Faculty of Science

Prospectus 2009 - 2010

Mathematics

Master

Radboud University Nijmegen

Preface

This booklet is the propectus for the Master program of Mathematics at the Radboud University Nijmegen.
It contains information about the objectives, the goals and the contents of the program.

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This prospectus has been made with great care. However the authors are not responsible for inaccuracies. If you have comments or proposals for improvements don't hesitate to contact them.

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1 Introduction

1.1 Structure

The Radboud University Nijmegen offers a Master of Science program in Mathematics. The English taught MSc program takes two years and provides students with a thorough knowledge of the relevant mathematics. The first year consists of core courses and electives in mathematics. The second year is largely devoted to the final thesis work, which involves participating in one of the department's advanced research projects or a traineeship or an internship within a company. If you pass the MSc exam you are awarded 'Master of Science'.
The Radboud University Nijmegen is a general university, offering almost all possible academic Programs, ranging from Arts and Law, to Medicine and Science. This Master program allows a substantial choice of topics from all these areas, thereby offering the possibility to combine Mathematics with other studies.

1.2 Admittance

Entering the Mathematics Master requires a bachelor degree in Mathematics from any Dutch university. With an equivalent degree one can also be admitted, but approval of the Exam Committee Mathematics will be required. In this case, the Exam Committee can demand that one adds specific courses to the master program, depending on the Master specialization. For example, with a bachelor degree in Physics with a minor in Mathematics, one will be admitted to the Mathematics Master with the specialization Physics.

1.3 Credit point system

The Radboud University uses the European Credit Transfer System (ec) employed by all universities in the European Union. One year consists of 60 ec credits, the total Master program consists of 120 ec.

1.4 Dutch Master Program in Mathematics

The Departments of Mathematics of the Dutch universities have coordinated their efforts to enhance their Master Programs in Mathematics. Part of the cooperation is aimed at organizing joint courses in mathematics. The joint courses offer the students the highest quality of instruction and open opportunities for interaction with students of other institutes of mathematics. For students who intend to pursue a PhD program after completion of their Master Program the joint program may widen the range options for continuing their studies. For more information concerning the Dutch Master Program in Mathematics see the web site www.mastermath.nl .
Each master student in mathematics is obliged to attend courses from the Dutch Master Program in Mathematics with a total weight of 30 ec or more.

1.5 Mathematics Clusters

Mathematics clusters form a new part of the Dutch mathematical landscape. A cluster is a collaboration between a number of Dutch universities, which is organized around a specific research area. Nijmegen takes part in two of the three clusters that are currently active, viz. **DIAMANT** (Discrete, Interactive & Algorithmic Mathematics, Algebra & Number Theory - involving CWI, RU, TU/e, UL) and **GQT** (Geometry and Quantum Theory, consisting of RU, UvA, UU). The RU does not take part in the third cluster **NDNS** (Nonlinear Dynamics of Natural Systems: CWI, RUG, UL, UU, VU).

While primarily founded in order to boost mathematical research in the Netherlands, the clusters are of great importance to master's students. This is firstly because they organize the bulk of the courses within the Dutch Master Program in Mathematics, and secondly because in writing your master's theses you will probably be attracted by some of the research themes offered by one of the clusters that Nijmegen takes part in.

The relevant websites are:
DIAMANT: http://www.win.tue.nl/diamant/
GQT: http://www.gqt.nl

1.6 Mathematical Research Institute

The Mathematical Research Institute (web site www.math.uu.nl/mri) is one of the research schools in The Netherlands. It is the combined research school for the mathematics departments of the universities of Groningen, Nijmegen, Twente and Utrecht. The MRI is one of three national research schools in mathematics in the Netherlands. The others are EIDMA and Stieltjes . The MRI participates in the European research institute EURANDOM .

The research programme of the Mathematical Research Institute focuses on the fundamental aspects of mathematics, as well as on interactions with its applications.

Each year the MRI organizes two Master Classes. The Master Classes offer a one-year programme centered around a theme that is close to one of the research areas supported by the MRI. Courses of these Masterclasses can be taken as part of

The 2009-2010 topics of the MRI Master Class are:
1) Arithmetic geometry and noncommutative geometry.
2) Numerical bifurcation analysis of dynamical systems.

More information on the specific courses in these masterclasses can be find on www.math.uu.nl/people/cornelis/mc.shtml and www.math.uu.nl/people/kuznet/mcnbds.html respectively.

In addition MRI organises an internation master semester with the topic: Geometry in the Sciences. More information on this programme can be foun on www.math.uu.nl/mri/education/education-ism.html.

2 Program

2.1 Tracks

The Master program at the Faculty of Science is offered in four tracks: a Research track (R), a Communication track (C), an Education track (E), and a Management & Technology track (MT). At this moment, only the Research track has a complete program in the English language. The other tracks are primarily aimed at the Dutch market and the Dutch educational system, and are therefore taught in Dutch.

- The R-track leads students to a high level of knowledge in mathematics. It consists of advanced courses and a final research project including a Master thesis and an oral presentation of it. Students with this MSc in Mathematics are admissible to a PhD program. The program is suited as preparation for an academic career, in particular via a subsequent PhD study, but also for a career as mathematical researcher outside the universities.
- The C-track is intended for a job in science communication in a broad sense. The program prepares students for a career in popularisation of science.
- The E-track is intended as a preparation for a job in teaching mathematics and mathematics curriculum development.
- The MT-track is intended as a preparation for jobs in the field of management. It prepares students for a career in science-related business and administration and for innovation and enterprise from a mathematical perspective.

Every master student chooses both a track and a specialization within mathematics. The specializations within mathematics are: Algebra & Logic, Mathematical Physics and Stochastics. These specializations are discussed in Chapter 3. The specialization consists of a certain amount (depending on the track one chooses) of advanced courses to be selected in correspondence with the research topic.

2.2 Master thesis

At the start of the Master program, the student is expected to contact one or more prospective Master thesis supervisors to discuss a program. Normally the student will contact a thesis supervisor in the first semester of the Master program. The courses that are needed to prepare for the Master thesis work are determined by the Master thesis supervisor and the student together. It is therefore advisable to contact the prospective Master thesis supervisor to discuss the content of these courses. The individual program needs approval by the examination committee. To select a prospective Master thesis supervisor, please look at the descriptions of the different specialisations within the department of mathematics. The contact persons of the departments can be approached at any stage for information or to set up a program in the electives section.
If you do not know yet who your thesis supervisor will be at the beginning of your Master program please contact the coordinator of the specialisation you are most interested in and together make a plan for the first year of your Master.

2.3 Regulations Graduation project

The Graduation project is the completion to the Master Program. The central part consists of either a thesis or an apprenticeship. In both cases there is a staff member to supervise. In this paragraph one can find a more elaborate description of the Graduation Project.

Graduation Project including master thesis
The project consists of:
1. Acquiring knowledge about a specific subject by way of literature study, consultation and/or participating in a seminar.
2. Conducting scientific research.
3. Writing a thesis.
4. Presenting the master thesis and defending it in front of an audience of experts.

Graduation Project including an apprenticeship.
The project consists of:
1. Acquiring knowledge about a specific subject by way of literature study, consultation and/or participating in a seminar
2. Doing work experience during an apprenticeship.
3. Writing an apprenticeship report.
4. Presenting the apprenticeship report and defending it in front of an audience of experts.

Assessment
The procedure for graduation project assessment consists of the following steps:
1. The supervisor approves of the thesis and /or the apprenticeship report, and notifies the program coordinator.
2. The program coordinator appoints a second rater, the supervisor organizes the presentation of the master thesis or the apprenticeship report in consultation with the student and the second rater.
3. After the presentation the supervisor determines the grade for the graduation project in consultation with the second rater.

2.4 The Research Track

The research track prepares the student for an academic career that includes a clear research component either in academia or in business, e.g. as a researcher in commercial laboratory, (academic) hospital, etc. In particular, students who aspire to continue in a PhD-programme need to take the research track.
The research track ends with a graduation project which usually consists of a master's thesis including some mathematical research. In particular, the research track can bring the student to some of the forefronts of research.The research track is closely related to the specialisations Mathematical Physics, Algebra and Logic and Stochastics.
We advise the student to contact as soon as possible a supervisor, so that a suitable programme can be put together at the beginning of the master.
With this tailor made programme the student is well prepared for the master mathematics.

