz, *Fluid Mechanics*, OUP. (A classic for those with a deep interest in fluid dynamics in modern physics.)

D.J. Tritton, Physical Fluid Dynamics , Oxford Science Publs. (The emphasis is on the physical phenomena and less on the mathematics.)

Additional Resources

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Year 2 regs and modules
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Exam information
Core module averages

MA3D4 Fractal Geometry

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

Lecturer: **Oleg Kozlovski**

Term(s): Term 2

Status for Mathematics students: List A

Commitment: 30 one-hour lectures

Assessment: 100% by 3 hour Examination

Prerequisites: MA260 Norms, Metrics and Topologies or MA222 Metric Spaces

Leads To:

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

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

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

Additional Resources

Archived Pages: Pre-2011 2011 2012 2013 2014 2015 2016 2017 2018

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Exam information
Core module averages

MA3D5 Galois Theory

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

Term(s): Term 2

Status for Mathematics students: List A

Commitment: 30 lectures + assessment sheets

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

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

Leads To:

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

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

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

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

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

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

Additional Resources

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Core module averages

MA3D9 Geometry of curves and Surfaces

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

Term(s): Term 1

Status for Mathematics students: List A

Commitment: 30 lectures

Assessment: 3-hour examination (100%)

Prerequisites: MA259 Multivarible Calculus. Some familiarity with MA260 Norms, Metrics and Topology may be useful but not essential.

Leads To:

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

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

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

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

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

Additional Resources

Archived Pages: 2011 2015 2017

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Exam information
Core module averages

MA3E1 Groups & Representations

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

Term(s): Term 1

Status for Mathematics students: List A

Commitment: 30 one-hour lectures

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

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

Leads To:

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

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

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

Objectives: To enable students to:

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

Books:

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

Additional Resources

Archived Pages: Pre-2011 2013 2014 2015 2016 2017

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Exam information
Core module averages

MA3E7 Problem Solving

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

Term(s): Term 2

Status for Mathematics students: List A for 3rd year G100 (and 4th year G101), List B for third 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 seminars, 40% from assignment, 50% two hour exam in June

Prerequisites: Core Maths modules from years 1 and 2

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

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

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

Intended Outcomes

Learning objectives

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

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

Organisation

The module runs in term 2, weeks 1-10. Typically there will be a weekly session for completing the problems counting towards 10% o 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

1. A flat 10% given for serious attempts at problems during the course. Each week, you will be assigned a problem for the seminar. At then end of the seminar, you should present a rubric of your work on that problem so far. If you submit at least 7 rubrics, deemed to be serious attempts, you will get 10%.
2. An assignment (40%) due in March.
3. A 2 hour examination in Summer Term (50%).

Additional Resources

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MA3F1 Introduction to Topology

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

Term(s): Term 1

Status for Mathematics students: List A

Commitment: 30 one-hour lectures (or equivalent in 20/21)

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

Prerequisites: MA132 Foundations, MA251 Algebra I, MA260 Norms, Metrics and Topologies (or MA222 Metric Spaces).

Leads To: MA3H6 Algebraic Topology, MA3H5 Manifolds, MA4J7 Cohomology and Poincaré Duality.

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).

Additional Resources (Moodle pages)

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Exam information
Core module averages

MA3F2 Knot Theory

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

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MA3G1 Theory of Partial Differential Equations

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

Term(s): Term 2

Status for Mathematics students: List A

Commitment: 30 lectures

Assessment: Exam 100%

Prerequisites: This module uses material from many of the Core 1st and 2nd year modules, particularly MA259 Multivariable Calculus, MA244 Analysis III and MA250 Introduction to Partial Differential Equations. A student taking this module will benefit from having taken MA260 Norms, Metrics and Topologies (or MA222 Metric Spaces) but this not a formal prerequisite.

Leads To: MA4A2 Advanced Partial Differential Equations, MA4L3 Large Deviation theory

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

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

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

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

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

More detailed advice on books will be given during lectures.

Additional Resources

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MA3G6 Commutative Algebra

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

Term(s): Term 1

Status for Mathematics students: List A

Commitment: 30 one-hour lectures.

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

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

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

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

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

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

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

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

Books:
Recommended texts:

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

Additional Resources

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MA3G6 Forum 2016

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

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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/undergrad/ughandbook/year3/ma3g7/)
Lecturer: Professor Vassili Gelfreich

Term(s): Term 1

Status for Mathematics students: List A

Commitment: 30 lectures

Assessment: 3 hour examination

Prerequisites: MA244 Analysis III (or MA258 Mathematical Analysis III); MA259 Multivariable Calculus and MA260 Norms, Metrics and Topoology or MA222 Metric Spaces would be useful but not essential; MA359 Measure Theory would be a natural course to take in parallel.