The programme should comply with the regulations as in the table below.

Research Track	
Major specialisation	30 ec
Minor specialisation	24 ec
Mathematical Electives	17 ec
Master Thesis Project	40 ec
Philosophy	3 ec
Free Electives	6 ec

The major specialisation should be a coherent package of courses of 30 ec of a certain area of mathematics. The minor or second specialization should also be a coherent package and can be either chosen in or outside mathematics. **In addition to the requirements in the table below, 30 ec have to be chosen from the national Dutch Master Program in Mathematics.** A maximum of 18 ec can be chosen from the third year Bachelor courses in Mathematics.

2.5 The Communication track

The communication track (C) educates people for the areas of scientific communication (research, applications, media).
The student who graduates in Communication is more than a science student, and has acquired complementary theoretical insights and communicative skills that broaden his own field of expertise (beta-gamma-integration). He has an insight in communication about innovation processes and processes of change, as well as an insight in the use of (mass) media and popularization.

If you are interested in the interaction between science and the society, science communication might be an interesting way to go. Science communication is one of the graduation variants on the beta-faculty in Nijmegen. Among other things, it deals with perceptions, participation processes, knowledge production, interdisciplinarity and risks and uncertainties in science.

Moreover, much attention is paid to writing skills (essay, columns), presentation skills and research methods. During your graduation project (30 ECTS), you link up theory from the courses with your beta background.

The job profile entails three fields: intermediary organisations between science and society (advisory bodies, interest groups and gouvernements), science communication research and science journalism.

The Science Communication graduation variant is not only a very interesting new field of study for which there is a need on the labour market, it provides you with knowledge that may come in handy in every speciality!

More information can be obtained at http://www.betacom.science.ru.nl/ from: Prof. dr H. Zwart, Room: HG 02.808, Tel. 3652038, E-mail: h.zwart@science.ru.nl

In this main subject in the Masterfase 63 ec are contributed to the beta education, and 57 ec to the modules and apprenticeship of the C-variant.

Communication track	
Mathematical Specialisation	30 ec
Mathematical Electives	24 ec
C-package	27 ec
Apprenticeship & Master Thesis	30 ec
Philosophy	3 ec
Free Electives	6 ec

In addition to the requirements in the table below, 30 ec have to be chosen from the national Dutch Master Program in Mathematics. A maximum of 18 ec can be chosen from the third year Bachelor courses in Mathematics.

The C-package includes: Framing Knowledge (3), Knowledge Society (3), Science, Media and Strategy (3), Introduction Science Communication (3), Science & Societal interaction (3), Risk Communication (3) and Boundary Work (3).

Free Electives
The free elective space can be filled with courses lectured by the Communication faculty. The approval for other free electives (for instance from Communication sciences, Psychology, Sociology, Biomedical Sciences, or other universities) will be given in consultancy with the student.

Apprenticeship & Master thesis. (24 ec + 6 ec)
The apprenticeship (24 ec) is communication research regarding the interface between Science and Society. Topics can be for instance: the role of scientists (experts) in conflicts between interest groups, conceptualization of social and scientific topics in the mass media (internet, film, tv. etc.), risk communication concerning disasters, the making of a Strategical Communication plan, the effectiveness of newsletters and websites, and political and social opinion forming.

The topic and methodology are always determined in consultation with the student, depending on his wishes and foreknowledge. The apprenticeship can be placed external (within a nonprofit organization, ministry, or commercial organization), or accommodated on the faculty. The master thesis (6 ec) considers the results from the communication research in context with relevant literature, and makes recommendations for further research.

The quality and intensity if the supervision regarding the student will be guaranteed through apprenticeship agreements made with the internal and external supervisors.

2.6 The Education track

The Education track prepares students for a career in High School education. It consists of a major course of 30 ec, in which preferably subjects are integrated that make it possible to view school mathematics from a higher point of view, for instance because of the historical importance of the development of Mathematics. Furthermore 14 ec free electives math, obligatory 3 ec Philosophy and 6 ec free electives. The study will be wound up in the fifth year with a final report of the career preparation at the ILS and a didactic thesis (10ec), if possible, both in mutual coherence.

Education Track	
Mathematical specialisation	30 ec
Mathatmatical Electives	14 ec
E-traineeships	57 ec
Master Thesis Project	10 ec
Philosophy	3 ec
Free Electives	6 ec

In addition to the requirements in the table below, 30 ec have to be chosen from the national Dutch Master Program in Mathematics. A maximum of 18 ec can be chosen from the third year Bachelor courses in Mathematics.

2.7 The Management and Applications track

Goal
The set-up and filling-in of the management and applications variant strives to integration of beta and gamma aspects.
In the MA variant the appliance of beta knowledge is the central aspect. Students are required to be capable of ding beta research in an applied setting; that also includes the handling of the company and managements difficulties, which cohere with those appliances.

For the filling-in of the MA variant thoughts go out to a mutual consensus about the contents of scientific professional education (in particular research apprenticeships) in the fourth year and the external apprenticeship location (organization that applies such beta know-how) in the fifth year.

Master education
In the main part of the Master 63 ec are contributed to the beta education, and 57 ec to the modules and apprenticeship of the MA-variant.

Mathematical Specialisation	30 ec
Mathematical Electives	24 ec
MA-package	30 ec
Master Thesis Project	27 ec
Philosophy	3 ec
Free Electives	6 ec

In addition to the requirements in the table , 30 ec have to be chosen from the national Dutch Master Program in Mathematics.
A maximum of 18 ec can be chosen from the third year Bachelor courses in Mathematics.

Courses
This year the following courses are being offered:
- *MA- courses:* Business & Society (5 ec), Organization Theory (5 ec).
- *MA-integration courses:* Innovation Management (5ec), Strategy & Marketing (5 ec), Finance & Accounting (5ec).
- *MA-free electives (*5ec*, choices of)*: Research Strategy & Management (3ec), Science & Entrepreneurship (3ec), Industrial Chemistry (3 ec), Project Management (3 ec).

Master project.
The master project consists of conducting research in the cutting edge of science, technology, society and organization, mostly within a profit- or non-profit organization or the government.

Together with the student projects and research questions will be actively looked for, in which not only company or management knowledge is required, but also a science/ physics background is an advantage. Also it is desirable that a connection can be made between the fourth' year beta research and the master project MA. We emphasize the expression master project and not apprenticeship, because the student isn't supposed to just work at a company or institution, but, based on a completed phrasing of a question, handles a problem that is relevant to the organization.

Possible research areas for master projects are:
- Developing and/or evaluating of instruments for innovation-, science-, and environment policy.
- Researching the bottlenecks in the implementation of a technological innovation in an organization.
- Researching the consequences of actions of (for instance) environmentalists on company policy.
- Developing and/or evaluating instruments for personnel policy of a R&D department.
- Evaluation of the decision process of research projects in a R&D department.
- Developing instruments for improving the collaboration between universities and businesses.
- Developing instruments for supporting produce development.

3 Specialisations

3.1 Introduction

Mathematical research in the Radboud University Nijmegen is focussed on the following themes:

- Algebra and Logic
- Mathematical Physics
- Stochastics

In any track (R, C, E, MA) it is important to find a specialisation for graduation and, accordingly, a matching program of courses. When you start your master you have to find a supervisor for you thesis and you put toghether a program with advice from your supervisor. Electives can be chosen freely, but the total package has to be approved by the examination board. If you do who the supervisor of you thesis will be at the beginning of your master contact the coordinator of the specialisation to put toghether a program for the first year.

3.2 Algebra and Logic

Coordinator: Prof. dr. Mai Gehrke.