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

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

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

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

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

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

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MA3G8 Functional Analysis 2

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

Term(s): Term 2

Status for Mathematics students: List A

Commitment: 30 lectures

Assessment: 3 hour examination (100%)

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

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

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

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

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

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

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

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

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

Additional Resources

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MA3H0 Numerical Analysis and PDE's

(https://warwick.ac.uk/fac/sci/maths/undergrad/ughandbook/year3/ma3h0/)
Lecturer: Dr Susana Gomes

Term(s): Term 2

Status for Mathematics students: List A

Commitment: 30 lectures

Assessment: Assignments (15%), 3 hour exam 85%

Prerequisites: This module uses material from many of the Core 1st and 2nd year modules, particularly MA259 Multivariable Calculus, MA244 Analysis III and MA250 Introduction to PDE. Although not prerequisites MA3G7 *Functional analysis Functional Analysis I* and MA3G1 *Theory of PDEs* are excellent companion courses.

Leads To:

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

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

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

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

Books:
Background reading:

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

Additional Resources

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MA3H1 Topics in Number Theory

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

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MA3H2 Markov Processes and Percolation Theory

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

Term(s): Term 1

Status for Mathematics students: List A

Commitment: 30 lectures

Assessment: 3 hour exam 100%.

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

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

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

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

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

Let us briefly explain the mathematical setting. Percolation is a simple probabilistic model which exhibits a phase transition. The simplest version of percolation takes place on $\mathbb{Z}^2$, which we view as a graph with edges between neighbouring vertices. All edges of $\mathbb{Z}^2$ are, independently of each other, chosen to be open with probability p and closed with probability $1-p$. A basic question in this model is `What is the probability that there exists an open path from the origin to the exterior of the square $S_n = [-n,n]^2$?' A limit as $n \to \infty$ of the question raised above is `What is the probability that there exists an open path from 0 to infinity?' This probability is called the percolation probability and is denoted by $\theta(p)$. Clearly $\theta(0) = 0$ and $\theta(1) = 1$, since

there are no open edges at all when $p = 0$ and all edges are open when $p = 1$. For some models there is a $0 < p_c < 1$ such that the global behaviour of the system is quite different for $p < p_c$ and for $p > p_c$. Such a sharp transition in global behaviour of a system at some parameter value is called a phase transition or a critical phenomenon, and the parameter value at which the transition takes place is called a critical value.

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

Books:

We will not follow a particular book.

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

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

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

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

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

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

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MA3H3 Set Theory

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

Term(s): Term 2

Status for Mathematics students: List A

Commitment: 30 lectures

Assessment: 3 hour exam 100%

Prerequisites: MA132 Foundations MA138 Sets and Numbers or PH126 Starting Formal Logic. Some exposure to at least one of MA260 Norms, Metrics and Topology, MA222 Metric Spaces, MA359 Measure Theory or PH210 Symbolic Logic is also recommended

Leads To:

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

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

Books:

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

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MA3H4 Random Discrete Structures

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

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MA3H5 Manifolds

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

Term(s): Term 1

Status for Mathematics students: List A

Commitment: 30 hours

Assessment: Three hour examination (100%)

Prerequisites: Basic theory of differentiation, including statements (though not proofs) of Inverse and Implicit Function Theorems. Integration in several variables i.e. MA259 Multivariable Calculus and MA260 Norms, Metrics and Topology

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

Content:

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)

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MA3H6 Algebraic Topology

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

Term(s): Term 2

Status for Mathematics students: List A

Commitment: 30 hours

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

Prerequisites: MA3F1 Introduction to Topology

Prerequisite for: MA4J7 Cohomology and Poincaré Duality

Leads To: MA4A5 Algebraic Geometry, MA5Q6 Graduate Algebra

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

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

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

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

Give the definitions of simplicial complexes and their homology groups and a geometric understanding of what these groups measure
Use standard techniques for computing these groups
Give the extension to singular homology
Understand the theoretical power of singular homology
Develop a geometric understanding of how to use these groups in practice

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

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

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

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MA3H7 Control Theory

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

Term(s): Term 2

Status for Mathematics students: List A

Commitment: 30 one hour lectures

Assessment: Three hour examination

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

Leads to:

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

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

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

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

Additional Resources

Archived Pages: Pre-2011 2011 2012 2013 2014 2015 2016 2017 2018

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

MA3J1 Tensors, Spinors and Rotations

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

Term(s): Term 2

Status for Mathematics students: List A

Commitment: 30 Lectures

Assessment: Summer exam (100%)

Prerequisites: MA241 Combinatorics

Leads To: MA4J3 Graph Theory

Content: Some or all of the following topics:

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

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

Objectives:
By the end of the module the student should be able to:
- state and prove particular results presented in the module
- adapt the presented methods to other combinatorial settings

• apply simple probabilistic and algebraic arguments to combinatorial problems
• use presented discrete abstractions of geometric and linear algebra concepts
• derive approximate results using the regularity method

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

Additional Resources

Archived Pages: 2015 2016 2017 2018

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/undergrad/ughandbook/year3/ma3j3/)
Lecturer: Dr. David Wood

Term(s): Term 2

Status for Mathematics students: List A

Commitment: 30 Lectures

Assessment: 100% exam

Prerequisites: MA133 Differential Equations, MA249 Algebra II, MA259 Multivariable Calculus. MA254 Theory of ODEs would be useful, but is not essential.

Leads to:

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

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

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

Further topics from (if time and interest):

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

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

Objectives:

Books:

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

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

Additional Resources

Year 1 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

MA3J4 Mathematical modelling with PDE

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

Term(s): Term 1

Status for Mathematics students:

Commitment: 30 Lectures

Assessment: 3 hour exam 100%.

Prerequisites: MA250 PDE

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

Content:

1. Mathematical modelling
    - Math. modelling in physics, chemistry, biology, medicine, economy, finance, art, transport, architecture, sports
    - Qualitative/quantitative models, discrete/continuum models
    - Scaling, dimensionless variables, sensitivity analysis
    - Examples: projectile motion, chemical reactions
2. Diffusion and drift
    - Microscopic derivation
    - Continuity equation and Fick's law
    - Heat equation: scaling, properties of solutions

- Reaction diffusion systems: Turing instabilities
- Fokker-Planck equation

3. Transport and flows
   - Conservation of mass, momentum and energy
   - Euler and Navier-Stokes equations
4. From Newton to Boltzmann
   - Newton's laws of motion
   - Vlasov and Boltzmann equation
   - Traffic flow models

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

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

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

Books:

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

Additional Resources

Year 1 regs and modules
G100 G103 GL11 G1NC

Year 2 regs and modules
G100 G103 GL11 G1NC

Year 3 regs and modules
G100 G103

Year 4 regs and modules
G103

Exam information
Core module averages

MA3J8 Approximation Theory and Applications

(https://warwick.ac.uk/fac/sci/maths/undergrad/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/undergrad/ughandbook/year3/ma3j9/)
Lecturer: Damiano Testa

Term(s): 2

Status for Mathematics students:

Commitment: 30 lectures, support classes

Assessment: Two hour exam 85% and Assignments 15%

Prerequisites: Mathematics core: MA131 Analysis, MA106 Linear Algebra, MA251 Algebra 1, MA249 Algebra 2, MA259 Multivariate Calculus (or equivalents)

Leads To:

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, 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

Year 4 regs and modules
G103

Exam information
Core module averages

MA3K0 High Dimensional Probability

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

Term(s): Not running 2020/21

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%)

Prerequisites: ST111 Probability A & B; (MA259 Multivariate Calculus and MA244 Analysis III) or (MA258 Mathematical Analysis III and ST208 Mathematical Methods); MA359 Measure Theory or ST342 Mathematics of Random Events.

Earlier probability modules will be of some use. The framework is some mild probability theory (e.g., the following modules can be useful: ST202 Stochastic Processes, MA3H2 Markov Processes and Percolation Theory).

Leads To: There are also strong links and thus suitable combinations to the following modules MA4K4 Topics in Interacting Particle Systems, MA4F7 Brownian Motions, MA427 Ergodic Theory, MA424 Dynamical Systems, MA4L2 Statistical Mechanics, MA4L2 Large deviation theory

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/undergrad/ughandbook/year3/ma3k1/)
Lecturer: Martin Lotz

Term(s): 1

Status for Mathematics students:

Commitment: 10 x 3 hour lectures, support classes.