Algebra, originally the study of arithmetic and the solution of equations, transformed over the latter part of the 19th century and the first part of the 20th into the study of abstract algebraic structures and their relationships. This transformation sprang from work on various types of algebraic systems including systems of linear equations, permutation groups, and propositional logics. This 'modern algebra' has had a profound impact on many domains of mathematics including functional analysis, geometry, topology, and logic.
As a consequence algebra has also been deeply influenced by various other fields. Applications in mathematical physics focus on operator algebra, algebraic geometry, and symmetry groups among other. Another source of applications and inspiration for algebra is logic. The algebraic nature of logic may be seen as having been explored already by Leibniz but was firmly identified by Boole in his analysis of 'the laws of thought' in the 1850s. These insights were properly turned into modern algebra by Tarski and Lindenbaum's construction of the free algebra describing a logic.
The connection between algebra and logic has also influenced algebra focusing on lattice-ordered algebras, categorical structures, categories as generalised algebras, algorithmic and constructivist issues, and topological duality theory as central subjects. This part of algebra has grown and expanded over the last half century, driven by the advent of computers and computer and information sciences. As the methods and issues of these new disciplines deepen and get more sophisticated, the synergistic impact on algebra is getting ever more important.
The Algebra and Logic group has a seminar:
http://www.math.ru.nl/~mgehrke/Algebra&Logic/Algebra&Logic.htm
The seminar provides an opportunity for students to get acquainted with the work of the group and provides a setting for informal talks by visitors to the group.

Research in Nijmegen

The research of the group covers a broad cross-section of the classical modern algebra topics including polynomial rings, groups, fields and lattice-ordered algebras. An identifying common thread is the focus on the interplay of computational, logical, and geometric ideas and methods.

Gehrke's work focuses on topological methods in algebra both as they pertain to applications in geometry and physics and in logic and foundations of computer science.

Van den Essen's research is in Affine Algebraic Geometry, a recently named subbranch of Algebraic Geometry which focusses on the a study of affine varieties.

Bosma's work is in computer algebra. His research is focussed on number theoretic algorithms and has applications in cryptography. He has also been involved in the development of the computer algebra programme, Magma.

Souvignier's research area is group theory with special emphasis on algorithmic methods in computational representation theory and crystallographic groups.

The leading question of Veldman's research has been to take Brouwer's proposals for a reform of mathematics seriously and to develop mathematics according to intuitionistic principles.

For more and current information on the research of the group, consult the page http://www.ru.nl/science/ca/ and the individual links from there.

Master programme

The master programme is tailor made for each student taking the research track in Algebra and Logic. We advise the to contact as soon as possible a supervisor in order to compose a programme for the research master Algebra and Logic.

In case you don't know who should act as your supervisor, please contact prof.dr. Mai Gehrke as soon as possible.

In 2009-2010 the following courses are given in Nijmegen that fit well into the research master Algebra and Logic:

First Semester	**Second Semester**
Category Theory 6 ec	Computer Algebra 6 ec
Commutative Algebra 8 ec	Groups and Representations 6 ec
Theory of Recursive Funcions 8 ec	Axiomatic Set Theory 8 ec

Furthermore in the Dutch National Master's Program the following courses are offered that fit well into the specialisation Algebra and Logic:

First Semester	**Second Semester**
Elliptic Curves 8 ec UvA	Topics in Number Theory 8 ec UU
Invariant Theory with Applications 8 ec UvA	Cryptology 8 ec UU
	Algebraic Geometry 8 ec UvA
	Gödel's Incompleteness Theorem 8 ec VU
	Model Theory with non-stand. analysis 8 ec VU

(MM: MasterMath; these courses are part of the national Dutch Master program in Mathematics)

This programme connects well with the Bachelor minor in informatics, and electives within the Master in theoretical computer science are recommended. For more information please follow the eductional programme link from the webpage of the group or talk to one of the members of the group.

3.3 Mathematical Physics

Coördinator: Prof. dr. Erik Koelink

From the time of Newton (1642-1727) until about 1930, mathematics and theoretical physics were inseparable.
Breakthroughs typically took place simultaneously in both areas, and progress at both fronts often even resulted from the work of a single scientist, such as Newton himself, Huygens, Euler, Lagrange, Laplace, Fourier, Gauss, Poisson, Cauchy, Jacobi, Hamilton, Riemann, and Poincaré. Their work provided the foundations of 'classical' mathematical physics (as well as of large areas of mathematics), which culminates in the field of partial differential equations (the Maxwell equations are a case in point).
A second stage in the development of mathematical physics is connected with some of the greatest names in 20th century science, like Einstein, Born, Dirac and Wigner on the physics side, and Hilbert, Weyl, von Neumann and Kolmogorov on the maths side.
The cross-fertilization of mathematics and physics led by these people was instrumental in

establishing key areas of modern physics like general relativity and quantum mechanics as well as parts of mathematics like differential geometry, Lie groups and functional analysis.

This typical cross-fertilization subsided between about 1930-1975, when research at the frontiers of physics felt no need for advanced or new mathematics (whose relevance to physics was even openly derided by Feynman), whilst simultaneously mathematics began to be developed according to its own internal criteria established by Hilbert and others (notably the French Bourbaki group). (In addition, after 1945 some of the greatest mathematicians like Grothendieck refused to make use of insights from modern physics because of its connection to nuclear weapons.) This has led, for example, to the creation of modern algebraic geometry and algebraic number theory by Weil, Grothendieck, Serre, Deligne, and others. This development may be said to have culminated in the extremely deep and abstract proof of Fermat's Last Theorem by Wiles in the mid-1990s. From about 1975, however, mathematical physics has began to regain the élan it used to have.

First, mathematicians like Atiyah, Singer and Penrose, and physicists like 't Hooft and Witten recognized the connection between differential geometry and gauge theories. This connection goes via the notion of index theory (originating in analysis) and is crucial, for example, in the technical implementation of Sacharov's scenario for baryogenesis mentioned earlier. This recognition has led to very important progress in both physics (magnetic monopoles, instantons, anomalies, and other topological phenomena in classical and quantum field theory) and mathematics (e.g. Donaldson theory and Floer homology).
In its immediate wake, deep relationships between algebraic geometry and quantum field theory and string theory were discovered and developed by Witten, Kontsevich and others. The work of Dijkgraaf, Verlinde and Verlinde also played an important role here.

Second, Connes began to develop an entire new domain of mathematics called noncommutative geometry on the basis of ideas from quantum physics (e.g. the Dirac equation), operator algebras (an area of mathematics created by von Neumann in the 1930's) and index theory (the field launched by Atiyah and Singer just mentioned). This body of work has led to breakthroughs in a number of areas in pure mathematics (like index theory and foliation theory).
Furthermore, as might have been expected, the subject was successfully applied to physics within a decade after its inception, for example to the quantum Hall effect, the theory of quasicrystals, and the Standard Model of elementary particle physics. More recently, noncommutative geometry has also been related to renormalization theory in perturbative quantum field theory, and to string theory.

Third, the classical area of integrable systems (going back to Lagrange, Jacobi and others, with important later contributions by Lax) underwent a complete rejuvenation in that it got related to the Langlands program (originally an area of pure mathematics in which number theory and representation theory interacted).
Also, the notion of a Frobenius manifolds emerged from the work of Witten, Manin, Dijkgraaf and others as a new setting for integrable systems. These three areas together have culminated in an independent field of research called the geometric Langlands program.

The above developments have been widely recognized by the mathematical community. Atiyah has been awarded both of the two most prestigious prizes in mathematics, viz. the Abel prize (with Singer) and the Fields Medal. Connes and Kontsevich won the Fields Medal as well, as did Witten (although he is a physicist). Lax and Serre were awarded the Abel Prize. Penrose has won the Wolf Prize and numerous other awards, as did 't Hooft, who won the Nobel prize. And so on and so forth.