Assessment: Two hour exam 85% and Assignments 15%

Prerequisites: MA260 Norms Metrics and Topologies, MA228 Numerical Analysis or MA261 Differential Equations: Modelling and Numerics.

Leads To:

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 algirthms 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

Year 4 regs and modules
G103

Exam information
Core module averages

CS349 Principles of Programming Languages

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

CS349-15 Principles of Programming Languages

Academic year	**20/21**
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/undergrad/ughandbook/year3/cs356/)

CS356-15 Approximation and Randomised Algorithms

Academic year	**20/21**
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/undergrad/ughandbook/year3/cs409/)

CS409-15 Algorithmic Game Theory

Academic year	**20/21**
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
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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/undergrad/ughandbook/year3/px408/)

Lecturer: Tom Blake

Weighting: 15 CATS

The module sets up the relativistic analogues of the Schrödinger equation and introduces quantum field theory. The best equation to describe an electron, due to Dirac, predicts antiparticles, spin and other surprising phenomena. However, Dirac's equation also showed the need for quantum field theory (QFT). This is where the wavefunctions of matter and light themselves are quantized (made into operators). QFT automatically builds the correct fermionic or bosonic statistics into the description of a many-particle system.

Aims:

This module should start from the premise that quantum mechanics and relativity need to be mutually consistent. The Klein Gordon and Dirac equations should be derived as relativistic generalisations of Schrödinger and Pauli equations. The module should also introduce quantum fields and illustrate how they can describe phenomena in interacting particle systems.

Objectives:

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

- Describe the Dirac equation, its significance and its transformation properties
- Explain how some physical phenomena including spin, the gyromagnetic ratio of the electron and the fine structure of the hydrogen atom can be accounted for using relativistic quantum mechanics
- Understand interactions between electrons in atoms and molecules
- Be able to work with quantum fields

Syllabus:

1. Introduction to Relativistic Quantum Mechanics (QM). Problems with the non-relativistic QM; phenomenology of relativistic quantum mechanics, such as pair production. Derivation and interpretation of the Klein- Gordon Equation
2. The Dirac Equation (DE). Derivation of the DE; spin; gamma matrices and equivalence transformations; Solutions of the DE; Helicity operator and spin; Dirac spinors; Lorentz transformation; interpretation of negative energy states; non-relativistic limit of the Dirac equation; gyromagnetic ratio of electron; fine structure of the hydrogen atom.
3. Introduction to 2nd Quantisation. Creation and annihilation operators, harmonic oscillator. Spin-statistics theorem. Description of the N-electron state: electronic structure and Bloch's theorem; electron exchange and correlation, Hartree-Fock; Feynman rules and diagrams.
4. Landau Fermi Liquid Theory. Notion of the quasiparticle, low temperature properties. Landau Fermi liquid parameters, the Stoner criterion. Application to (some of) normal 3He, magnetism, superconductivity and BCS theory

Commitment: 30 Lectures

Assessment: 2 hour examination

Recommended Text: R.Feynman, Quantum Electrodynamics, Perseus Books 1998
A. Altland & B. D. Simons, Condensed Matter Field Theory, Cambridge University

Year 1 regs and modules
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Year 2 regs and modules
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Year 4 regs and modules
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Exam information
Core module averages

PX420 Solar Magnetohydrodynamics

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

Lecturer: Valery Nakariakov

Weighting: 15 CATS

This module starts by introducing a hydrodynamic model of the Sun, which treats the solar matter as a fluid. It discusses how this theory, called magnetohydrodynamics, is used to model and understand phenomena like sunspots, coronal loops, prominences, solar flares, coronal mass ejections and space weather. The Sun also emits a stream of energetic charged particles in what is called the solar wind. The module will look at how the solar wind interacts with the Earth and other planets in the Solar System.

Aims:
To review the physics underlying the structure and the dynamics of the Sun using magnetohydrodynamics. It should discuss its ejections including the solar wind and how this interacts with planets in the Solar System.