Research in Nijmegen
Each of the three current research directions in mathematical physics just mentioned is well represented at Nijmegen, and there are other themes as well, so students interested in research in mathematical physics are offered a rich choice.
Clauwens' research is in algebraic topology.
Heckman's research lies in the interaction between Lie theory, integrable systems, and geometry, and is closely related to the third topic above. It is currently centered around the link between the geometric Langlands program and Hitchin's integrable system.
Koelink's research is on the interplay of representation theory of Lie and quantum groups and special functions as well as the interaction of quantum groups and operator algebras and non-commutative geometry.
Landsman's research combines noncommutative geometry with quantization theory (i.e. the theory that tries to establish the precise mathematical relationship between classical and quantum physics). One goal is the quantization of singular spaces, in the hope of eventually developing a quantum theory of the Big Bang (a purely classical notion which according to Stephen Hawking and others is probably smoothened out in quantum theory).
Maassen works in quantum probability, including the application of stochastic calculus to the interaction of molecules with light, and the functional analysis of quantum noise. In addition he works in the modern theory of quantum information and quantum computing.
Van Suijlekom's main interest is in the mathematical structure of quantum gauge theories: the building blocks of the Standard Model of elementary particle physics. Again, noncommutative geometry provides an ideal mathematical setup for studying these theories.
Müger specializes in category theory, operator algebras and their applications to quantum field theory. He is also interested in constructive quantum field theory.
Steenbrink's work is mainly in algebraic geometry. Over the last few years it has focused on two streams: the study of discriminant complements and moduli spaces, and the study of threefolds which are double covers of projective space (double solids).

Preparation
When coming from the BSc Program in mathematics, the student is recommended to prepare for the MSc Program by filling in the free space in the BSc Program with (a slection of) the following courses:

1st semester:
Mechanics 1B (3 ec)
Mechanics 2B (3 ec)

2nd semester:
Mechanical waves(3 ec)
Introduction to quantum mechanics (3 ec)

3d semester:
Analytical mechanics (3 ec)
Special relativity (3 ec)
Vibrations and waves (3 ec)

4th semester:
Quantum mechanics 1a & 1b (6 ec)
Electricity and magnetism 1 & 2 (6 ec)
Introduction Fourier theory (3 ec)
Curves and surfaces (3 ec)

5th semester:
Introduction to Functional Analysis (6 ec)
Quantum mechanics 2 (6 ec)

6th semester:
Introduction to partial differential equations (6 ec)
Quantum mechanics 3 (6 ec)

Up to 18 ec of courses from the 5th and 6th semester may be taken in the master programme.

Master programme
The master programme is tailor made for each student taking the research variant in Mathematical Physics. We advise the to contact as soon as possible a supervisor in order to compose a programme for the research master Mathematical Physics. In case you don't know who should act as your supervisor, please contact prof.dr. E. Koelink as soon as possible.

In 2009-2010 the following courses fit well into the research master Mathematical Physics:

First Semester	**Second Semester**
Lie Algebras 9 ec	Hodge Theory 6 ec
Algebraic Topology 8 ec	Quantum Invariant Theory 6 ec
Quantum Stochastics 6 ec	

Furthermore the following courses are offered in the National Master Program or by the MRI that fit well with the research master Mathematical Physics:

First Semester	**Second Semester**
C*-algebras 8 ec UU	Noncommutative Geometry 8 ec MRI
Analysis on Manifolds 8 ec UU	Riemann surfaces 8 ec UvA
Functional Analysis 8 ec UU	Algebraic Geometry 8 ec UvA
	Stochastic Processes 8 ec VU
	Partial Differential Equations 8 ec VU

Also a selection of courses form the Physics MSc programme can be taken, such as Group Theory, Classical Electrodynamics, Statistical Mechanics and Quantum Mechanics.

3.4 Stochastics

Coördinator: Prof. dr. Frank Redig

Stochastics (from the Greek "stochos" (guess)) is the area of mathematics dealing with systems and processes where randomness plays a role.
This is the case for almost all processes studied in the sciences: in particular in economy and biology, but also in classical physics, where the laws are deterministic, systems depend so sensitively on initial conditions that random processes provide the only effective description. Quantum physics has its own peculiar notion of randomness.
Probabilistic concepts were first introduced in relation to games of chance, then to population statistics, and later to statistical physics, where Boltzmann and others used them to describe equilibrium distributions of atoms and molecules, and provided a link between microscopic laws of motion and those of thermodynamics.
The modern mathematical theory of probability, based on measure theoretic concepts, was created by Kolmogorov. This framework allows for introducing probability in abstract spaces, which is crucial in the theory of stochastic processes, the study of the Wiener process (Brownian motion) and stochastic calculus (the basic tool for financial mathematics).
The theory of Markov processes, associated semigroups and generators links stochastics with functional analysis and partial differential equations. The theory of martingales, developed by

Doob (and others), gives the fundamental convergence theorems of probability (law of large numbers, central limit theorems) and links probability with potential theory and abstract harmonic analysis.
The theory of large deviations, developed by Varadhan (Abel prize 2007), studies the exponentially small probabilities of deviations on the scale of the law of large numbers. This theory is intimately related to statistical physics via the concept of entropy.

Many of the probabilistic models, as described above, are used to describe real world phenomena. The problem of finding values of parameters in a model to fit to the real world is the domain of statistics. In many situations the existing statistical techniques are fully adequate. Statistics is a science that also is in development.
For example, the current efficient techniques for the analysis of genetic material, and the potentially extremely valuable understanding of the effect of genetic traits on the effectivity of medical treatments, opened a field of research that was neglected in former times. Use of statistics is also very promising in machine learning.

At present, stochastics is an active and fast-developing field with connections to the natural sciences, as well as to other areas of mathematics, such as analysis, combinatorics and number theory.

Research in Nijmegen
The research program in stochastics in Nijmegen contains probability in relation to physics, and statistics. The first part focusses on random systems consisting of many interacting degrees of freedom. Examples are systems of statistical physics, such as Ising models, and models of non-equilibrium such as driven interacting particle systems.
An important subject is the development of a rigorous theory of self-organized criticality, i.e., understanding how many systems in nature (sandpiles, forest fires, landslides, networks) tend to evolve towards a critical state without fine-tuning of parameters.
An important paradigm here is the abelian sandpile model where explicit analytic results can be obtained.
A second focus is on non-commutative probability, a generalization of Kolmogorov's scheme that can deal with quantum-mechanical phenomena. Subjects are quantum information handling, and stochastic versions of the Schrodinger equation in quantum mechanics.

The current program in statistics is focused on developing techniques applicable in audit sampling, one of the methods available to auditors in auditing a financial report. We are also involved in the development of risk assessments in environmental science.

Here are some other concrete research themes:
1. Stochastic models of heat conduction, Fourier law.
2. Stochastic models of evolution (adaptive dynamics).
3. Functional inequalities (concentration inequalities).
4. Transformations of Gibbs measures, Gibbs-non-Gibbs transitions.
5. Non-commutative filtering and control theory.
6. Insurance mathematics, risk measures.
7. Applied statistics for financial auditing and environmental science.

Master programme
The master programme is tailor made for each student taking the research track in Stochastics. We advise the student to contact as soon as possible a supervisor in order to compose a programme for your master. In case you don't know who should act as your supervisor, please contact prof.dr. Frank Redig as soon as possible.

In 2009-2010 the following courses are given in Nijmegen that fit well into the research master Stochastics:

First Semester	**Second Semester**
Quantum Stochastics 6 ec	Insurance Mathematics 6 ec

Furthermore in the National Master's Program the following courses are offered that fit well into the research master Stochastics:

First Semester	**Second Semester**
Introduction to Stochastic Processes 4 ec UU	Applied Statistics 6ec UU
Measure Theoretic Probability 8 ec UvA	Stochastic Differential Equations 6 ec UU
Asymptotic Statistics 8 ec UvA	Stochastic Processes 8 ec VU
	Time Series 8 ec VU

3.5 Research Master in the Mathematical Foundations of Computer Science

Apart from choosing between one of the three mathematical specialisations offered in Nijmegen there is also the possibility to choose for a new interdisciplinary master's program in the theoretical foundations of computer science. This program will start from september 2009.

Introduction
Throughout the centuries there has been a fruitful and mutually inspiring interaction between physics and mathematics. A similarly fruitful and exciting interaction has existed right from the start between computer science and mathematics. This ranges from the use of mathematics to model the foundations and explore the potentials and limits of computer science to the use of computers to help solve mathematical problems with a discrete component. This Research Master Program places itself squarely on this exciting and quickly developing interdisciplinary edge of deep theoretical developments.