Objectives:

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

- Explain structure of the Sun and the main features and phenomena observed on the solar surface and in the solar atmosphere
- Describe the physical processes at work in the Sun
- Describe the dynamic processes operating in the Sun, in terms of MHD
- Explain the solar wind and its interactions with planets in the Solar System

Syllabus:

Introduction to the Sun, magnetohydrodynamics (MHD), magnetostatic equilibria, coronal loops, potential and force-free magnetic fields, application to prominences, magnetic reconnection, MHD coronal waves, helioseismology;

Structure of the solar wind, Parker solution, Parker spirals and co-rotating interaction regions, Heliosphere and heliopause;

Transients in the solar wind, coronal mass ejections, MHD shocks, Turbulence;

Earth's magnetosphere, structure, co-rotating region: plasmasphere, radiation belts; Advective region: plasmapause, magnetotail, Dungey cycle; Substorms, aurora, ionosphere, concepts of space weather;

Comparative solar wind/planet interaction: Earth, Venus, Mars, Jupiter, outlook beyond the solar system

Commitment: 30 Lectures

Assessment: 2 hour examination

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

Year 1 regs and modules
G100 G103 GL11 G1NC

Year 2 regs and modules
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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/undergrad/ughandbook/year3/px425/)

Lecturer: Nick Hine

Weighting: 15 CATS

The module will address the increased use of computer simulation and data analysis on high performance computers in all fields of computational physics and other sciences. Computing skills are greatly valued across science and beyond and we encourage students to go as far as they can to develop such skills.

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

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

- Identify and correct common inefficiencies in both serial scientific computer codes
- Write a parallel program using shared-memory or message passing constructs in a physics context, and to write a simple GPU accelerated program
- Choose an appropriate programming paradigm and identify sources of performance bottlenecks and parallelisation errors in parallel computer programs and understand how these relate to the computer architecture
- Process very large datasets with appropriate tools, and use machine-learning to efficiently extract simple functional forms describing sparse data

Syllabus:

Programming for efficiency. What does a compiler do that an interpreter cannot? The mechanics of linking C and Python. Modern cache architectures and CPU pipelining. Avoiding expensive and repeated operations. Compiler optimisation flags.

Introduction to parallel computing. Modern HPC hardware and parallelisation strategies. Analysing algorithms and codes to identify opportunities for parallelism.

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

Distributed memory programming. The MPI standard for message passing. Point-to-point and collective communication. Synchronous vs asynchronous communication. MPI communicators and topologies.
GPU programming. CUDA vs OpenCL. Kernels and host-device communication. Shared and constant memory, synchronicity and performance. GPU coding restrictions.

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

"Big Data" in physics: handling very large datasets. Examples derived from astronomy and particle physics.

Commitment: 25 Lectures + 5 Laboratory Sessions

Assessment: Assignments (100%)

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

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

PX429 Scattering and Spectroscopy

(https://warwick.ac.uk/fac/sci/maths/undergrad/ughandbook/year3/px429/)
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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
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/undergrad/ughandbook/year3/px430/)

Lecturer: Paul Harrison

Weighting: 15 CATS

The Standard Model (SM) of Particle Physics is a quantum field theory with local gauge symmetries. We describe these symmetries and show how to calculate cross sections (experimental observables). We will discuss the Higgs mechanism and spontaneous symmetry breaking, which explain the origin of mass in the SM. Finally, we will look beyond the group structure of the current Standard Model to discuss possible mechanisms for unification of the strong process with the electroweak interaction.

Aims:
To develop ideas used in gauge theories and apply these to the field of particle physics. To describe the theory underpinning the Standard Model of Particle Physics and to highlight the symmetry properties of the theory. To discuss the formulation of the Standard Model, including the concept of spontaneous symmetry breaking, and consider further model extensions.

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

- Explain the gauge principle, the mathematical description of symmetry, and the symmetry properties associated with gauge invariance
- Describe how the quarks and leptons, and the bosons that mediate their interactions, can be described by local gauge theories
- Derive Feynman rules from the Lagrangian description of quantum fields
- Use the gauge structure of each of the three interactions, to calculate basic processes in QED
- Explain how the electromagnetic and weak forces were unified and how the concept of spontaneous symmetry breaking (and the Higgs Mechanism) can account for massive gauge fields
- Describe some of the current ideas for extensions of the Standard Model

Syllabus:

Introduction and revision of relativistic quantum mechanics

The mathematical description of symmetries

The gauge principle and implications of gauge invariance

Quantum Field Theory and the generation of Feynman Rules

The gauge structure of QED, QCD and the Electroweak forces

Electroweak unification, predictions and experimental validation

Spontaneous Symmetry Breaking and the Higgs Mechanism

Extensions of the gauge structure of the Standard Model

Commitment: 30 Lectures

Assessment: 2 hour examination

Recommended Texts:
I. J. R Aitchison and A.J.G. Hey, Gauge Theories in Particle Physics, CRC Press (2013)
M. Thomson, Modern Particle Physics, Cambridge University Press (2013)
D. Griffiths, Introduction to Elementary Particles, Wiley (2008)