In this Research Master Program, mathematicians working in areas pertinent to (theoretical) computer science, like algebra and logic, and theoretical computer scientists, working in areas as formal methods and theorem proving, join forces to establish a master program in the Mathematical Foundations of Computer Science, (MFoCS). The emphasis of the Master is on a combination of a genuine theoretical and up-to-date foundation in the pertinent mathematical subjects combined with an equally genuine and up-to-date training in key aspects of theoretical computer science. For this reason, the mathematics courses in this curriculum concentrate on Algebra, General Topology, Logic, Number Theory, and Combinatorics. The computer science courses concentrate on Formal Methods, Type Theory and Theorem Proving.
For this master program we solicit students with a bachelor in mathematics or computer science that have a strong mathematical background and theoretical interests. We will select students based on their motivation and their background.

Master Programme
It is intended that students of this master program obtain a broad knowledge and understanding over a wide range of material in mathematics and theoretical computer science, bringing them in contact with the research frontier of the field. Consequently, the curriculum consists of both lectures (with exercise classes) and of research projects, which are organized in a Research Seminar and a Research Lab. There are 6 fixed courses for all students and the rest can be chosen from a list of elective courses.

Year 1:

Semester 1		**Semester 2**	
3 x 6 ec fixed	18 ec	3 x 6 ec fixed	18 ec
Elective	6 ec	Elective	6 ec
Kaleidoscope*	6 ec	Research Seminar	6 ec
Total	**30 ec**	**Total**	**30 ec**

* Kaleidoscope consists of selected topics of semantics of programming languages, basic complexity theory and rings and fields. This course will provide a crash course of some of the basic knowledge that we assume the students to be familiar when starting this master.
** In Research Seminar, the various teachers of this Master will give a short introduction to their research and present some research projects that the students can select one from for a small project. *** In Research Lab, the students do a larger Research project. The aim is to select ones own project, write a short paper on it and present the result to the fellow students. The projects will be supervised by staff members.

Year 2:

Semester 1		**Semester 2**	
Philosophy	3 ec	3 x 6 ec fixed	18 ec
2 x 6 ec Electives	12 ec	Elective	6 ec
Master Thesis	6 ec	Research Seminar	6 ec
Total	**30 ec**	**Total**	**30 ec**

Fixed Courses

Type Theory and Theorem Proving	1	Geuvers and Wiedijk
Introduction Category Theory	1	Jacobs
Lattice Theory	1	Gehrke
Semantics and Domain Theory	2	Geuvers and McKinna
Universal algebra	2	Gehrke
Computer Algebra	2	Bosma

Elective Courses

Here is a list of elective courses. The C/M denotes whether it is more a Computer Science or more a Mathematics course, or it can be seen as both. NB. Some of the electice courses may require specific advance knowledge. Not all the courses are offered every year.

Coalgebras	Rutten	CM
Complexity Theory	van Leijenhorst	C
Proof Assistants	Wiedijk	C
Analysis of Embedded Systems	Vaandrager	C
Term Rewriting Systems	Zantema	C
Advanced Lambda Calculus	Barendregt	C
Advanced Programming	Plasmeijer	C
Algebraic Topology	Clauwens	M
Groups and Representations	Souvignier	M
Commutative Algebra	Maubach	M
Duality Theory	Gehrke	M
Algorithmic Number Theory	Bosma	CM
Graph Theory	Bosma	CM
Recursion Theory	Veldman	CM
Intuitionistic Mathematics	Veldman	M
Axiomatic Set theory	Veldman	M
Model Theory	Veldman	M

Apart from the courses mentioned above, students can follow Master courses, at Mastermath, including courses offered by Diamant. It should be noted that the Mastermath courses are 8 ec, so choosing one (or two) Mastermath courses implies that you are doing more ecs in total. There's also the possibility of going abroad in the 3rd semester, for example there are possibilities to follow courses with the Radboud University's partners in the IRUN network, notably the Theoretical Computer Science group at the Faculty of Mathematics and Computer Science of the Jagiellonian University in Krakow, Poland.

Grants

See the university's International Masters page for general information about doing a master at the Radboud University.

Students from an EEA country may apply for either a student grant within the Dutch student grants and loans system or a tuition fee allowance: Read more.... Students from the Netherlands can use their normal *studiefinanciering* from IB, as this Master curriculum officially falls under both the master of computer science and the master of mathematics of the Radboud University Nijmegen, which are CROHO-accredited.

The Radboud University has special scholarships for non-EEA students, like the Radboud Scholarship Programme. The university provides a special information page on scholarships and grants.

Students who need **financial support** may be interested to know that the Dutch government, runs special schemes to help students finance their education.

- **Scholarships from the Dutch government/Nuffic**
  The Dutch government offers a broad range of scholarships for international students, for example the Huygensscholarship. Further information: www.nuffic.nl/
- All sorts of information on **grants** can be found on the student grantfinder: www.grantfinder.nl/content/index.asp

Contact

Prof.dr. Mai Gehrke, IMAPP
Prof.dr. Herman Geuvers, ICIS

Faculty of Science
Radboud University Nijmegen
Netherlands

Advice In case you are interested in doing this master program, please get in touch with Professor Gehrke of Professor Geuvers.

4 Dutch Master Program in Mathematics

4.1 Program and schedule

In this chapter you find a list of all Master courses offered in 2009/2010 in the framework of the **DUTCH MASTER PROGRAM IN MATHEMATICS.** For descriptions of these courses and further details see: http://www.mastermath.nl .
You have to register for these courses at: http://www.mastermath.nl/registration/ .
Abbreviations:

- (LNMB)= these courses are organized by the Dutch Network on the Mathematics of Operations Research
- (MRI)= these courses are organized by the Mathematics Research Institute and are recommended only for students who specialize in dynamics of differential equations.
- (3TU)= these courses are part of a joint MSc program in Applied Mathematics of the 3 Dutch technical universities (Technische Universiteit Eindhoven, Universiteit Twente and Technische Universiteit Delft)

4.2 Course schedule fall 2009

Monday	**Universiteit Utrecht**
10:15 - 12:00 hrs:	Continuous Optimization (6 cp)
Instructors:	Still, G. (Universiteit Twente)
Venue:	Minneartbuilding, week 39 through 45, Room 211 week 46 through 51, AWK Utrecht
10:15 - 14:45 hrs:	Introduction to Stochastic Processes (4 cp)
Instructors:	Litvak, N. (Universiteit Twente) Scheinhardt, W.R.W. (Universiteit Twente)
Venue:	This is a crash course. Meetings only on Mondays and Tuesdays. September 7, 8, 14 and 15 2009 Mathematical Building, Room 611AB Budapestlaan 6 Utrecht
13:00 - 14:45 hrs:	Discrete Optimization (6 cp)
Instructors:	Uetz, M. (Universiteit Twente)

Venue:	Minneartbuilding, week 39 through 45, Room 211 week 46 through 51, AWK Utrecht
15:00 - 16:45 hrs:	Heuristic Methods in Operations Research (6 cp)
Instructors:	Hurink, J.L. (Universiteit Twente)
Monday	**Universiteit Utrecht / Universiteit Twente**
10:15 - 12:00 hrs:	Systems and Control (Intensive course) (6 cp)
Instructors:	Polderman, J.W. (Universiteit Twente)
Venue:	This is an intensive course. See Courses and Exams for more information about the organization of intensive courses. First meetings will be in Utrecht, the intensive week will be in Twente (Enschede). Buys Ballot Lab, room 273, Utrecht: 14-09, 28-09, 12-10 (23-11?). Intensive week in Twente: Week 44
Tuesday	**Universiteit Utrecht**
14:00 - 17:00 hrs:	Dynamical Systems generated by ODE and Maps (8 cp)
Instructors:	Kuznetsov, Yu.A. (Universiteit Utrecht) Diekmann, O. (Universiteit Utrecht)
Tuesday	**Vrije Universiteit**
10:15 - 13:00 hrs:	Elliptic Curves (8 cp)
Instructors:	Stevenhagen, P. (Universiteit Leiden) Luijk, R.M. van (Universiteit Leiden)
14:00 - 16:45 hrs:	Invariant Theory with Applications (8 cp)
Instructors:	Draisma, J. (Technische Universiteit Eindhoven) Gijswijt, D.C. (Universiteit van Amsterdam)
Tuesday	**Universiteit Utrecht**
10:15 - 13:00 hrs:	Functional Analysis (8 cp)
Instructors:	Jeu, M.F.E. de (Universiteit Leiden) Ran, A.C.M. (Vrije Universiteit)

Venue:	Buys Ballot Lab, room 276 Utrecht
Wednesday	**Universiteit Utrecht**
10:15 - 13:00 hrs:	Analysis on Manifolds (8 cp)
Instructors:	Ban, E.P. van den (Universiteit Utrecht) Crainic, M.N. (Universiteit Utrecht)
10:15 - 13:00 hrs:	Parallel Algorithms (8 cp)
Instructors:	Bisseling, R.H. (Universiteit Utrecht)
Venue:	Minneartbuilding, room 207 Utrecht
14:00 - 16:45 hrs:	Numerical Linear Algebra (8 cp)
Instructors:	Gijzen, M.B. van (Technische Universiteit Delft) Sleijpen, G.L.G. (Universiteit Utrecht)
14:00 - 16:45 hrs:	C*-algebras (8 cp)
Instructors:	Müger, M. (Radboud Universiteit Nijmegen)
Wednesday	**Universiteit van Amsterdam**
10:15 - 13:00 hrs:	Measure Theoretic Probability (8 cp)
Instructors:	Spreij, P.J.C. (Universiteit van Amsterdam)
14:00 - 16:45 hrs:	Asymptotic Statistics (8 cp)
Instructors:	Jongbloed, G. (Technische Universiteit Delft)

4.3 Course schedule spring 2010

Monday	**Universiteit Utrecht**
10:15 - 12:00 hrs:	Advanced Linear Programming (6 cp)
Instructors:	Stougie, I. (Technische Universiteit Eindhoven)
10:15 - 13:00 hrs:	Applied Statistics (6 cp)
Instructors:	Meulen, F.H. van der (Technische Universiteit Delft)

13:00 - 15:45 hrs:	Applied Finite Elements (6 cp)
Instructors:	Vegt, J.J.W. van der (Universiteit Twente)
Venue:	This is an intensive course. More information will follow.
13:00 - 14:45 hrs:	Nonlinear System Theory (6 cp)
Instructors:	Schaft, A.J. van der (Rijksuniversiteit Groningen)
13:00 - 14:45 hrs:	Scheduling (6 cp)
Instructors:	Hurink, J.L. (Universiteit Twente)
13:00 - 14:45 hrs:	Stochastic Differerential Equations (6 cp)
Instructors:	Weide, J.A.M. van der (Technische Universiteit Delft)
15:00 - 16:45 hrs:	Queueing Theory (6 cp)
Instructors:	Adan, I.J.B.F. (Technische Universiteit Eindhoven) Resing, J.A.C. (Technische Universiteit Eindhoven)
Monday	**Universiteit Utrecht / Universiteit Twente**
10:15 - 13:00 hrs:	Advanced Modelling in Science (6 cp)
Instructors:	Heemink, A.W. (Technische Universiteit Delft)
Venue:	This is an intensive course.
10:15 - 13:00 hrs:	Topics in Number Theory: p-adic numbers and zeta functions (8 cp)
Instructors:	Beukers, F. (Universiteit Utrecht) Jeu, M.F.E. De (Universiteit Leiden)
Tuesday	**Universiteit Utrecht**
14:00 - 16:45 hrs:	Cryptology (8 cp)
Instructors:	Cramer, R.J.F. (CWI) (Universiteit Leiden) Lange, T. (Technische Universiteit Eindhoven)

Tuesday	**Universiteit van Amsterdam**
10:15 - 13:00 hrs:	Fourier Analysis and distribution theory (8 cp
Instructors:	Stolk, C.C. (Universiteit van Amsterdam) Wiegerinck, J.J.O.O. (Universiteit van Amsterdam)
14:00 - 16:45 hrs:	Mathematical Biology (8 cp)
Instructors:	Diekmann, O. (Universiteit Utrecht) Planqué, R. (Vrije Universiteit)
Wednesday	**Universiteit van Amsterdam**
10:15 - 13:00 hrs:	Riemann surfaces (8 cp)
Instructors:	Geer, G.B.M. van der (Universiteit van Amsterdam)
14:00 - 16:45 hrs:	Algebraic Geometry (8 cp)
Instructors:	Looijenga, E.J.N. (Universiteit Utrecht)
Wednesday	**Universiteit Utrecht**
10:15 - 13:00 hrs:	Goedel's Incompleteness Theorem (8 cp)
Instructors:	Barendregt, H.P. (Radboud Universiteit Nijmegen) Oosten, J. van (Universiteit Utrecht)
14:00 - 16:45 hrs:	Model Theory with non-standard analysis (8c
Instructors:	Gehrke, M. (Radboud Universiteit Nijmegen) Vaananen, J. (Universiteit van Amsterdam)
Wednesday	**Vrije Universiteit**
10:15 - 13:00 hrs:	Numerical Methods for Time-dependent PDE's (8 cp)
Instructors:	Zegeling, P. (Universiteit Utrecht)
10:15 - 13:00 hrs:	Stochastic Processes (8 cp)
Instructors:	Spieksma, F.M. (Universiteit Leiden)
14:00 - 16:45 hrs:	Partial Differential Equations (8 cp)
Instructors:	Vorst, R.C.A.M. van der (Vrije Universiteit)
14:00 - 16:45 hrs:	Time Series (8 cp)
Instructors:	Vaart, A.W. van der (Vrije Universiteit)

5 Description of the Courses

Algebraic Topology

Course ID: **WM045B** *8 ec* first semester dr. F.J.B.J. Clauwens

Teaching methods
- 28 hrs lecture
- 28 hrs problem session

Objectives
The student should be familiar with the notion of simplicial complex and be able to compute the homology of a polyhedron effectively in practical cases. He can list the properties of both simplicial and singular homology and can reproduce the derivation of these properties. He should also be able to explain important applications of these theories like the Lefschtez Fixed Point Theorem and the Generalized Jordan Curve Theorem.

Contents
The course starts with the geometry of 'simplicial complexes'. These are spaces built from simplces (= line segments, triangles, tetrahedra etc.). From the way these simplces fit together we construct certain abelian groups, the so called 'simplicial homology groups'. The definition enables one to compute these groups effectively.
Subsequently we study what happens when a space is dissected differently into simplices. This results in the theorem that homeomorphic spaces have isomorphic homology groups. Thus sometimes spaces can be shown to be essentially different by computing their homology. As a further application we show how a continuous map from a polyhedron to itself gives rise to a 'Leftschetz number' in the integers with the property that it vanishes for a map without fixed point.
Next we discuss the singular homology groups of an arbitrary topological space. These can not be computed directly from their definition. We will list a number of properties of these groups the so called 'Eilenberg-Steenrod axioms'. These properties characterize the theory on polyhedra. We will also see how these properties can be used to compute these groups.
Finally we prove a high-dimensional generalization of the Jordan Curve theorem: consider a continous map from the unit sphere in Euclidean space to the same Euclidean space; then the complement of its image has two open components with that image as a common border.

Literature
J.R. Munkres: `*Elements of Algebraic Topology'*, Addison-Wesley Publ. Comp., 1984.

Examination
Oral.

Axiomatic Set Theory

Course ID: **WM038B** *8 ec* second semester dr. W.H.M. Veldman

Teaching methods

- 28 hours lecture
- 28 hours tutorial

Objectives

The student comes to know the story of the formalization of set theory and some of its heroic results and open questions.

Contents

We explain how set theory started with *Cantor's diagonal* argument and his *continuum hypothesis*.
We consider Zermelo's *Axiom of Choice* and some famous applications, including *Zorn's Lemma* and the *Banach-Tarski-paradox*.
We then list the axioms given by Zermelo and Fraenkel and develop set theory from them including the theory of ordinals and cardinals. We go on to consider Gödel's *constructible sets* and his proof of the consistency of the continuum hypothesis.
We try to obtain some idea of the *forcing method* developed by Cohen for proving the consistency of the negation of the continuum hypothesis.
If time permits, we also discuss Mycielski's *Axiom of Determinacy*, and/or Aczel's *Anti-foundation axiom*.