Year 1 regs and modules
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Year 4 regs and modules
G103

Exam information
Core module averages

CS301 Complexity of Algorithms

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

CS301-15 Complexity of Algorithms

Academic year	**20/21**
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
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Year 4 regs and modules
G103

Exam information
Core module averages

CS324 Computer Graphics

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

CS324-15 Computer Graphics

Academic year	**20/21**
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**

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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
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Year 4 regs and modules
G103

Exam information
Core module averages

CS325 Compiler Design

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

CS325-15 Compiler Design

Academic year	**20/21**
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
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Year 2 regs and modules
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Year 4 regs and modules
G103

Exam information
Core module averages

PX308 Physics in Medicine

(https://warwick.ac.uk/fac/sci/maths/undergrad/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/undergrad/ughandbook/year3/px350/)
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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
G100 G103

Year 4 regs and modules
G103

Exam information
Core module averages

PX366 Statistical Physics

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

Lecturer: Gareth Alexander

Weighting: 15 CATS

The collective behaviour of large numbers of interacting particles, or components, in a system can lead to the emergence of novel structures and patterns. Phase transitions, the configurations taken up by polymers, and stock market trends are examples. This module looks at how we classify this behaviour, how the different classes of behaviour come about, and how we model it quantitatively.

We will revise the statistical material from Thermal Physics II, as statistical mechanics is the natural starting point for describing how patterns are nucleated and grow from initial fluctuations. We will then discuss how collective behaviour can be related to order parameters and how these can change across phase transitions.

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

Objectives:

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

- Work with equilibrium thermodynamics
- Describe the statistical mechanics of long chain molecules (polymers)
- Work with the Ginzburg-Landau theory of continuous symmetry breaking phase transitions and scaling theory
- Appreciate a range of emergent phenomena including some of quantum phase order and/or the Fermi liquid state, non-equilibrium phenomena such as turbulence, growth patterns, forest fires, crowd & congestion models

Syllabus:

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

Phase Transitions: thermodynamic description. PVT system: coexistence lines, triple point, critical point, Gibbs phase rule. First order transitions (latent heat) and continuous phase transitions (no latent heat, divergence of susceptibilities). Mean-field description. Universality, importance of symmetries, concept of order parameter and spontaneous symmetry breaking. Mean field theory, Curie temperature and emergence of spontaneous magnetisation. Critical exponents. Ginzburg- Landau description of phase transitions (continuous and first order). Failure of mean field and concept of critical dimension.

Further topics in Collective Phenomena selected from:

1. Polymers: Motivate a treatment of polymers based on statistical physics emphasising an insensitivity to the chemistry. Ideal and non-ideal chains. Different models for ideal chains -Gaussian chain, lattice chain, freely jointed chain. Master equation and derivation of diffusion equation.
2. Extended quantum systems: Fermi liquids, quantitative modelling through Density Functional Theory. Emergent quantum phase ordering: Superconductivity and/or Superfluidity.
3. Non-equilibrium systems: Turbulence, growth patterns, forest fires, crowd & congestion models

Commitment: 30 Lectures

Assessment: 2 hour examination

Recommended Texts: F. Mandl, Statistical Physics, Wiley David Chandler, Introduction to Modern Statistical Mechanics, OUP P-G de Gennes Scaling Concepts in Polymer Physics, Cornell Univ. Press G Rowlands, Non-Linear Phenomena in Science and Engineering, Ellis Horwood James P. Sethna Statistical mechanics: entropy, order parameters, and complexity OUP 2007

Year 1 regs and modules
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Year 2 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/undergrad/ughandbook/year3/px370/)
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Year 1 regs and modules
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Year 2 regs and modules
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Exam information
Core module averages

PX382 Quantum Physics of Atoms

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

Lecturer: Martin Lees

Weighting: 10 CATS

The principles of quantum mechanics are applied to a range of phenomena in atomic physics including the operation of a laser. The module also covers perturbation theory and variational methods.

Aims:

To develop the ideas of quantum theory

Objectives:

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

- Use the approximate methods of quantum theory – perturbation theory (time-dependent and time-independent), variational methods
- Explain the role of spin and the Pauli exclusion principle
- Explain atomic spectra and the structure of the periodic table
- Describe the operation of lasers

Syllabus:

Revision of 2nd year quantum theory

1. Approximation methods in quantum mechanics. Time-independent perturbation theory, non-degenerate case, ground state of helium atom, degenerate case, Stark effect in hydrogen. Variational methods: Rayleigh - Ritz, ground state of helium atom
2. Spin-orbit coupling and the Zeeman effect. Effects of spin-orbit coupling, and the strong and weak field Zeeman effect using time-independent perturbation theory
3. Many electron effects-indistinguishability of identical particles. Identical particles and spin; symmetric and anti-symmetric states; discussion of periodic table, ionisation energies
4. Time-dependent perturbation theory and the lasers. Derivation of Fermi's golden rule; radiation from atoms; operation of the laser including stimulated emission and population inversion. Density matrix and Bloch equations.

Commitment: 20 lectures

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

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

Year 1 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/undergrad/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 4 regs and modules
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Exam information
Core module averages

PX389 Cosmology

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

Lecturer: Ben McMillan

Weighting: 15 CATS

Plasmas are 'fluids' of charged particles. The motion of these charged particles is controlled by the electromagnetic fields which are imposed from outside and by the fields which the moving charged particles themselves set up. This module will cover the equations which describe such plasmas. It will examine some predictions derived on the basis of these equations and compare these with laboratory observations and with remote observations of astrophysical systems.

The module will also discuss the physics of thermonuclear fusion, which is a candidate solution for the energy demands of our society. Fusion occurs only at temperatures at which all matter is ionized and exists as a plasma. The module discusses the two main approaches: inertial confinement and magnetic confinement, with the emphasis on the latter since it is further developed. The module will deal with both the physics in the plasma as well as with the boundary conditions that must be satisfied for a working reactor.

Aims:
The module should discuss particle dynamics in plasmas, and aspects of nuclear fusion and advanced plasma physics relevant to the construction of fusion power stations. The interaction of EM fields with a fully ionised fluid (plasma) should be considered in detail leading to ideas of magnetohydrodynamics.

Objectives:

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

- Work with single particle dynamics, guiding centre motion and adiabatic invariants, the plasma approximation and waves in plasmas
- Describe the nature of fluid instabilities and micro-instabilities with application to confinement devices and astrophysics
- Explain the interaction of electromagnetic waves with plasmas
- Appreciate how plasma physics sets the design parameters of fusion power plants
- Explain the physics of fusion power plasma heating, confinement and stability

Syllabus:

Foundations, Debye shielding, Plasma oscillations, Gyration and drifts; Dielectric description of magnetised plasmas;
Dispersion relations for high-frequency EM waves in a cold plasma;
Elements of plasma kinetics: Landau damping, Bump-on-tail instability; Magnetohydrodynamics: Framework, Equilibria, Waves, Instabilities;

Fusion Foundations, Lawson criterion;
Cylindrical equilibria, including z pinch;
Mirror machines, Tokamaks and stellarators; Laser-plasma interaction and inertial confinement fusion; Transport and turbulence

Commitment: 30 Lectures

Assessment: 2 hour examination.

Year 1 regs and modules
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Exam information
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PX390 Scientific Programming

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

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Exam information
Core module averages

PX384 Electrodynamics

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

Lecturer: David Leadley

Weighting: 10 CATS

Einstein's 1905 paper on special relativity was called "On the electrodynamics of moving bodies". It derived the transformation of electric and magnetic fields when moving between inertial frames of reference. The module works through this transformation and looks at its implications. The module starts by covering the magnetic vector potential, A, which is defined so that the magnetic field B=curl A and which is a natural quantity to consider when looking at relativistic invariance.

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

Aims:

To introduce the magnetic vector potential and to show that electromagnetism is Lorentz invariant.

Objectives:

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

- Work with the vector potential and Lorentz invariant form of Maxwell's equations
- Manipulate Maxwell's equations and solve representative problems using 4-vectors
- Describe physics of EM radiation and scattering and be able to describe the propagation of EM waves through free space and in waveguides
- Solve Maxwell's equations to calculate the EM field from known source distributions

Syllabus:

1. Revision of special relativity. Revision of Maxwell's Equations in vacuum and in a macroscopic medium. Simple models of polarization. Displacement current; Potentials ϕ and A. Coulomb and Lorenz gauge. Laplace's and Poisson's equations and the solution of Maxwell's equations. Retarded potentials.
2. Lorentz invariance of Maxwell's equations. Four vectors. Covariant and contravariant representation. Minkowski's metric tensor. Four vector formulation of Maxwell's equation.
3. Generation of EM waves and retarded potentials. The power radiated by accelerating charges.
4. The scattering of EM waves. Rayleigh scattering and Thompson scattering.
5. Role of interaction of waves with electrical geometry. Waveguides and optical fibres.