Literature

K. Kunen, *Set Theory, an Introduction to the Independence Proofs*, North Holland Publ. Co., Amsterdam, 1980.
K. Devlin, *The Joy of Sets: an Introduction to Contemporary Set Theory*, Springer Verlag, New York, 1987
T. Jech, *Set Theory*, Springer verlag, New York, 1997
Y.N. Moschovakis, *Notes on Set Theory*, Springer Verlag, New York, 1994
R.L. Vaught, *Set theory: an Introduction*, Birkhäuser, Boston, 1985

Examination

After having completed and submitted a number of exercises, students have to pass an oral examination.

C* Algebras

Course ID: **WM067B** *8 ec* first semester dr. M.H.A.H. Muger

Teaching methods
Lectures, exercise classes, homework.

Prerequisites
Solid grounding in classical and functional analysis. An excellent reference for the latter is provided by (roughly the first 100 pages of)
G. Pedersen: Analysis NOW, Springer-Verlag, 1989.

Objectives
The student is familiar with the basics of the theory of Banach algebras, in particular the Gelfand isomorphism, and C*-algebras as well as the most basic constructions involving them, like crossed products.
The student will be ready to embark on a study of more recent work on connections between C*-algebras and number theory.

Contents
The course will provide an introduction to the theory of C*-algebras, including many examples, with special focus on those that occur in number theory (such as crossed product algebras, non-commutative tori and Cuntz-Krieger algebras).

Subjects
- Basics of Banach algebras.
- Basics of C*-algebras and their representations.
- Some material on von Neumann algebras.
- C*-algebras of isometries.
- Irrational rotation algebras.
- Group C*-algebras and crossed products.

Literature
Kenneth R. Davidson: C*-Algebras by example. American Mathematical Society, 1996.

Examination
Homework to be handed in.

Extra information
This course is part of the Dutch National Master Program in Mathematics and will take place in Utrecht.

Category Theory

Course ID: **WM033C** *6 ec* first semester prof. dr. B.P.F. Jacobs

Teaching methods
Lectures and tutorials

Prerequisites
A certain level of mathematical maturity is required.
Courses like topology, rings and fields, logic, universal algebra, lattice theory are useful.

Objectives
The student will learn to use the language of categories, the basic constructions, and how to recognise and use them in various contexts.

Contents
Category theory provides an abstract language for mathematics that concentrates on the essentials, namely "objects" and "morphisms" between them. The language of categories is elegant and remarkably powerful. It arose in the 1940s algebraic topology but is now used in many branches, not only of mathematics but also of theoretical computer science and physics. With a "categorical mindset" one recognises the structural aspects in a partical context, which helps to guide further investigation.

The course will introduce the basic concepts, for mathematicians, computer scientists and physicists.

Literature
The following book will be used:

Steve Awodey, Category Theory, Oxford Univ. Press, 2006.

Examination
Written exam, at the end of the course.

Commutative Algebra

Course ID: **WM026B** *8 ec* first semester S.J. Maubach

Teaching methods

- 28 hours lecture
- 28 hours tutorial

Objectives

The student is acquainted with the theory of modules over commutative rings. In particular he is familiar with the theory of Noetherian and Artin modules, tensor products, localization and all basic notions of commutative algebra.

Contents

What is commutative algebra about? To make this clear let's start with a *k*-vector space *V*, where *k* is a field. So *V* is a set equipped with an addition, which makes *V* into an abelian group, and a scalar multiplication with scalars from *k*. Furthermore the classical distibutive laws hold. If we replace *k* by an arbitrary commutative ring *R* we get a so-called *R*-module. This notion generalises most of the notions one meets during a Bachelor's study Mathematics. For example it will turn out that a Z-module is the same as an abelian group, a *k*[*x*]-module is the same as a *k*-vector space together with a linear transformation and an ideal *I* in a ring *R* is an example of a so-called *R*-submodule of *R*.
Also the quotient ring *R/I* is an *R*-module etc. The theory of *R*-modules is much more complicated than the theory of vector spaces; many problems are still unsolved. The general philosophy is that the 'nicer' the ring *R* is, the more we know about its *R*-modules. The language of modules is an indispensable tool in nowadays Mathematics. In this course we discuss the most fundamental concepts and results of modern commutative algebra. Many of the notions introduced in this course will also be used in various other courses.
If you are planning to specialize in algebraic geometry, algebraic topology, number theory, computer algebra or polynomial mappings, this course is a must.

Literature

We follow the excellent book *'Introduction to commutative algebra'* by M.F. Atiyah and I.G. MacDonald.

Examination

The student has to make a series of exercises.

Computer Algebra

Course ID: **WM069B** *6 ec* second semester dr. W. Bosma

Prerequisites
Linear algebra, groups, rings and fields

Contents
The aim of the lectures will be to provide an introduction into the area of computer algebra. The main focus will be on algebra and algorithms, but there will also be some attention to complexity and implementation issues.
On the one hand this should give some insight into the underlying mathematics, on the other hand also some ability to use computer algebra systems will be acquired. This should lead to an understanding of the theoretical possibilities and the practical limitations of computer algebra.
Among others, topics will be algorithms for efficient integer, rational and modular arithmetic, and computing with polynomials, rational functions and power series, determining the factorization and common factors of integers and of polynomials over finite fields or the integer ring, as well as some techniques from linear algebra and algebraic geometry.

Examination
In overleg

Groups and Representations

Course ID: **WM010B** *6 ec* second semester dr. B.D. Souvignier

Teaching methods
- 28 hours lecture
- 28 hours tutorial

Prerequisites
Linear algebra, groups, rings and fields (Lineaire Algebra, Symmetrie, Ringen en Lichamen)

Objectives
The student is acquainted with the basic theory of group representations and is able to deal with representations and characters in concrete examples. He knows how interesting properties of groups can be derived from their representations and characters and how the information required can be computed explicitly.

Contents
In order to compute in an abstract group we require an explicit realization of the group elements. One possibility for such a realization is to view the group as a group of matrices defined as the image of a homomorphism from the group to a matrix ring. Such a homomorphism is called a representation of the group.
The analysis of groups via their representations is a powerful tool which contributes to many and varied problems, such as the classification of finite simple groups, the theory of Lie groups or the determination of possible tilings of planes or spaces.
In this course we will both deal with the theory of group representations and with algorithmic methods that allow to apply the theory to explicit examples. In particular we will see how to construct representations, how to decompose representations into irreducible constituents and how to utilize the distillation of representations to their characters.

Literature
A syllabus will be provided.
- M.Burrow: *Representation Theory of Finite Groups*, Academic Press, 1965;
- J.H.Conway, R.T.Curtis, S.P.Norton, R.A.Parker, R.A.Wilson: *Atlas of Finite Groups*, Clarendon Press, 1985;
- C.W.Curtis, I.Reiner: *Methods of Representation Theory*, Wiley-Interscience, 1981;
- I.M.Isaacs: *Character Theory of Finite Groups*, Academic Press, 1976;
- G.James, M.Liebeck: *Representations and Characters of Groups*, Cambridge UP., 1993.

Examination
Homework assignments and presentation of solutions in class. The course will be rounded off by an oral examination.

Hodge Theory

Course ID: **WM032B** *6 ec* second semester prof. dr. J.H.M. Steenbrink

Teaching methods
Lecture

Prerequisites
Bachelor mathematics

Objectives
The student acquires an understanding of the cohomology of compact Kähler manifolds

Contents
Introduction to complex manifolds,
harmonic theory,
primitive decomposition,
Kähler metrics,
Hodge decomposition,
Hodge index theorem.

Examination
Oral

Insurance Mathematics

Course ID: **WM022B** *6 ec* second semester dr. H.W.M. Hendriks

Teaching methods
28 hours formal lecture, 14 hours tutorial

Prerequisites
Basic course in Probability theory or Stochastic processes

Objectives
The student is familiar with utility functions and expected utility. He understands the individual and the collective risk model. He is familiar with Panjer's recursion. He understands the ruin theory according to Lundberg. He has insight in the properties of several risk premium principles. He understands the concept of reinsurance. The student is familiar with utility functions and expected utility. He understands the individual and the collective risk model. He is familiar with Panjer's recursion. He understands the ruin theory according to Lundberg. He has insight in the properties of several risk premium principles. He understands the concept of reinsurance.

Contents
Utility functions, individual and collective risk model. Panjer's recursion. Cramér-Lundberg model for the surplus process, adjustment coefficient, Beekman's convolution formula for ruin probability. Various premium principles and their properties. Bonus-malus systems. First order and second order of stochastic dominance. In Insurance Mathematics methods are studied for determining premiums and for the management of the capital reserves, based on the data about the risks in a portfolio.
In this course we will discuss several premium calculation principles, mathematical models for the process of claiming times and claim sizes and bonus-malus systems. A highlight is the derivation of an integral equation for the probability of ruin (bankruptcy). That is the probability that, given a certain premium income and initial capital, at any moment the received premiums together with the initial capital are insufficient to cover the claims up to that moment.
In the near future insurance companies will have to satisfy a continuity requirement, for which obviously the above theory could be applied. The course is meant for students interested in applications of mathematics in the financial world. It is part of the standard curriculum of Financial Mathematics.

Literature
Kaas, R.et al., *Modern actuarial risk theory*, 1st ed., Springer/Kluwer. The course is based on this book.
Bühlmann, H., *Mathematical methods in risk theory*, Springer.

Examination
Written assignment with oral presentation.

Lie Algebras

Course ID: **WM062B** *9 ec* first semester prof. dr. G.J. Heckman

Teaching methods
- 42 hours lecture
- 14 hours tutorial

Prerequisites
Symmetry or Introduction Group Theory

Objectives
The student becomes familiar with the following subjects:
- Poisson algebras
- Universal enveloping algebras
- The representation theory of SL(2)
- Representations via constructions of linear algebra
- Reductive Lie algebras.
- Verma representations
- The representation theory of SL(3)
- Physical applications: Spin and quarks
- The Weyl character formula Spherical harmonics, and SO(n)
- Physical application: The Kepler problem.

Contents
In this course we discuss the mathematics of Lie algebras and their representations. The basic examples are the Heisenberg algebra, the special linear algebra SL(n) and the orthogonal algebra SO(n).
For each of these algebras we discuss the physical relevance which lie mainly in the realm of particle physics. We also discuss the link with invariant theory, an important subject in geometry.
The course is interesting for students in both physics and mathematics, and standard for students in mathematical physics. The material of the course is useful for the courses "Beyond the Standard Model" and "Introduction to String Theory" of Prof. dr. B. Schellekens.

Literature
is given in the class

Examination
Oral exam

Noncommutative Geometry

Course ID: **WM068B** *8 ec* second semester prof. dr. N.P. Landsman

Teaching methods
- 30 hrs lecture
- 30 hrs tutorial

Prerequisites
Hilbert Spaces and C*-algebras

Objectives
The students will be familiar with the basic toolkit of noncommutative geometry

Contents
Spectral triples,
cyclic cohomology,
K-theory.

Literature
A. Connes, Noncommutative Geometry (Academic Press, 1994)

Examination
Written exam or possibly an essay.

Extra information
This course is part of the MRI Masterclass on Arithmetic and Noncommutative Geometry and will take place in Utrecht.

Philosophy of mathematics

Course ID: **WM040B** *3 ec* first semester dr. W.H.M. Veldman

Teaching methods
- 30 hrs lecture

Objectives
The student will learn to see that the question about the nature of mathematics is one of the most important questions in philosophy, and that meticulous mathematical thinking and philosophical contemplation can stimulate each other.

Contents
During the course we discuss: Plato's Ideas and the place of the mathematical objects,
Aristotle's view,
Kant's view on the nature of mathematical statements,
Frege and Russell's logics, Russell's paradox, Cantor's discoveries,
Brouwer's intuitionist criticism,
Goedel's incompleteness thesis,
Goedel's Platonism,
Wittgenstein's thoughts.

Literature
The students will be given home texts that will be discussed in the lectures, during which one will be able to ask questions, or have discussions.

Examination
The student studies various texts of choice, and is assessed about them orally.

Quantum Invariant Theory

Course ID: **WM071B** *6 ec* second semester dr. M.H.A.H. Muger

Website
http://www.math.ru.nl/~mueger/QIT.html

Teaching methods
- 30 hours of lectures
- homework

Prerequisites
Bachelor in mathematics. Some knowledge of Lie groups and knot theory is helpful, but not mandatory.

Objectives
The student gains an understanding of the connections between quantum groups and quantum invariants from a point of view that emphasizes the analogies with classical invariant theory, to a point where (s)he can approach the current literature.

Contents
The title of the course allows two readings, both of which refer to developments that have ancient roots but witnessed explosive growth since the mid 1980s:
(A) The theory of *Quantum Invariants*, referring to the invariants for knots and 3-manifolds discovered by Jones, HOMFLY, Kauffman, Reshetikhin, Turaev and others.
(B): the *quantum* group version of *Invariant Theory*, by which we mean the intermediate theory of Schur and Weyl (rather than the old theory of Clebsch and Gordan or the modern geometric theory due to Mumford).

The point of the course is that these two subjects are inextricably linked into a marvelous whole, irrespective of the fact that many important questions are still open. We will try to keep abstract general machinery (Hopf algebras, tensor categories) to the necessary minimum.

Subjects

Classical theory

Representation theory of S_n and of SU(n) and GL(n).
Schur-Weyl duality for SU(n).
Schur-Weyl duality for orthogonal and symplectic groups, Brauer algebra.
Deligne's geometric construction of the classical representation categories.
Comments on exceptional groups.

Quantum theory

Basics on knots, links, braid groups (theorems of Reidemeister, Markov, etc.).
The link invariants of Jones, HOMFLY and Kauffman.
Quasi-triangular Hopf algebras and braided tensor categories.
Quantum groups à la Drinfeld-Jimbo.
Hecke algebra and Schur-Weyl duality for $SU_q(n)$.
BMW algebra and Schur-Weyl duality for orthogonal and spin groups.
Characterization and geometric construction of the classical quantum group categories.
(Results of Turaev, Wenzl, Kazhdan, Tuba, Blanchet, Beliakova).
Outlook on the root-of-unity case and modular categories.

Literature

There is no satisfactory single reference. We will draw upon a variety of books, but also on material from the research literature that has not yet appeared in textbooks. An extensive list of references will be made available in time. Here are some useful books:

R. Goodman, N. R. Wallach: Representations and invariants of the classical groups. Cambridge UP 1998.
C. Procesi: Lie groups. An approach through invariants and representations. Springer, 2007.
W. B. R. Lickorish: An introduction to knot theory. Springer, 1997.
V. Chari, A. Pressley: A guide to quantum groups. Cambridge UP, 1995.
C. Kassel: Quantum groups. Springer, 1995.

Examination

Oral exam or mini thesis on one of a choice of topics.

Quantum Stochastics

Course ID: **WM066B** *6 ec* first semester dr. J.D.M. Maassen

Teaching methods
Lectures and exercises.

Prerequisites
Linear algebra, advanced probability. Functional analysis is helpful.

Objectives
The student is familiarized with finite dimensional *-algebras, their states and operations, as a model of what can be done in the physical world.
He/she can follow arguments in current quantum information research, can devise simple quantum codes and quantum operation diagrams.

Contents
This is a Master course in quantum probability, quantum information theory, with some applications to quantum computing.
Quantum probability is a mathematical theory based on operators on a Hilbert space, which is general enough to contain both ordinary probability theory and quantum mechanics. The well-known "strangeness" of quantum mechanics leads naturally to a new kind of information, which can be put to use in cryptography, but also holds the promise of a future quantum computer, an engine able to reform certain tasks essentially faster than ordinary computers can.
We start with Bell's inequality, build up the mathematical theory, and treat principles such as "no cloning", the Heisenberg principle, and the impossibility of joint measurement of incompatibles. On the positive side, we consider examples such as superdense coding, teleportation of states, and indeed fast computation.

Literature
A course text will be provided. Useful, but not mandatory: Nielsen and Chuang, "Quantum information and quantum computing".

6 List of lecturers

Bosma, Dr. W.	w.bosma@math.ru.nl	52311	HG03.716
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