Commitment: 20 Lectures

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

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

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PX392 Plasma Electrodynamics

(https://warwick.ac.uk/fac/sci/maths/undergrad/ughandbook/year3/px392/)
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PX396 Nuclear Physics

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

Lecturer: Kathrin Becker and Steve Boyd

Weighting: 15 CATS

The Standard Model (SM) of Particle Physics describes elementary particles (the quarks, leptons, and bosons) and their interactions. This module explores the symmetries on which the SM is based, outlines the defining properties of the three interactions and discusses the experimental evidence for the Standard Model. We will look at Noether's theorem (for any continuous symmetry there is a conserved quantity, eg conservation of charge and invariance under gauge transformations are the same thing), flavour symmetry, parity and others, as well as the reasons for quark confinement. We will also study the concept of a momentum-transfer dependent coupling, quark mixing and questions about unification.

Aims:

To describe the main features of the Standard Model of particle physics and to identify major pieces of experimental evidence supporting the key theoretical ideas

Objectives:

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

- Explain qualitatively how elementary particles and their interactions are described by local gauge theories
- Demonstrate quantitatively important aspects of the model and quote experimental evidence that supports it
- Discuss the limitations of the established theory

Syllabus:

Introduction and the language of Particle Physics

The structure of the Standard Model

Symmetries and Conservation Rules

Aspects of Quantum Electrodynamics, the Weak Interaction, the Strong Interaction

Triumphs and Limitations of the Standard Model

Commitment: 30 Lectures

Assessment: 2 hour examination

Recommended Texts:

B.R. Martin, Nuclear and Particle Physics, Wiley (2016)
B.R. Martin and G. Shaw, Wiley-Blackwell (2017)
Introduction to High Energy Physics, Donald Perkins, Addison Wesley (2000)
D. Griffiths, Introduction to Elementary Particles, Wiley (2008)

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PX397 Galaxies

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

Lecturer: tba

Weighting: 15 CATS

We will discuss the compact objects - white dwarfs, neutron stars and black holes (BH) - that can form when burnt out stars collapse under their own gravity. The extreme conditions in their neighbourhood mean that they affect strongly all nearby objects as well as the surrounding structure of space-time. For example, they can lead to very high luminosity phenomena, such as synchrotron radiation and jets of ionised particles that we can observe from Earth.

These compact objects accrete material from surrounding gases and nearby stars. In the case of BHs this can lead to the supermassive BHs thought to be at the centre of most galaxies. In the most extreme events (mergers of these objects), the gravitational waves (GW) that are emitted can sometimes be detected on earth (the first GW detection was reported in 2015 almost exactly 100 years after their prediction by Einstein).

Aims:
To cover the physics of black holes, white dwarfs and neutron stars highlighting the role of observation. To give an overview of the possible formation and growth channels of these objects and to discuss their interactions.

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

- be aware of the structure of our own Galaxy and how it fits into the 'zoo' of galaxies distributed through the Universe
- understand the physical principles behind the observations used to study galaxies
- be aware of some of the outstanding, and only partially understood, problems in the study of galaxies including the nature of galaxy cores and the roles of dark matter and dust.

Syllabus:

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

1. Observational instrumentation, telescope design, detectors
2. Accretion onto compact objects as a source of energy, Eddington limit: a maximum accretion rate, structure and the emission of accretion disks, accretion onto magnetic stars, Alven radius
3. High energy astrophysics: jets in astrophysical objects, radiation from free electrons, synchrotron radiation, cyclotron radiation, thermal Bremsstrahlung from hot accretion plasmas
4. Nuclear physics: stable and unstable nuclear shell burning in accreting white dwarfs and neutron stars
5. Formation pathways for black holes. Supernovae, gamma-ray bursts. Exploding white dwarfs, merging neutron stars. Mergers and associated gravitational wave emission

Commitment: 30 lectures

Assessment: 2 hour examination

This module has a home page.

Recommended texts: H Bradt, Astronomy Methods: A Physical Approach to Astronomical Observations, Cambridge University Press
J Frank, AR King and DJ Raine, Accretion Power in Astrophysics, CUP
C Hellier Cataclysmic Variables: How and why they vary, Springer

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PX436 General Relativity

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PX439 Statistical Mechanics of Complex Systems

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ES3C8 Systems Modelling and Control

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